THE REPUBLIC OF KENYA
MINISTRY OF ENVIRONMENT,
WATER AND NATURAL RESOURCES
WATER RESOURCES MANAGEMENT
AUTHORITY

THE REPUBLIC OF KENYA

THE PROJECT
ON
THE DEVELOPMENT OF
THE NATIONAL WATER MASTER PLAN 2030

FINAL REPORT
VOLUME - IV SECTORAL REPORT (1/3)

OCTOBER 2013

JAPAN INTERNATIONAL COOPERATION AGENCY

NIPPON KOEI CO., LTD.

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FINAL REPORT

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EXCHANGE RATE

US$1.00 = KSh 85.24 = ¥79.98

as of November 1, 2012

Sectoral Report (A)
Socio-economy

THE PROJECT
ON
THE DEVELOPMENT OF
THE NATIONAL WATER MASTER PLAN 2030
IN
THE REPUBLIC OF KENYA

FINAL REPORT
VOLUME – IV SECTORAL REPORT (1/3)

A: SOCIO-ECONOMY

Abbreviation

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List of Abbreviations and Acronyms

BOPA	:	Budget Outlook Paper
CBS	:	Central Bureau of Statistics
GDP	:	Gross Domestic Product
GIS	:	Geographic Information System
HGF	:	High Grand Falls
JICA	:	Japan International Cooperation Agency
KIHBS	:	Kenya Integrated Household Budget Survey
LAPSET	:	Lamu Port- Southern Sudan- Ethiopia Transport project
LVN	:	Lake Victoria North
LVS	:	Lake Victoria South
MTEF	:	Medium Term Expenditure Framework
MWI	:	Ministry of Water and Irrigation
NIB	:	National Irrigation Board
NWCPC	:	National Water Conservation and Pipeline Corporation
NWMP	:	National Water Master Plan
SAGA	:	Semi Autonomous Government Agency
UN	:	United Nations
WRMA	:	Water Resource Management Authority
WSB	:	Water Service Board

Abbreviations of Measures

Length

mm	=	millimeter
cm	=	centimeter
m	=	meter
km	=	kilometer

Area

ha	=	hectare
m^2	=	square meter
km^2	=	square kilometer

Volume

1, lit	=	liter
m^3	=	cubic meter
m^3/s, cms	=	cubic meter per second
CM	=	cubic meter
MCM	=	million cubic meter
BCM	=	billion cubic meter
m^3/d, cmd	=	cubic meter per day
BBL	=	Barrel

Weight

mg	=	milligram
g	=	gram
kg	=	kilogram
t	=	ton
MT	=	metric ton

Time

s	=	second
hr	=	hour
d	=	day
yr	=	year

Money

KSh	=	Kenya shilling
US$	=	U.S. dollar

Energy

kcal	=	Kilocalorie
kW	=	kilowatt
MW	=	megawatt
kWh	=	kilowatt-hour
GWh	=	gigawatt-hour

Others

%	=	percent
o	=	degree
'	=	minute
"	=	second
°C	=	degree Celsius
cap.	=	capital
LU	=	livestock unit
md	=	man-day
mil.	=	million
no.	=	number
pers.	=	person
mmho	=	micromho
ppm	=	parts per million
ppb	=	parts per billion
lpcd	=	litter per capita per day

NOTE

1. The National Water Master Plan 2030 was prepared based on the material and data provided from Kenyan Government and its relevant organisations during field surveys in Kenya carried out until November 2012. The sources etc. of the material and data utilised for the study are described in the relevant part of the reports.

2. The names of ministries and related organisations of Kenyan Government are as of November 2012.

3. Information to be updated

   The following information which is given in the report is needed to be updated properly:

   (1) Information on the proposed development projects

   The features and implementation schedules of the proposed development projects may be changed toward implementation of the project. After the subject projects were clearly featured for implementation, the project features and implementation schedules in this report should be updated.

   (2) Information on the water demand

   The water demand projected in this master plan should be revised when the large scale development plans, other than the projects proposed in this master plan, were formulated, as they will significantly affect to the water resources development and management.

4. Exchange rate for cost estimate

   The costs of the proposed development and management plans were estimated by applying the following exchange rate as of November 1, 2012.

EXCHANGE RATE
US$1.00 = KSh 85.24 = ¥79.98
as of November 1, 2012

CHAPTER 1 INTRODUCTION

The main objectives of this Master Plan are to provide a policy framework for water resources development based on the updated water balance calculation and establish a sustainable water resource management system in Kenya by 2030. This socioeconomic report aims to present the basic information/data necessary for 1) water demand calculation, 2) calculation of economic evaluation for selected water subsector projects, and 3) estimation of available government budgets for financing the proposed development plans. Figure 1.1.1 shows the workflow of the overall NWMP 2030 and the roles of socioeconomic framework, economic evaluation, and financing plan for formulating the Master Plan. As shown in this figure, this sectoral report is placed as a basis for water demand and water balance calculation, which will then be used for the formulation of each of the water-related development plans. The cost estimate and preliminary economic evaluation for selected projects will be carried out for each development plan, and the overall implementation plan for water resources development will be presented. Based on the implementation plan, a financing plan for each development plan will be performed and located at the final stage of the Master Plan.

In this context, Chapter 1 describes the basis of administrative divisions, by which socioeconomic data are to be distributed. Chapter 2 provides the present and future conditions of the population, while Chapter 3 presents the present economic performance and the gross domestic product (GDP) growth projection up to year 2030, both of which will be used for future water demand analysis. Chapter 4 briefly explains the current public finance at the national level and within the water sector, which will be the basis for examining a financing plan. Chapter 5 summarizes the household welfare, including household expenditure, which will be used for the calculation of the current and future household income in the economic analysis, and the current poverty conditions in Kenya.

CHAPTER 2 ADMINISTRATIVE DIVISION

2.1 Geographical Features

The administrative divisions and geographical data are the basis for estimating the socioeconomic data for this study. Due to the transition period of the latest 2010 Constitution (hereinafter referred to as the "New Constitution"), it was hardly possible to confirm the official boundaries of the 47 newly created counties. However, the JICA Study Team obtained GIS data with county boundaries from the Kenya National Bureau of Statistics, which was used for estimating the land area of each country through GIS techniques. Table 2.1.1 shows the land area by county in Kenya. Figure 2.1.1 shows the administrative boundary by county and by catchment area.

The total area of the country is estimated at 582,646 km^2. Of the total area, 571,416 km^2 or 98% is composed of land area while the remaining 2% is composed of water bodies such as lakes and ponds. Of the total land area, 90,270 km^2 or 16% was established as reserved areas (hereinafter, referred to as "unlivable area") such as gazetted forests, protected areas for use of national reserve, national parks, national sanctuaries, and a buffer of 50 m around rivers. The remaining of around 490,000 km^2 or 84% of land area are habitable areas (hereinafter referred to as "livable area"), where the development of water resources can be carried out. The largest county in terms of land area is the Marsabit County, which consists of 66,502 km^2 or 11.7% of the total land area. As for water bodies, Marsabit County has the largest water body, followed by Turkana County and Homa Bay County.

Table 2.1.2 shows the geographical distribution of county area by catchment area of Water Resources Management Authority (WRMA). The largest catchment area is Ewaso Ng'iro North (ENNCA: 210,520 km^2), followed by Rift Valley (RVCA: 138,000 km^2), Tana (TCA: 126,690 km^2), Athi (ACA: 58,639 km^2), Lake Victoria South (LVSCA: 31,734 km^2), and Lake Victoria North (LVNCA: 18,374 km^2). If a county includes areas with several catchments, socioeconomic data are distributed by the percentage of area through GIS techniques. For instance, the Siaya County is located both in LVNCA and LVSCA. The area includes 2,367 km^2 (93.3%) in LVNCA and 178 km^2 (6.7%) in LVSCA. The proportions can be used to distribute the population in the catchment.

2.2 Central Government and Devolved Units

Previously, administrative division comprised the 1) provinces, 2) districts, 3) divisions, 4) locations, and 5) sublocations. With the New Constitution, the administrative division in Kenya has changed to a central government and a devolved county government for each county. There are 47 county governments established under the New Constitution which will generate revenues and deliver public services such as water and sanitation services to citizens. The devolution of power to county governments is expected to commence after the general elections in March 2013.

As the devolution of governments under the New Constitution is anticipated to be effective in the study period, the report uses the countyas a basic administrative division. At present, the County Government Bill 2012 has been formulated. According to the bill, a county government shall be further decentralised into: 1) urban areas and cities within the county established by the Urban Areas and Cities Act 2011, 2) subcounties equivalent to constituencies within the county, and 3) wards within the county. According to the interview with the Ministry of Local Government, previous provinces shall be changed to regions in the future. These decentralised units have been under discussion at the Parliament and have not been established yet. Since these decentralised units have not been effective at the moment, this study uses the previous decentralised administrative units such as division, location, and sublocation, which were described in the 2009 Census. Table 2.2.1 compares the administrative units by county created from the 2009 Census with the 1989 Census (NWMP 1992). In Kenya, administrative divisions have been frequently changed and more administrative divisions have been created since 1989. At the time of the 1989 Census, the number of divisions was 261, however, it has now increased to 634 divisions.

Since the 2009 Census, other statistical data were based on the previous administration division, water demand and time-series data were calculated based on the district level for data consistency.

2.3 Local Government

In urban areas, four autonomous local authorities were established by the "Local Government Act (Chapter 265)", namely, 1) City Council, 2) Municipal Council, 3) County Council, and 4) Urban Council. According to the 2009 Census, an urban area was defined as "an area with an increased density of human-created structures in comparison to the areas surrounding it and has a population of 2000 and above," which includes cities, municipalities, town councils and urban councils.

With the New Constitution, the Urban Areas and Cities Act 2011 was enacted in 2012. In this act, two categories on urban areas were created, namely, 1) urban areas which include a municipality and a town and 2) cities. An urban area with a population of at least 500,000 residents is classified as a city, while a municipality comprises a population with more than 250,000, and a town means an urban area with a population of more than 10,000. The act had established three cities, namely, 1) Nairobi, 2) Mombasa, and 3) Kisumu. Nairobi is further classified as a city county. This means that it is a city and also a county. This new classification has been in a transition, but will be effective during the study period. Although the previous urban areas include urban centres with a population of less than 10,000, there is a possibility that the population in these urban centres would increase in the future.

For data consistency, the study uses four types of local authorities used in the 2009 Census, such as 1) City Council, 2) Municipal Council, 3) Town Council, and 4) County Council. Table 2.3.1 shows a list of the local authorities as of 2012, and Table 2.3.2 shows an inventory of local authorities by county. The number of municipal councils and town councils had increased from 28 in 1990 to 41 in 2012 and from 24 in 1990 to 64 in 2012, respectively. These local authorities have the ability to provide public services such as water and sanitation services and health facilities to the citizens.

In rural areas, a county council is an autonomous local authority which provide public services to the population. At present, there are several county councils in each county, partly because it is still in a transition period to establish a county government. The number of county councils had increased from 39 in 1990 to 68 in 2012.

CHAPTER 3 POPULATION

3.1 Present Conditions of Population

3.1.1 Historical Trend of the Population of Kenya

Kenya has been undertaking its census every ten years since 1969. The number of persons during the 2009 Population and Housing Census was 38,610,097, representing an increase of 35% from the 1999 Census at an average rate of 3.0% annually. The national enumerated population was lower by 2.1% compared to the projected figures.

Projected and Enumerated Population of Kenya in 2009

Projected Population	Enumerated Population	Difference Between Enumerated and Projected Population	
		Number	Percentage
39,423,264	38,610,097	-813,167	-2.1%

Source: 2009 Kenya Population and Housing Census, Kenya National Bureau of Statistics

The following table shows the trends in average annual population growth rates from 1969. At the national level, the growth rate increased marginally from 2.9% to 3.0% annually in the past ten years. In the 1999-2009 period, growth rates in all provinces except Rift Valley decreased.

Population Growth Since 1969

(Unit: %)

Province	1969-79	1979-89	1989-99	1999-2009
Nairobi	4.9	4.7	4.8	3.8
Central	3.4	2.8	1.8	1.6
Coast	3.5	3.1	3.1	2.9
Eastern	3.6	3.3	2.1	2.0
North Eastern	4.2	-0.1	9.5	8.8
Nyanza	2.2	2.8	2.3	2.1
Rift Valley	3.8	4.2	3.4	3.6
Western	3.8	3.4	2.8	2.5
Whole Country	3.4	3.4	2.9	3.0

Source: 2009 Kenya Population and Housing Census, Kenya National Bureau of Statistics

The following table shows the population distribution, household number, and population density of each province in 2009. Population density was calculated by multiplying the total population and the land area estimated by the JICA Study Team. The most populous province was Rift Valley, with more than ten million population, while the largest population density was Nairobi Province (4509 population/km^2), followed by Nyanza Province (599 population/km^2) and Western Province (531 population/km^2). The average population density in Kenya was calculated at 68 population/km^2.

Population, Households, and Density in Each Province

Province	Male	Female	Population Number	Households Number	Land Area (km^2)	Density (population/km^2)
Nairobi	1,605,230	1,533,139	3,138,369	985,016	696	4,509
Central	2,152,983	2,230,760	4,383,743	1,224,742	13,220	332
Coast	1,656,679	1,668,628	3,325,307	731,199	82,638	40
Eastern	2,783,347	2,884,776	5,668,123	1,284,838	148,994	38
North Eastern	1,258,648	1,052,109	2,310,757	312,661	125,806	18
Nyanza	2,617,734	2,824,977	5,442,711	1,188,287	9,091	599
Rift Valley	5,026,462	4,980,343	10,006,805	2,137,136	181,432	55
Western	2,091,375	2,242,907	4,334,282	904,075	8,167	531
Whole Country	19,192,458	19,417,639	38,610,097	8,767,954	570,044	68

Note: Land area was calculated by the JICA Study Team as mentioned in Section 1.1, and excluded water bodies.
Source: 2009 Population Census, Kenya National Bureau of Statistics; JICA Study Team

3.1.2 County Distribution

The population distribution by county was calculated by integrating the previous districts into counties using information from Statistical Abstract 2011. Table 3.1.1 shows the population distribution, household size, and population density by county in 1999 and 2009. The most populous county in 2009 was Nairobi City County (3,138,369 population), followed by Kakamega County (1,660,651 population) and Kiambu County (1,623,383 population). In terms of population density, Mombasa County has the highest density, accounting for more than 5307 population per km^2, followed by Nairobi City County (4509 population/km^2) and Nyamira County (950 population/km^2). Figure 3.1.1 shows the population density by county.

Among the 47 counties, Mandera County was highest when it comes to family size (8.17 people/household), followed by Wajir (7.47 people/household) and Turkana (6.94 people/household). These counties were also among the low population density areas, accounting for less than 50 population/km^2. The average family size in Kenya was estimated at 4.41 people/household.

Due to the frequent change of administrative division in Kenya, it is not reasonable to compare the population growth between the present and previous census. However, the table shows that the population in Mandera County increased from 250,372 in 1999 to 1,025,756 in 2009, whose annual growth rate was calculated at 15.1%. Wajir County, Turkana County, and Bomet County were also seen as counties with growing populations. These counties may have received massive migration from neighbouring counties, which may be the reason for the rapid population increase[1].

3.1.3 Catchment Area Distribution

As described in Section 2, the population by county in Kenya was further disaggregated by each catchment area in proportion to the percentage of catchment area. Table 3.1.2 shows the population distribution by catchment area. ACA is the most populous catchment area with a population of 8,979,672. It is followed by LVNCA (8,414,265 population), TCA (6,346,231 population), and LVSCA (6,094,882 population).

[1] The results of the 2009 Census has been under review, since the population in North-Eastern and Rift Valley Provinces near the border has been questioned in the court.

3.1.4 Urban Population

As discussed in Chapter 2, urban areas were defined as areas with a population more than 2,000 in the 2009 Census. The 2009 Census provided both the population in urban areas and the population in urban centres, whose total figures are slightly different. Table 3.1.3 compares the urban and rural areas in the 1999 Census and 2009 Census. The urban population in 1999 was calculated by adding the population of urban centres with more than 2,000 people. According to the table, majority of the population in Kenya still resides in rural areas. As of 2009, around 68% of the total population lives in rural areas, whereas around 32% of the total population are located in urban areas. The urban population increased from 9,904,044 in 1999 to 12,487,375 in 2009, but the percentage of population living in urban areas has not changed significantly, estimated at around 32%-33% of the urban population both in 1999 and 2009. Except for Nairobi and Mombasa counties, the most urbanised county is Kiambu County (62%), followed by Kisumu (52%) and Machakos (52%).

As for the urban population in urban centres within urban and peri-urban areas, the urban population was estimated at 11,546,351, accounting for around 30% of the population living in urban centres in 2009. Table 3.1.4 shows the population in urban centres in 2009. As demonstrated in Figure 3.1.2, Nairobi and Mombasa have a population greater than 500,000 in 2009. On the other hand, there are also six urban centres with a population of more than 250,000. Most urban centres are concentrated in highlands and coastal areas. Among the 215 urban centres, 137 urban centres with populations greater than 10,000 were selected as the target areas for urban water supply development plan. In addition, 95 urban centres were selected as the target areas for sewerage development plan.

3.2 Population Projection

3.2.1 Base Data

The latest available information regarding population and its distribution is the 2009 Census. Thus, this study was conducted based on the data of the Census 2009.

Population distribution and composition are one of the most basic pieces of information required in formulating a water resources development plan. There are two main composition categories that are central to the plan, these are urban and rural populations. The split is required in order to assess water supply levels of services in both rural and urban areas as these are distinctly different in Kenya.

There are also two main distribution categories that are critical to development of the plan, namely, spatial distribution by administrative boundary, and spatial distribution by catchment boundary. The former is required for the assessment of the present and future water demands, while the latter is required for calculation of water balance and the water resources development plan.

The 2009 Census does not provide data distributed by counties, therefore, the district boundaries were used. Counties similar with WSBs include multiple districts within their boundaries and therefore redistribution of water demand per county was calculated.

For the water resources development plan, water demand distribution per catchment area and sub-basin are required. Domestic water demand is calculated directly in relation with the population. It was identified that districts were too large compared to the sizes of the sub-basins. Therefore, the domestic water demand was estimated on the basis of the division population distribution data from the 2009 Census. Catchment distributions employed the ratio method to redistribute the division population and derive water demand into the sub-basins. The methodology to be adopted is described as follows.

If a division falls wholly within a sub-basin boundary, 100% of both urban and rural demands was assigned to that sub-basin. In the case that a division crosses over two or more sub-basins, then (i) the urban demand was allotted as a percentage depending on the urban spread within the sub-basin, and (ii) the rural population was distributed proportionally to the division part area that is included in the sub-basin. Some adjustments were required for urban areas that cross sub-basin boundaries for (i) and areas that are known to have no population for (ii).

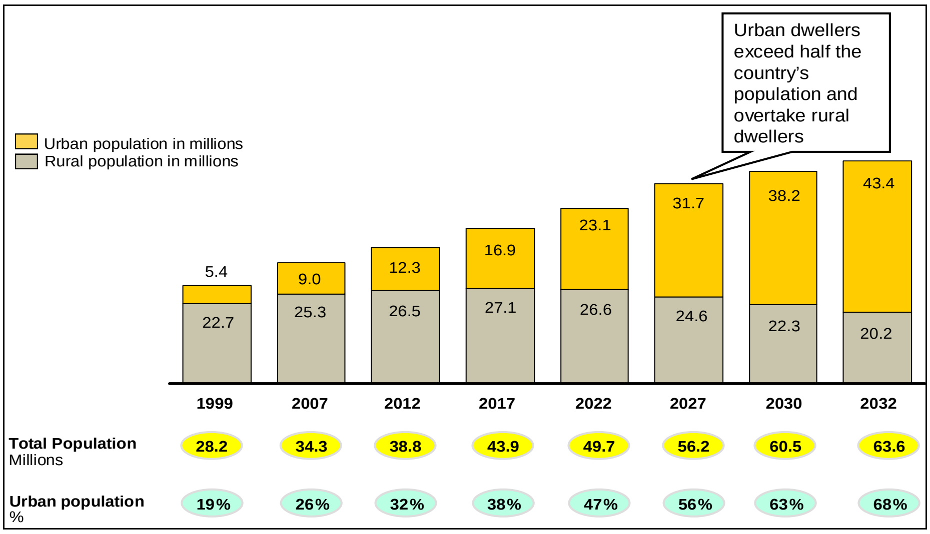
3.2.2 Projection Years

The population projection was made for the following years. The target year is 2030 as mentioned in the objective of this study.

Year 2010: Present condition
Year 2030: Target year for NWMP 2030
Year 2050: Year to assess the climate change effects on the country's water resources.

3.2.3 Population Projection

Kenya Vision 2030 presents the future population up to 2032 using the 1999 Census results as the base year. The figure below has been extracted from the Kenya Vision 2030 document. It shows the projected population figures.



Note: * Based on projections from 1999 National Census
Source: CBS

Population Projection by Kenyan Vision 2030

The complete results of the 2009 Census were not available at the time of this analysis, but the census report highlights some anomalous results in eight districts. From the report, the data indicating the rate of increase is higher than the population dynamics (births, deaths, etc.). Age and sex profiles deviate from the norm and significant growth is observed in household size without the accompanying growth in number of households (refer to 2009 Census). Eight anomalous districts were extracted and their population results were compared with the results from the 1999 Census projected to 2009, using the Kenya Vision 2030's growth rates.

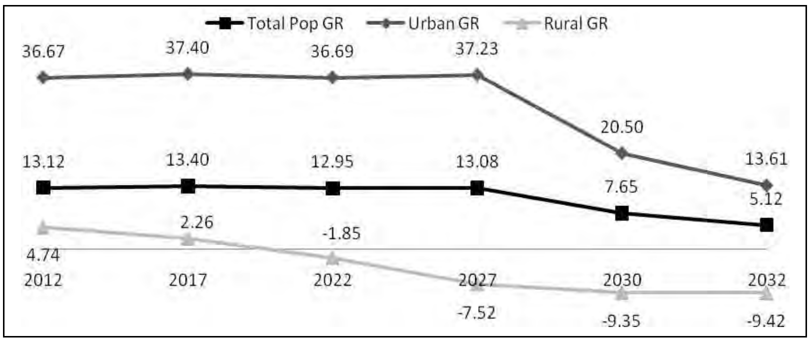
Correction of 2009 Census Population

Districts	2009 Census Population	1999 Census Population Projected in 2009*	Difference
Lagdera	245,123	207,966	37,157
Wajir East	224,418	145,964	78,454
Mandera (Central, East, West)	1,025,756	321,062	704,694
Turkana (Central, North, South)	855,399	564,075	291,324

Note: * Based on Kenya Vision 2030's growth rates
Source: JICA Study Team based on Census 2009 data and Kenya Vision 2030

Based on the 1999 Census projected to 2009, Mandera should have a total population of 321,062 as opposed to 1,025,756. The difference is 704,694 people. Similarly, Turkana has a difference of 291,324, while Lagdera 37,157, and Wajir East 78,454. The total difference is 1.112 million. This indicates that the 2009 Census population should be approximately 38.61 – 1.112 = 37.5 million, which closes the gap with Kenya Vision 2030.

Following this correction, the 2009 Census population is still ahead of Kenya Vision 2030 but it is believed that the residual difference is probably due to an underestimation of the Kenya Vision 2030 projection. Based on information from MWI, the family planning policies have not been effective in the last decade and an increase in birth rates has been observed. It is expected that the policies will be more efficient in the future and birth rates are expected to fall. Based on this information and assumptions, the study adopts the 2009 Census data as the base year. Adjustments on the anomalies in the eight districts were made and the resulting data were projected based on Kenya Vision 2030's growth rates presented below.



Note: Projections for 2010 and 2011 utilised yearly growth rates calculated from Kenya Vision 2030
Source: Kenya Vision 2030

Average Population Growth Rate in Kenya Vision 2030

Projections beyond 20 years are not available and are very difficult to predict. The United Nations projects the population to be 96.89 million by 2050, which is the indicative figure for this study. The population for the period between 2030 and 2050 is projected to increase at an average annual growth rate of 1.94%, indicating a more developed country with a decrease in birth rates and a reduction in internal migration rates from rural to urban.

The table below summarizes the national population projected based on the procedure mentioned above. Table 3.2.1 shows the projected population distribution by county and catchment area in 2030.

Projected Population

(Unit: million persons)

Year	2009 (Census)*		2010		2030		2050	
Area	No.	%	No.	%	No.	%	No.	%
Urban	12.29	32.8	13.08	33.9	46.02	67.8	65.69	67.8
Rural	25.11	67.2	25.45	66.1	21.82	32.2	31.20	32.2
Total	37.40	100	38.53	100	67.84	100	96.89**	100

Note: * 2009 Census population adjusted for eight anomalous Districts

** UN World Urbanization Prospects: The 2011 Revision

Source: JICA Study Team based on Kenya Vision 2030 and UN projection

CHAPTER 4 MACRO ECONOMY

4.1 Present Economic Performance

In the past, the economy of Kenya has been largely dependent on agriculture and tourism. According to the 2012 Economic Survey, Kenya continues to recover steadily from the multiple shocks that the country suffered since 2008. The World Bank's Kenya Economic Update for June 2012 projected a GDP growth rate of 5.0% in 2012, while the government estimated at the same level at 5.2%. The following table shows macroeconomic indicators between 2007 and 2011.

Kenya is one of the most industrially developed countries in East Africa. Yet, the manufacturing sector accounts only for 9.4% of the GDP. Economic development in recent years can be attributed to expansions in the tourism, telecommunications, transport, and construction sectors, as well as the recovery in agriculture. Agriculture (including coffee and tea cultivation) is the main source of revenue for around 70% of the population in Kenya. In addition, this sector, which is around 24% of the GDP, is still seen as the largest contributor to the Kenyan economy. This is followed by the transport and communications sectors, contributing to 9.7% of the GDP in 2011. The energy subsector consists of 0.9% of the GDP on average in the past five years, while the water supply subsector contributes to 0.7% of the GDP in 2011. The tourism sector has also been growing in recent years, comprising around 17% of export earnings[2]. The GDP per capita has been increasing steadily, accounting for US$774 in 2011. Kenya is considered to be on the path to reach a lower middle-income status (US$1,000). Table 4.1.1 shows the GDP by activity/industry between 2007 and 2011.

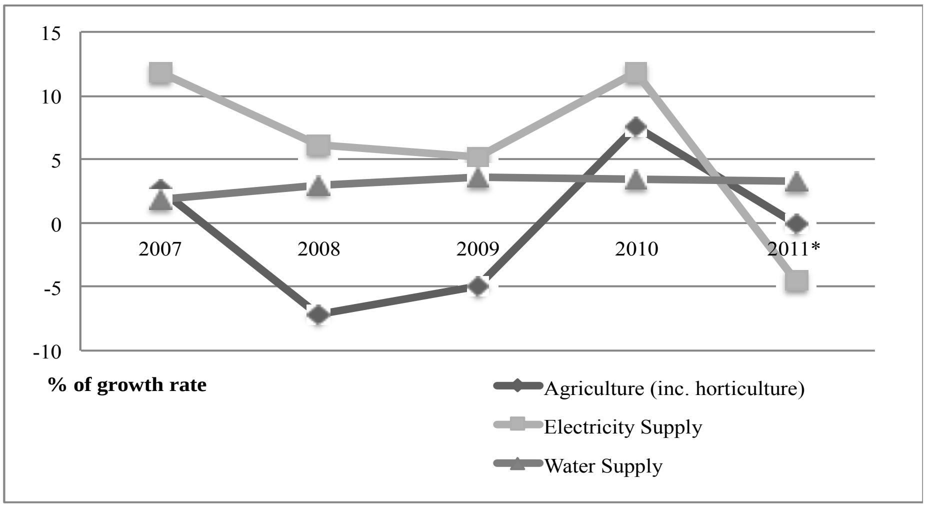
Economic Statistics

Item	2007	2008	2009	2010	2011*
GDP (current price- Ksh) (billions)	1,834	2,108	2,367	2,550	2,671
GDP growth (annual %)	7.0	1.5	2.7	5.8	4.4
Inflation (annual %)	4.3	16.2	10.5	4.1	14.0
GDP by Selected Sectors					
Agriculture, value added (% of GDP)	21.7	22.3	23.5	21.4	24.0
Manufacturing (% of GDP)	10.4	10.8	9.9	9.9	9.4
Electricity and Water Supply	1.5	2.1	1.9	1.4	0.9
Electricity (% of GDP)	0.8	1.5	1.2	0.7	0.2
Water Supply (% of GDP)	0.6	0.6	0.6	0.7	0.7
Transport and communications (% of GDP)	10.6	10.3	9.9	10.0	9.7
Hotels and restaurants (% of GDP)	1.6	1.1	1.7	1.7	1.7
GDP growth rate by selected sectors					
Growing of crops and horticulture (growth rate %)	2.7	-7.2	-5	7.5	0.0
Electricity (growth rate %)	11.8	6.1	5.2	11.9	-4.5
Water Supply (growth rate %)	1.8	2.9	3.6	3.5	3.2
GDP per capita (US$)	719	774	738	760	774
Balance of trade (KSh billion)	-330	-426	-443	-537	-805

Note: * Provisional
Source: Economic Survey 2012; Kenya Economic Update June 2012, World Bank

[2] Kenya Economic Update, June 2012.

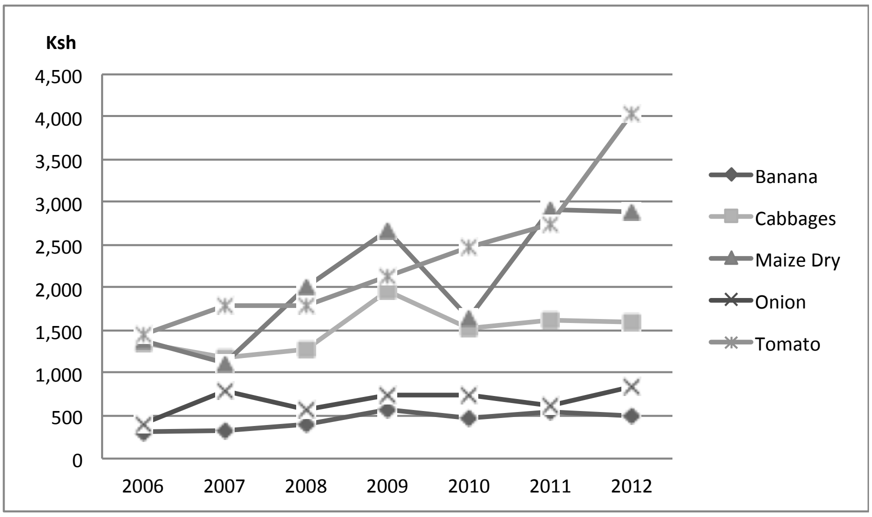
The energy subsector declined growth in 2011 due to insufficient rainfall and subsequent increase in the use of more expensive thermal power, as shown in the succeeding graph. However, the energy subsector has grown by 6.1% on average between 2007 and 2011, which is higher than the average GDP growth in this period (4.3%). The water subsector grew gradually from 1.8% in 2007 to 3.2% in 2011. This trend is expected to continue in the medium term, with gradual urbanization in Kenya and expected external financing for water supply and sanitation projects (see Chapter 5).



Note: * Provisional
Source: Economic Survey 2012

Growth Rate of Water, Energy, and Crops and Horticulture Between 2007 and 2011

On the other hand, the agriculture sector deteriorated in 2011 due to erratic weather conditions and high price of farm inputs. Table 4.1.2 shows the wholesale prices for selected agricultural commodities between 2006 and 2012. Although the prices of most agricultural products have been gradually increasing in this period, the wholesale prices have fluctuated due to weather conditions, erratic prices in international markets, and other factors. The figure below demonstrates the change of wholesale prices for selected agricultural commodities between 2006 and 2012. Maize particularly fluctuates year by year, partly due to weather conditions and partly due to government intervention in cereal commodities. In general, the wholesale prices of horticulture such as tomatoes and onions have been increasing with an average annual growth rate of around 10%.



Note: Annual average price, except for the price in 2012 as of November 1, 2012
Source: Economic Review of Agriculture 2012; Business Daily, November 2, 2012

Wholesale Prices of Major Agricultural Commodities Between 2006 and 2012

East Africa is the second highest growing region in the world and Kenya is taking advantage of its location. Trade with East African countries has been rapidly growing in the past five years (annual growth rate of around 19% in export). Kenya serves as a regional hub to cater the service and finance industries in East Africa. Kenya's neighbouring countries, Tanzania and Uganda, have a surplus in agriculture and they have recently discovered gas and oil which boosted its economy. Kenya's export earnings from Uganda consists of around 15% of the total, which is the highest among other of Kenya's export destinations. The development of the Northern Corridor and the Lamu Port-Southern Sudan-Ethiopia Transport Project (LAPSET) which would connect Lamu Port to Southern Sudan and Ethiopia is expected to enhance the growth in the transport sector and trade among countries. In the water sector, a water supply project for transferring water from the High Grand Falls (HGF) to the Lamu area, and an energy generation project from the HGF have been planned as part of the LAPSET.

Kenya's Export by Destination, 2007-2011

(Unit: KSh million)

Destination	2007	2008	2009	2010	2011	% of Total in 2011	Growth (July 2011)
Europe Total	79,277	98,513	100,975	109,422	134,959	26%	14%
America Total	20,520	22,054	18,961	24,380	27,491	5%	8%
Africa Total	124,029	162,541	162,732	188,914	247,601	48%	19%
South Africa	2,347	3,641	3,580	2,444	2,835	1%	5%
Rwanda	5,801	8,953	9,536	10,535	13,555	3%	24%
Egypt	9,111	15,490	11,885	18,116	23,422	5%	27%
Tanzania	22,326	29,224	30,087	33,211	41,743	8%	17%
Uganda	33,571	42,285	46,240	52,108	75,954	15%	23%
Brundi	2,424	3,479	4,597	5,458	5,904	1%	25%
Sudan	11,589	14,073	12,763	18,815	22,154	4%	18%
Congo, D.R.	8,308	9,852	11,324	12,792	17,537	3%	21%
Other	28,552	59,468	56,808	67,042	84,189	16%	31%
Asia Total	46,227	57,241	59,236	81,600	95,449	19%	20%
All Other Countries	3,340	3,280	2,130	4,712	4,504	1%	8%
Total Export	274,658	344,947	344,949	409,794	511,038	100	17%

Source: Economic Survey 2012

4.2 GDP Projection

4.2.1 Base Data

GDP is widely considered as a parameter directly related to industrial growth and in turn to the increase in water demand by the industrial sector.

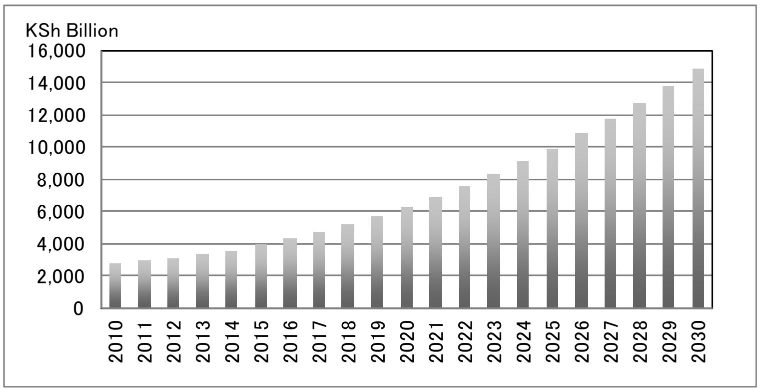
Kenya Vision 2030 sets a very ambitious plan aiming to achieve a 10% GDP growth in 2017 and sustain the same level thereafter. The sector must, however, surmount some challenges, including high fuel prices, exchange rate risks, inadequate and unreliable power supply, as well as world economic crisis, and global and regional instability.

The 2011 Budget Outlook Paper (BOPA) provides the basis of the GDP projection for the medium-term projection. In addition, the overall target of Kenya Vision 2030 to achieve a 10% GDP growth by 2017 will be considered for the long-term GDP projection.

4.2.2 GDP Projection

The 2011 BOPA provides the basis of the GDP projection for the medium-term projection. BOPA expects a moderate rate of 6.1% in 2012 with a weaker global economy and tighter domestic macroeconomic conditions. But in the medium term, the economy is expected to grow up to 7% to accelerate towards the Kenya Vision 2030 target.

In addition, the overall target of Kenya Vision 2030 to achieve 10% GDP by 2017 will be considered for the long-term GDP projection. Originally, Kenya Vision 2030 aimed at achieving a 10% GDP growth rate by 2012 and thereafter sustaining such growth. However, due to the slowdown of the economy since 2007, Kenya Vision 2030 has been revising its projection of the future growth rate. According to Kenya Vision 2030, a 10% growth rate was projected starting from 2016, and would be sustained up to 2023. Given the growth prospect of BOPA in the medium term and the recent growth trend in East Africa, the target of high economic growth envisaged in Kenya Vision 2030 is expected to be achieved if key infrastructure developments and oil exports from Kenya are to be undertaken. The high growth rate would be sustained as the Vision 2030 projects, but will then decline gradually as the economy becomes mature thereafter. Therefore, it was projected that Kenya will gradually achieve high growth by approximately 2016, provided the global economy is constant and infrastructure development and oil export are on track. The projected GDP values are shown in the following graph and table below.



Source: Budget Outlook Paper 2011 (BOPA), Projection by Kenya Vision 2030

GDP Projection up to 2030 (Based on BOPA 2011 and Kenya Vision 2030)

Projected GDP Growth Rate up to 2030

Year	%	Year	%	Year	%	Year	%
2010	4	2016	10	2021	10	2026	9
2011	5	2017	10	2022	10	2027	9
2012	6	2018	10	2023	10	2028	8
2013	7	2019	10	2024	9	2029	8
2014	8	2020	10	2025	9	2030	8
2015	9						

Source: Kenya Vision 2030 Secretariat

It is not possible to carry out projections for the next 20 years in similar details as stated above, due to the lack of long-term data and the unpredictable nature of the relevant parameters. For this study, it was assumed that following the implementation of Kenya Vision 2030, the Kenyan economy would have reached a level of relative maturity and with reference to the current GDP rates of stable economies. Therefore, a GDP rate of 4% per year was applied.

CHAPTER 5 PUBLIC FINANCE

5.1 Central Government

The government has managed to maintain a stable fiscal and macro framework that was first developed under the Economic Recovery Strategy, and subsequently, the Medium Term Plan 2008-2012.

According to the Economic Survey 2012, the central government's revenue was expected to record a 15.1% increase, accounting for KSh 766.2 billion in 2011-2012. The central government's expenditure as a percentage of GDP was expected to rise to 30.1% in 2011-2012. The fiscal consolidation policy to contain the fiscal deficit started in 2010-2011, but the fiscal deficit was expected to widen due to the increased public spending in areas such as drought mitigation and the war in Somalia. The stock of total outstanding debt as of June 30, 2011 amounted to KSh 1,322.6 billion compared to KSh 1,082.7 billion owed one year earlier.

A summary of government operations from the financial year of June 2005 to the financial year of October 2009 is provided in the table below.

Statement of Government Operations 2007-2012

(Unit: KSh million)

Item	2007-2008	2008-2009	2009-2010	2010-2011*	2011-2012+
GDP at Market Price	1,833,511	2,107,589	2,366,984	2,549,825	3,024,782
1 Revenue[1]	468,243	498,895	574,135	665,462	766,176
Increase of Revenue	20.8%	6.5%	15.1%	15.9%	15.1%
% of GDP	25.5%	23.7%	24.3%	26.1%	25.3%
2 Expenses (2.1+2.2)	448,762	492,669	574,253	673,215	909,911
% of GDP	24.5%	23.4%	24.3%	26.4%	30.1%
2.1 Current Expenditure	417,381	465,970	525,671	621,493	740,975
2.2 Capital Transfers	31,380	26,699	48,581	51,721	168,936
3 Gross Operating Balance (GOB) (1-2)	19,481	6,226	-117	-7,753	-143,735
4 Acquisition of Non-Financial Assets (net)	74,386	113,198	114,823	125,401	156,649
5 Net Lending/Borrowing (3-4)	-54,904	-106,972	-114,941	-133,154	-300,384
Financing	38,677	83,422	168,285	149,882	143,113
6 Net Acquisition of Financial Assets (6.1+6.2)	46,244	-9,126	5,659	6,316	5,795
7 Net Incurrence of Liabilities (7.1+7.2)	-7,566	92,549	162,625	143,566	137,317
Memorandum Items:					
8 Public Debt Redemption (8.1+8.2)	92,269	75,361	91,714	124,543	89,225

Note: * Provisional, + revised estimates, 1 includes grants and A-I-A
Acquisition of non-financial assets (net) = Acquisition of non-financial assets - Disposal of non-financial assets
Source: Economic Survey 2012

The form in which government accounts are kept and published is determined by the administrative structure and the requirements of financial control. The total government spending has doubled since 2007-2008; in particular, a rapid increase in capital expenditure by more than four times of the 2007-2008 level. The rise in spending has largely been classified under the development budget. Development expenditures increased from 1.7% of the GDP in 2003-2004 to 5.6% of the GDP in 2011-2012. About 3.5% of the GDP or 40% of the development budget will be spent through project loans and grants not related to development partners.

The Budget Policy Statement 2012 updated the priority sectors for allocating public resources for targets described in the first Medium Term Plan of Kenya Vision 2030. The improvement of infrastructure such as roads, energy, water, and irrigation were given priority in the share of public resources. The environmental protection, water and housing sectors have a 5% share of the total government expenditure.

5.2 Water Sector

The water sector's government grant remains below 3% of the government's total budget. This is equivalent to less than 1% of the country's GDP, although these aspects are both on an upward trend with the 2012-2013 fiscal year recording in highest levels (estimated at KSh20.4 billion for development grant). The following table shows the revenue and expenditures in the water sector under MWI.

Current and Future Projected Revenue and Expenditure in Water Sector (MWI), 2012-2016

(Unit: KSh billion)

Item		Actual	Projected		
		2012-2013	2013-2014	2014-2015	2015-2016
Total Revenue	(a: b+c+d)	50.3	54.1	57.3	58.9
Internally Generated	(b)	1.8	2.1	2.1	2.1
Government Grants	(c)	24.8	25.9	27.8	29.4
% of Government's Budget		3.0%	2.9%	2.9%	2.8%
Recurrent Grants	(d)	4.4	4.4	4.7	4.7
Development Grants	(e)	20.4	22.0	23.7	25.4
External Resources	(f)	23.7	26.1	27.4	27.4
Total Expenditure for Development (including External Resources)	(h: f+i)	44.1	47.6	50.5	52.1
Estimated Development Expenditure by Government Grant	(i: j+k+l+m+n)	20.4	22.0	23.7	25.4
Water Supply	(j)	6.1	6.8	7.3	8.0
Sewerage and Sanitation	(k)	0.7	0.7	0.8	0.8
Irrigation	(l)	8.0	8.4	9.0	9.9
Water Resource Development (Storage)	(m)	5.2	5.6	5.9	6.0
Water Resource Management	(n)	0.4	0.5	0.6	0.7

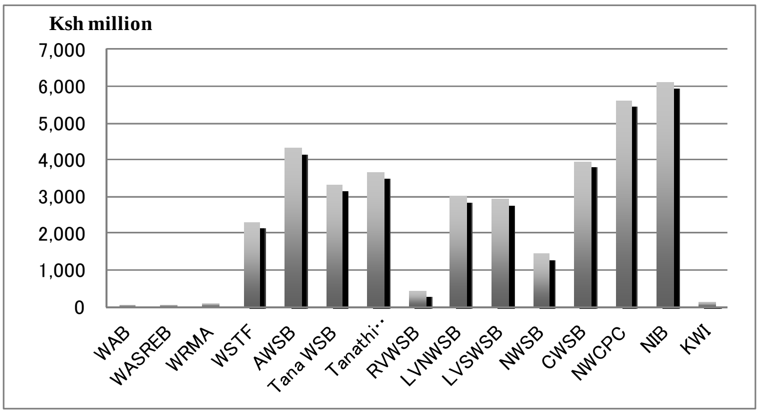
Source: Ministry of Water and Irrigation, National Irrigation Board, estimated by the JICA Study Team

Within the development expenditure, external resources consist of around 54% of the total in 2012-2013 (KSh 23.7 billion). In the water sector, irrigation received majority of the sector's government grant, comprising around 39% of the country's development expenditure (KSh 8.0 billion in 2012-2013), followed by water supply, water resource development (storage), and sewerage.

The investment for irrigation was relatively small in the past three years, but the government announced to allocate KSh 8.0 billion for the expansion and construction of irrigation schemes in 2012-2013. The Katilu irrigation scheme in Turkana County (1,200 acres of maize), the Bura irrigation scheme (7,000 acres of maize), the Ahero and West Kano (6,000 acres of rice), and other irrigation schemes will be financed in the current financial year. While irrigation schemes have largely been financed by government grants, around 75% of water supply projects have been funded by external resources.

The process of devolution and new financing mechanism for public services has been in progress. KSh 148.0 billion will be allocated for the preparation of a transition of functions to county governments during the 2012-2013 fiscal year, which is expected to commence after the next general elections in 2013.

There are 15 semi-autonomous government agencies (SAGAs) in the water and irrigation subsectors. The resource allocation and requirements of SAGAs between 2011-2012 and 2012-2013 are presented in the table below. The government grant by SAGAs in 2012-2013 is shown in the following figure. SAGAs that implement development projects, such as the NIB and the NWCPC, have a higher resources requirement, and the deficiency of investment funds is also seen in such agencies. These two SAGAs have received the most resources from the central government, while the Water Service Boards (WSBs) generally rely on external resources for their capital expenses. In 2012-2013, the NIB was allocated with a total of KSh 6,102 million.



Source: Annual Water Sector Review 2010-2011

Government Grant among SAGAs in 2012-2013

Resource Allocation and Requirements 2011-2013:
Semi-Autonomous Government Agencies in Water and Irrigation

(Unit: KSh million)

Semi Autonomous Government Agencies	Allocation 2011-2012	Requirements (1) 2012-2013	Allocation (2) 2012-2013	Variance (1)- (2)
Water Appeal Board	15.00	20.00	15.00	-5.00
Water Services Regulatory Board	20.00	131.00	20.00	-111.00
Water Resources Management Authority	100.00	1,918.00	100.00	-1,818.00
Water Services Trust Fund	2,182.00	2,576.00	2,302.00	-274.00
Athi Water Services Board	4,322.00	3,224.00	4,322.00	1,098.00
Tana Water Services Board	3,293.00	3,293.00	3,293.00	-
Tanathi Water Services Board	3,770.00	6,387.00	3,640.00	-2,747.00
Rift Valley Water Services	428.00	2,500.00	428.00	-2,072.00
Lake Victoria North Water Services Board	2,998.00	3,008.00	2,998.00	-10.00
Lake Victoria South Water Services Board	2,921.00	2,931.00	2,921.00	-10.00
Northern Water Services Board	1,431.00	2,060.00	1,431.00	-629.00
Coast Water Services Board	3,947.00	4,000.00	3,947.00	-53.00
National Water Conservation and Pipeline Corporation	5,588.00	16,969.00	5,598.00	-11,371.00
National Irrigation Board	6,402.00	12,294.00	6,102.00	-6,192.00
Kenya Water Institute	120.00	130.00	120.00	-10.00
Subtotal Water and Irrigation	37,267.00	63,441.00	37,237.00	-26,204.00

Source: Environmental Protection, Water & Housing Sector Report: MTEF 2012/13-2014/15

The following table shows the revenue and expenditure in the Water Resources Management Authority (WRMA) between 2010/11 and 2012/13. WRMA currently receives around 36% of the revenue from the central government, while internal revenue are generated from collecting water charges which comprise around 19% of the total revenue. The revenue from water use charges has been gradually increasing but it could not cover the full cost of recurrent expenses (only 37% of coverage). On the other hand, development expenditures in WRMA have mostly been financed by external resources, accounting around 88% of the development expenditure. Most donor funded resources have been allocated for capital expenses such as catchment management, flood mitigation measures, and capacity building activities. On the other hand, government development grants accounted for KSh 120 million in 2012-2013, which could not cover some essential functions of water resources management such as the regulation of use of water resources (KSh 142.5 million) and water resources data management (KSh 150 million).

Revenue and Expenditure of WRMA in 2010-2013

(Unit: KSh million)

Items	2010-2011	2011-2012	2012-2013	% of Total
	Actual	Actual	Estimate	Revenue
Total Revenue	1,364	2,269	2,220	100%
Recurrent Budget	533.48	1,062.41	1,113.75	50%
Internally Generated	250.98	406.30	415.50	19%
Water Permit Fees	47.50	76.00	78.00	4%
Water Use Charges	195.32	314.30	320.00	14%
Other Charges	8.16	16.00	17.50	1%
Government Recurrent Grant	282.50	656.11	698.25	31%
Development Budget	830.64	1,206.23	1,106.64	50%
Government Recurrent Grant	231.31	100.00	120.00	5%
External Resources	599.33	1,106.23	986.64	44%
Development Expenditure	830.64	1,206.23	1,106.64	50%
Office Set up and Institutional Development	137.29	285.09	163.20	7%
Water Resources Data Management	108.36	146.88	150.00	7%
Catchment Management	314.34	440.60	394.48	18%
Regulation of Use of Water Resources	100.76	121.03	142.50	6%
Design, Planning and Establishment of Water Storage Facilities	60.30	58.68	125.00	6%
Policy and Planning	109.59	153.95	131.46	6%

Source: Water Resource Management Authority

The devolution of public finance for water and sanitation services has been planned. KSh 5.5 billion will be allocated to the newly created equalization fund in 2012-2013. The fund will provide basic services such as water, roads, and electricity in the marginal areas. Other institutional reforms under the 2010 Constitution and the Water Bill 2012 have been elaborated. Public financing in the water sector will be subject to change accordingly.

CHAPTER 6 HOUSEHOLD WELFARE AND POVERTY

6.1 Household Welfare

It is commonly said that household welfare can be measured by household or individual expenditure rather than income per capita in developing countries, partly because there are many individuals engaged in self-employed or informal economies in a country like Kenya. The Kenya Integrated Household Budget Survey (KIHBS) for 2005-2006 provides the most recent available data on household expenditure in Kenya. The following table shows the monthly expenditure per adult by region in 2005-2006. On average, the monthly expenditure per adult in Kenya accounts for KSh 3,432 in 2005-2006. There is a huge difference between the urban and rural areas in terms of expenditure per adult. Adults in urban areas spend KSh 6,673 per month, while the expenditure of adults in rural areas was estimated at KSh 2,331, which is around one-third the expenditure of the urban population

Monthly Expenditure per Adult by Region in 2005-2006

(Unit: KSh)

Region	Monthly Expenditure per Adult		
	Total	Food	Non-Food
Kenya	3,432	1,754	1,678
Total Rural	2,331	1,453	878
Central	2,959	1,696	1,263
Coast	1,731	1,179	552
Eastern	2,231	1,425	806
North Eastern	1,578	1,204	374
Nyanza	2,262	1,478	786
Rift Valley	2,457	1,474	984
Western	1,965	1,300	665
Total Urban	6,673	2,642	4,032
Nairobi	8,706	3,010	5,696
Mombasa	5,503	2,285	3,218
Kisumu	5,711	2,172	3,539
Nakuru	4,010	2,302	1,708

Source: Basic Report on Well-Being in Kenya, 2007

Based on the above data, the monthly expenditure per adult in 2012 was calculated by taking into account the growth rate of real GDP and inflation rate. The table below shows the estimated monthly and annual expenditures per adult between 2007 and 2012. The annual expenditure per adult in urban areas in 2012 was estimated at around KSh 175,000, while in rural areas it was at around KSh 61,000.

Estimated Monthly and Annual Expenditure per Adult Between 2007 and 2012

Region	Projection of Monthly Expenditure per Adult (KSh)						Annual Expenditure	
	2007	2008	2009	2010	2011	2012	2012 (KSh)	2012 (US$)
Kenya	3,830	4,517	5,126	5,646	6,720	7,501	90,007	1,056
Total Rural	2,601	3,068	3,482	3,835	4,564	5,094	61,133	717
Central	3,302	3,895	4,420	4,868	5,794	6,467	77,602	910
Coast	1,932	2,278	2,586	2,848	3,389	3,783	45,397	533
Eastern	2,490	2,937	3,333	3,670	4,368	4,876	58,510	686
North Eastern	1,761	2,077	2,357	2,596	3,090	3,449	41,384	486
Nyanza	2,524	2,977	3,379	3,721	4,429	4,944	59,323	696
Rift Valley	2,742	3,234	3,670	4,042	4,811	5,370	64,437	756
Western	2,193	2,586	2,935	3,233	3,847	4,294	51,534	605
Total Urban	7,447	8,783	9,968	10,978	13,066	14,584	175,005	2,053
Nairobi	9,716	11,459	13,004	14,323	17,046	19,027	228,323	2,679
Mombasa	6,141	7,243	8,220	9,053	10,775	12,027	144,321	1,693
Kisumu	6,374	7,517	8,531	9,396	11,182	12,481	149,776	1,757
Nakuru	4,475	5,278	5,990	6,597	7,852	8,764	105,166	1,234

Source: JICA Study Team based on Basic Report on Well-Being in Kenya, 2007

Half of urban households have access to electricity, compared with only 5% of households in rural areas. According to the KIHBS, around half of the urban households have access to piped water in their compounds or dwelling or get water from public taps, while only 12.8% of the rural population have access to piped water. Table 6.1.1 shows the percentage of households by main source of drinking water by region and county. In Nairobi, piped water and public tap are the main sources of drinking water, whereas public taps and water vendors are the dominant sources of drinking water in Mombasa. The Western Province is primarily deficient in piped water services, with only 4.6% of its population having access to piped water. About 70% of Kenyan households are located within 15 minutes of their drinking water supply.

6.2 Poverty

The reduction of poverty was cited as one of the major objectives in Kenya Vision 2030. The KIHBS 2005-2006 provided data on the poverty rate (headcount index[3]) by district and at the national level, which are shown in the following figure and table. The KNBS defined the official poverty lines for rural and urban populations. The poverty lines were set at KSh 1,562 per month per person in rural areas (approximately US$0.75 per day per adult equivalent at the time), and KSh 2,913 per person in urban areas (US$1.4 per day per adult). The defined poverty lines included food poverty line and non-food poverty line. The food poverty line was measured on the basis of the expenditure required to purchase a food basket that allows minimum nutritional requirements to be met, which was set at the daily equivalent intake of 2,250 kilocalories per adult per day.

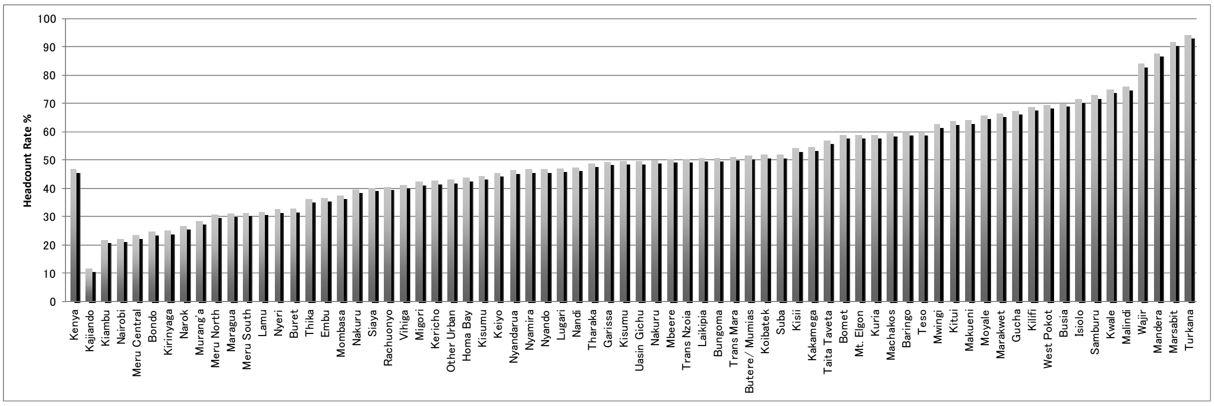
On average, around 47 % of the population in Kenya were below the poverty line in 2005-2006. Based on the poverty rate in 2005-2006 and the 2009 Census, around 18.0 million people were estimated to be under the poverty line in 2009. The poorest area was located in the North Eastern Region, wherein around 74% of its people are poor. In terms of the number of poor people, the Rift Valley Region has the most at around 4.9 million people. There was a huge difference in terms of the

[3] The headcount index is defined as the proportion of people whose consumption (per capita) is below the poverty line. Poverty line is based on the expenditure required to purchase a food backet that allows minimum nutritional requirement (2250 Calories).

poverty rate between rural and urban areas, in which around 13.0 million of the population in rural areas were estimated to be under the poverty line (72% of the poor people live in rural areas).

The poorest districts were concentrated in arid and semi-arid areas such as Turkana District (94.3% of its people are poor), Marsabit District (91.7%), and Mandera District (87.8%). Kenya Vision 2030 gives special attention to poor districts in arid and semi-arid areas for future investments.

Poverty Rate (Headcount Index) per Individual by District in 2005-2006



Source: Basic Report on Well-being in Kenya, 2007

Poverty Rate by Region in 2005-2006 and Estimated Number of Poor People in 2009

Region	Poverty Rate in 2005-2006 (Headcount Index, %)	Estimated Number of Poor People in 2009 (million)
Kenya	46.6	18.0
Urban	34.4	4.3
Rural	49.7	13.0
Central	30.7	1.3
Coast	70.1	2.3
Eastern	51.5	2.9
North Eastern	73.5	1.7
Nyanza	47.5	2.6
Rift Valley	49.3	4.9
Western	53.1	2.3

Source: Basic Report on Well-being in Kenya, 2007

Tables

Table 2.1.1 Land Area by County in Kenya

(Unit: km^2)

Old Administration in 1992		County	Total Area	Water Body	Land Area		
Province	District				Livable	Unlivable	Total
Western	Bungoma	Bungoma	3,019	0	2,299	720	3,019
	Busia	Busia	1,689	137	1,531	21	1,552
	Kakamega	Kakamega	2,707	0	2,287	420	2,707
		Vihiga	889	0	860	29	889
Nyanza	South Nyanza	Homa Bay	3,198	2,064	903	231	1,134
		Migori	2,646	0	2,627	19	2,646
	Kisii	Kisii	1,474	0	1,466	8	1,474
		Nyamira	758	0	754	4	758
	Kisumu	Kisumu	2,106	567	1,505	34	1,539
	Siaya	Siaya	2,545	1,005	1,514	26	1,540
Rift Valley	Baringo	Baringo	11,043	163	9,848	1,032	10,880
	Kericho	Kericho	2,176	0	1,723	453	2,176
		Bomet	2,831	0	2,146	685	2,831
	Elgeyo Marakwet	Elgeyo Marakwet	3,031	0	1,668	1,363	3,031
	Kajiado	Kajiado	22,272	142	21,354	776	22,130
	Laikipia	Laikipia	9,514	0	0	9,514	9,514
	Nakuru	Nakuru	7,586	176	5,758	1,652	7,410
	Nandi	Nandi	2,904	0	2,364	540	2,904
	Narok	Narok	18,278	0	15,139	3,139	18,278
	Samburu	Samburu	21,014	0	17,167	3,847	21,014
	Trans Nzoia	Trans Nzoia	2,509	0	0	2,509	2,509
	Turkana	Turkana	68,555	2,279	65,025	1,251	66,276
	Uasin Gishu	Uasin Gishu	3,364	0	0	3,364	3,364
	West Pokot	West Pokot	9,115	0	8,702	413	9,115
Central	Kiambu*	Kiambu	3,165	3	2,681	481	3,162
	Kirinyaga	Kirinyaga	1,479	0	0	1,479	1,479
	Muranga**	Muranga	1,968	0	1,705	263	1,968
	Nyandarua	Nyandarua	3,248	0	2,420	828	3,248
	Nyeri	Nyeri	3,363	0	0	3,363	3,363
Nairobi	Nairobi	Nairobi	696	0	604	92	696
Eastern	Embu	Embu	2,830	0	0	2,830	2,830
	Isiolo	Isiolo	25,201	0	24,066	1,135	25,201
	Kitui	Kitui	30,558	0	21,165	9,393	30,558
	Machakos	Machakos	6,247	5	6,141	101	6,242
		Makueni	8,058	0	6,530	1,528	8,058
	Marsabit	Marsabit	70,628	4,126	61,417	5,085	66,502
	Meru	Meru	6,952	0	0	6,952	6,952
		Tharaka-Nithi	2,651	0	0	2,651	2,651
Coast	Kilifi	Kilifi	12,626	109	11,913	604	12,517
	Kwale	Kwale	8,366	65	7,871	430	8,301
	Lamu	Lamu	6,245	308	4,459	1,478	5,937
	Mombasa	Mombasa	242	65	164	13	177
	Taita Taveta	Taita Taveta	17,346	16	7,031	10,299	17,330
	Tana River	Tana River	38,376	0	33,305	5,071	38,376
North Eastern	Garissa	Garissa	44,071	0	41,036	3,035	44,071
	Mandera	Mandera	25,551	0	24,565	986	25,551
	Wajir	Wajir	56,184	0	56,062	122	56,184
Other Areas for adjustment			1,372	0	1,372	0	1,372
Total			582,646	11,230	481,146	90,270	571,416

Note: * Unlivable land means all lands located within gazetted forests, protected areas (national reserve, national park, and national sanctuary), and a buffer zone of 50 m around the rivers.

Source: JICA Study Team and Statistical Abstract 2011

Table 2.1.2 Geographical Distribution of County Area by Catchment Area

(Unit: km^2)

Old Administration 1992		County	Area	Area of County by Catchment Area					
Province	District			LVNCA	LVSCA	RVCA	ACA	TCA	ENNCA
Western	Bungoma	Bungoma	3,019	3,019	0	0	0	0	0
	Busia	Busia	1,689	1,689	0	0	0	0	0
	Kakamega	Kakamega	2,707	2,707	0	0	0	0	0
		Vihiga	889	756	133	0	0	0	0
Nyanza	South Nyanza	Homa Bay	3,198	0	3,198	0	0	0	0
		Migori	2,646	0	2,646	0	0	0	0
	Kisii	Kisii	1,474	0	1,474	0	0	0	0
		Nyamira	758	0	758	0	0	0	0
	Kisumu	Kisumu	2,106	1,011	1,095	0	0	0	0
	Siaya	Siaya	2,545	2,367	178	0	0	0	0
Rift Valley	Baringo	Baringo	11,043	0	0	11,043	0	0	0
	Kericho	Kericho	2,176	1,654	522	0	0	0	0
		Bomet	2,831	0	2,831	0	0	0	0
	Elgeyo Marakwet	Elgeyo Marakwet	3,031	1,091	0	1,940	0	0	0
	Kajiado	Kajiado	22,272	0	0	8,018	14,254	0	0
	Laikipia	Laikipia	9,514	0	0	951	0	0	8,563
	Nakuru	Nakuru	7,586	0	1,214	6,372	0	0	0
	Nandi	Nandi	2,904	2,643	261	0	0	0	0
	Narok	Narok	18,278	0	9,870	8,408	0	0	0
	Samburu	Samburu	21,014	0	0	4,623	0	0	16,391
	Trans Nzoia	Trans Nzoia	2,509	2,308	0	201	0	0	0
	Turkana	Turkana	68,555	0	0	68,555	0	0	0
		Lake Turkana	7,260	7,260	0	0	0	0	0
	Uasin Gishu	Uasin Gishu	3,364	3,364	0	0	0	0	0
	West Pokot	West Pokot	9,115	0	0	9,115	0	0	0
Central	Kiambu*	Kiambu	3,165	0	0	253	1,962	950	0
	Kirinyaga	Kirinyaga	1,479	0	0	0	0	1,479	0
	Muranga**	Muranga	1,968	0	0	0	0	1,968	0
	Nyandarua	Nyandarua	3,248	0	0	1,819	0	195	1,234
	Nyeri	Nyeri	3,363	0	0	0	0	2,320	1,043
Nairobi	Nairobi	Nairobi	696	0	0	0	696	0	0
Eastern	Embu	Embu	2,830	0	0	0	0	2,829	0
	Isiolo	Isiolo	25,201	0	0	0	0	2,520	22,681
	Kitui	Kitui	30,558	0	0	0	1,528	29,030	0
	Machakos	Machakos	6,247	0	0	0	4,123	2,124	0
		Makueni	8,058	0	0	0	8,058	0	0
	Marsabit	Marsabit	70,628	0	0	10,594	0	0	60,034
	Meru	Meru	6,952	0	0	0	0	3,615	3,337
		Tharaka-Nithi	2,651	0	0	0	0	2,650	0
Coast	Kilifi	Kilifi	12,626	0	0	0	10,732	1,894	0
	Kwale	Kwale	8,366	0	0	0	8,366	0	0
	Lamu	Lamu	6,245	0	0	0	0	6,245	0
	Mombasa	Mombasa	242	0	0	0	242	0	0
	Taita Taveta	Taita Taveta	17,346	0	0	0	17,346	0	0
	Tana River	Tana River	38,376	0	0	0	0	38,376	0
North Eastern	Garissa	Garissa	44,071	0	0	0	0	29,528	14,543
	Mandera	Mandera	25,551	0	0	0	0	0	25,551
	Wajir	Wajir	56,184	0	0	0	0	0	56,184
Total			588,534	18,384	27,530	138,000	67,428	126,690	210,502

Source: JICA Study Team based on the data from Kenya National Bureau of Statistics

Table 2.2.1 Inventory of Administrative Units (1/2)

County		Previous Districts in the 2009 Census	2009			1990		
Code	Name		Division	Location	Sub-Location	Division	Location	Sub-Location
110	Nairobi City	Nairobi West, Nairobi East, Nairobi North, Westlands	8	49	112	8	29	63
201	Nyandarua	Nyandarua North, Nyandarua South	8	28	82	6	22	64
202	Nyeri	Nyeri North, Nyeri South	11	41	196	9	30	148
203	Kirinyaga	Kirinyaga	5	23	81	4	17	77
204	Murang'a	Muranga North, Muranga South, Thika East, Gatanga	14	66	206	6	31	145
205	Kiambu	Kiambu East, Kikuyu, Kiambu West (Limuru), Lari, Githunguri, Thika West, Ruiru, Gatundu	18	67	187	7	29	142
301	Mombasa	Mombasa, Kilindini	7	18	34	4	12	25
302	Kwale	Kwale, Kinango, Msambweni	10	38	85	4	25	70
303	Kilifi	Kilifi, Kaloleni, Malindi	15	59	169	5	35	117
304	Tana River	Tana River, Tana Delta	9	44	93	4	17	43
305	Lamu	Lamu	7	23	39	5	9	24
306	Taita/Taveta	Taita, Taveta	12	36	93	5	16	55
401	Marsabit	Marsabit, Chalbi, Laisamis, Moyale	15	60	118	6	16	40
402	Isiolo	Isiolo, Garbatula	8	22	43	4	11	27
403	Meru	Meru Central, Imenti North, Imenti South, Igembe, Tigania	33	128	328	12	51	148
404	Tharaka-Nithi	Meru South, Maara, Tharaka	10	48	123			
405	Embu	Embu, Mbeere	12	43	112	5	20	75
406	Kitui	Kitui, Mutomo, Mwingi, Kyuso	23	95	314	5	36	161
407	Machakos	Machakos, Mwala, Yatta, Kangundo	16	63	225	11	43	232
408	Makueni	Makueni, Mbooni, Kibwezi, Nzaui,	27	79	202			
501	Garissa	Garissa, Lagdera, Fafi, Ijara	17	59	92	9	26	41
502	Wajir	Wajir South,Wajir North,Wajir East,Wajir West	15	78	108	6	23	45
503	Mandera	Mandera Central, Mandera East, Mandera West	18	85	119	6	15	31
601	Siaya	Siaya, Bondo, Rarieda	12	49	179	6	31	152
602	Kisumu	Kisumu East, Kisumu West, Nyando	9	57	168	6	29	114
603	Migori	Migori, Rongo, Kuria West, Kuria East	13	69	164	9	64	205
604	Homa Bay*	Homa Bay, Suba, Rachuonyo	15	86	211			
605	Kisii	Kisii Central, Kisii South, Gucha, Gucha South	12	50	133	12	40	128
606	Nyamira	Nyamira, Masaba, Manga, Boruba	9	32	106			
701	Turkana	Turkana Central, Turkana North, Turkana South	17	46	157	7	29	54

Table 2.2.1 Inventory of Administrative Units (2/2)

(Continuation)

County		Previous Districts in the 2009 Census	2009			1990		
Code	Name		Division	Location	Sub-Location	Division	Location	Sub-Location
703	Samburu	Samburu Central, Samburu East, Samburu North	6	40	108	4	21	69
704	Trans Nzoia	Trans Nzoia East, Trans Nzoia West, Kwanza	8	28	58	3	16	28
705	Baringo	Baringo Central, Baringo North, East Pokot, Koibatek	25	109	269	8	43	117
706	Uasin Gishu	Eldoret West, Eldoret East, Wareng	6	51	97	4	25	62
707	Elgeyo-Marakwet	Marakwet, Keiyo	12	55	180	5	26	115
708	Nandi	Nandi North, Nandi Central, Nandi East, Nandi South, Tinderet	11	99	289	5	26	101
709	Laikipia	Laikipia North, Laikipia East, Laikipia West	9	42	79	4	21	43
710	Nakuru	Nakuru, Naivasha, Molo, Nakuru North	28	93	210	9	34	63
711	Narok	Narok North, Narok South, Trans Mara	16	88	114	5	28	66
712	Kajiado	Kajiado Central, Kajiado North, Loitoktok	13	55	143	4	20	53
713	Kericho	Kericho, Kipkellion	19	102	244	7	33	112
714	Bomet	Bomet, Sotik, Buret	9	50	137			
801	Kakamega	Kakamega Central, Kakamega South, Kakamega North, Kakamega East, Lugari, Mumias, Butere	22	69	231	13	41	213
802	Vihiga	Vihiga, Emuhaya, Hamisi	9	29	115			
803	Bungoma	Bungoma South, Bungoma North, Bungoma East, Bungoma West, Mt.Elgon	15	61	149	8	25	74
804	Busia	Busia, Teso North, Samia, Bunyala, Teso South	10	60	181	6	15	64
		Total	634	2,730	7,000	261	1,102	3,669

Note: * Homa Bay county was previously called South Nyanza.
** There has been an increase in number of administrative boundaries.
Source: 2009 Kenya Population and Housing Census; Sectoral Report (A) Socio-Economy in the NWMP 1992.

Table 2.3.1 List of Local Authorities as of 2012 (1/4)

County		No	Local Authority		
Code	Name		Name of Local Authority	Type of Authority *[1]	Location *[2]
101	Nairobi	1	Nairobi	CITY	Nairobi
201	Nyandarua	2	Olkalou	TC	Olkalou
		3	Nyandarua	CC	Nyandarua
202	Nyeri	4	Nyeri	MC	Nyeri
		5	Karatina	MC	Karatina
		6	Othaya	TC	Othaya
		7	Nyeri	CC	Nyeri
203	Kirinyaga	8	Kerugoya/Kutus	MC	Kerugoya
		9	Sagana	TC	Sagana
		10	Kirinyaga	CC	Kerugoya
204	Murang’a	11	Murang’a	MC	Murang’a
		12	Kangema	TC	Kangema
		13	Maragua	TC	Maragua
		14	Kandara	TC	Muruka
		15	Makuyu	TC	Kandara
		16	Maragua	CC	Maragua
		17	Murang’a	CC	Murang'a
205	Kiambu	18	Kiambu	MC	Kiambu
		19	Thika	MC	Thika
		20	Thika	CC	Thika
		21	Kikuyu	TC	Kikuyu
		22	Limuru	MC	Limuru
		23	Ruiru	MC	Ruiru
		24	Karuri	TC	Karuri
		25	Kiambu	CC	Kiambu
301	Mombasa	26	Mombasa	CITY	Mombasa
302	Kwale	27	Kwale	TC	Kwale
		28	Kwale	CC	Kwale
303	Kilifi	29	Malindi	MC	Malindi
		30	Malindi	CC	Malindi
		31	Kilifi	TC	Kilifi
		32	Mariakani	TC	Mariakani
		33	Kilifi	CC	Kilifi
304	Tana River	34	Tana River	CC	Hola
305	Lamu	35	Lamu	CC	Lamu
306	Taita/ Taveta	36	Voi	MC	Voi
		37	Taveta	TC	Taveta
		38	Taita/Taveta	CC	Wundanyi
401	Marsabit	39	Marsabit	CC	Marsabit
		40	Moyale	CC	Moyale
402	Isiolo	41	Isiolo	CC	Isiolo
403	Meru	42	Meru	MC	Meru
		43	Naymbene	CC	Maua
		44	Maua	MC	Maua
		45	Meru	CC	Meru
404	Tharaka_Nithi	46	Chogoria	TC	Chogoria
		47	Chuka	MC	Chuka
		48	Meru South	CC	Chuka
		49	Tharaka	CC	Tharaka

Table 2.3.1 List of Local Authorities as of 2012 (2/4)

(Continuation)

County		No.	Local Authority		
Code	Name		Name of Local Authority	Type of Authority*[1]	Location*[2]
405	Embu	50	Embu	MC	Embu
		51	Runyenjes	TC	Runyenjes
		52	Mbeere	CC	Siakago
		53	Embu	CC	Embu
406	Kitui	54	Kitui	MC	Kitui
		55	Mwingi	TC	Mwingi
		56	Mwingi	CC	Mwing
		57	Kitui	CC	Kitui
407	Machakos	58	Machakos	MC	Machakos
		59	Kangundo	TC	Tala
		60	Mavoko	MC	Athi River
		61	Masaku	CC	Machakos
		62	Matuu	TC	Matuu
408	Makueni	63	Mtito Andei	TC	Mtito Andei
		64	Wote	TC	Wote
		65	Makueni	CC	Wote
501	Garissa	66	Garissa	MC	Garissa
		67	Garissa	CC	Garissa
		68	Ijara	CC	Ijara
502	Wajir	69	Wajir	CC	Wajir
503	Mandera	70	Mandera	TC	Mandera
		71	Mandera	CC	Mandera
601	Siaya	72	Siaya	MC	Siaya
		73	Bondo	TC	Bondo
		74	Bondo	CC	Bondo
		75	Ukwala	TC	Ukwala
		76	Yala	TC	Yala
		77	Siaya	CC	Siaya
		78	Ugunja	TC	Ugunja
602	Kisumu	79	Kisumu	CITY	Kisumu
		80	Ahero	TC	Ahero
		81	Kisumu	CC	Kisumu
		82	Nyando	CC	Awasi
		83	Kisumu	CC	Kisumu
		84	Muhoroni	TC	Muhoroni
603	Migori	85	Migori	MC	Migori
		86	Rongo	TC	Rongo
		87	Awendo	TC	Awendo
		88	Kehancha	MC	Kejancha
		89	Migori	CC	Migori
604	Homa Bay	90	Homa Bay	MC	Homa Bay
		91	Mbita Point	TC	Mbita
		92	Kendu Bay	TC	Kendu Bay
		93	Oyugis	TC	Oyugis
		94	Suba	CC	Mbita
		95	Rachuonyo	CC	Kosele
		96	Homa Bay	CC	Homa Bay

Table 2.3.1 List of Local Authorities as of 2012 (3/4)

(Continuation)

County		No.	Local Authority		
Code	Name		Name of Local Authority	Type of Authority *[1]	Location *[2]
605	Kisii	97	Kisii	MC	Ksii
		98	Nyamache	TC	Kisii
		99	Masimba	TC	Masimba
		100	Ogembo	TC	Ogembo
		101	Suneka	TC	Nyambunwa
		102	Tabaka	TC	Tabaka
		103	Nyamarambe	TC	Nyamarambe
		104	Keroka	TC	Keroka
		105	Gusii	CC	Kisii
		106	Gucha	CC	Ogembo
606	Nyamira	107	Nyamira	TC	Nyamira
		108	Nyasiongo	TC	Nyansingo
		109	Nyamira	CC	Nyamira
701	Turkana	110	Lodwar	MC	Lodwar
		111	Turkana	CC	Turkana
702	West Pokot	112	Kapenguria	TC	Kapenguria
		113	Chepareria	TC	Kapenguria
		114	Pokot	CC	Kapenguria
703	Samburu	115	Samburu	CC	Maralal
		116	Maralal	TC	Maralal
704	Trans Nzoia	117	Kitale	MC	Kitale
		118	Nzoia	CC	Kitale
705	Baringo	119	Kabarnet	MC	Kabarnet
		120	Eldama Ravine	TC	Eldama Ravine
		121	Baringo	CC	Kabarnet
		122	Koibatek	CC	Eldoma Ravine
706	Uasin Gishu	123	Eldoret	MC	Eldoret
		124	Burnt Forest	TC	Burnt Forest
		125	Wareng	CC	Wareng
707	Elgeyo Marakwet	126	Iten	TC	Iten
		127	Keiyo	CC	Iten
		128	Marakwet	CC	Kapsokwony
708	Nandi	129	Kapsabet	MC	Kapsabet
		130	Nandi Hills	TC	Nandi Hills
		131	Nandi	CC	Kapsabet
709	Laikipia	132	Nyahururu	MC	Nyahururu
		133	Nyanyuki	MC	Nanyuki
		134	Rumuruti	TC	Rumuruti
		135	Laikipia	CC	Nanyuki
710	Nakuru	136	Nakuru	MC	Nakuru
		137	Naivasha	MC	Naivasha
		138	Molo	TC	Molo
		139	Nakuru	CC	Nakuru
711	Narok	140	Narok	TC	Narok
		141	Narok	CC	Narok
		142	Trans Mara	CC	Kilgoris
712	Kajiado	143	Kajiado	TC	Kajiado
		144	Olkejuado	CC	Kajiado

Table 2.3.1 List of Local Authorities as of 2012 (4/4)

(Continuation)

County		No.	Local Authority		
Code	Name		Name of Local Authority	Type of Authority *[1]	Location *[2]
713	Kericho	145	Kericho	MC	Kericho
		146	Londiani	TC	Londiani
		147	Litein	TC	Litein
		148	Kipkelion	TC	Kipkelion
		149	Bureti	CC	Litein
		150	Kipsigis	CC	Kericho
714	Bomet	151	Bomet	MC	Bomet
		152	Sotik	TC	Sotik
		153	Bomet	CC	Bomet
801	Kakamega	154	Kakamega	MC	Kakamega
		155	Mumias	MC	Mumius
		156	Malava	TC	Malava
		157	Kakamega	CC	Kakamega
		158	Butere-Mumias	CC	Butere
		159	Lugari	CC	Lumakanda
802	Vihiga	160	Vihiga	MC	Mbale
		161	Luanda	TC	Luanda
		162	Vihiga	CC	Mbale
803	Bungoma	163	Bungoma	MC	Bungoma
		164	Webuyu	MC	Webuye
		165	Kimilili	MC	Kimilili
		166	Sirisia	TC	Sirisia
		167	Malakisi	TC	Malakisi
		168	Mt.Elgon	CC	Kapisakwony
		169	Bungoma	CC	Bungoma
804	Busia	170	Busia	MC	Busia
		171	Funyula	TC	Funyula
		172	Nambale	TC	Nambale
		173	Port Victoria	TC	Port Victoria
		174	Malaba	TC	Kamurai
		175	Teso	CC	Amagoro
		176	Busia	CC	Busia

Note: *[1] The following shows the abbreviation used in the above:
CITY: City Council
MC: Municipal Council
TC: Town Council
CC: County Council
*[2] “Location” points out a location where the Council is located.
Source: Ministry of Local Government

Table 2.3.2 Inventory of Local Authorities by Type and By County as of 2012

Code	County Name	City Council	Municipal Council	Town Council	County Council
110	Nairobi City	1	-	-	-
201	Nyandarua	-	-	1	1
202	Nyeri	-	2	1	1
203	Kirinyaga	-	1	1	1
204	Murang'a	-	1	4	2
205	Kiambu	-	4	2	2
301	Mombasa	1	-	-	-
302	Kwale	-	-	1	1
303	Kilifi	-	1	2	2
304	Tana River	-	-	-	1
305	Lamu	-	-	-	1
306	Taita/Taveta	-	1	1	1
401	Marsabit	-	-	-	2
402	Isiolo	-	-	-	1
403	Meru	-	2	-	2
404	Tharaka-Nithi	-	1	1	2
405	Embu	-	1	1	2
406	Kitui	-	1	1	2
407	Machakos	-	2	2	1
408	Makueni	-	-	2	1
501	Garissa	-	1	-	2
502	Wajir	-	-	-	1
503	Mandera	-	-	1	1
601	Siaya	-	1	4	2
602	Kisumu	1	-	2	3
603	Migori	-	2	2	1
604	Homa Bay	-	1	3	3
605	Kisii	-	1	7	2
606	Nyamira	-	-	2	1
701	Turkana	-	1	-	1
702	West Pokot	-	-	2	1
703	Samburu	-	-	1	1
704	Trans Nzoia	-	1	-	1
705	Baringo	-	1	1	2
706	Uasin Gishu	-	1	1	1
707	Elgeyo- Marakwet	-	-	1	2
708	Nandi	-	1	1	1
709	Laikipia	-	2	1	1
710	Nakuru	-	2	1	1
711	Narok	-	-	1	2
712	Kajiado	-	-	1	1
713	Kericho	-	1	3	2
714	Bomet	-	1	1	1
801	Kakamega	-	2	1	3
802	Vihiga	-	1	1	1
803	Bungoma	-	3	2	2
804	Busia	-	1	4	2
Kenya		3	41	64	68

Source: Ministry of Local Government

Table 3.1.1 Population Change, Household Size, and Density in 2009 (1/3)

County		Previous Districts in 2009 Census	Area (km^2)	1999 Census	2009 Census			
Code	Name			Population	Population	No. of Household	Family Size	Density ($/km^2$)
110	Nairobi City	Nairobi West, Nairobi East, Nairobi North, Westlands	696	2,143,254	3,138,369	985,016	3.19	4,509
201	Nyandarua	Nyandarua North, Nyandarua South	3,248	479,902	596,268	143,879	4.14	184
202	Nyeri	Nyeri North, Nyeri South	3,363	661,156	693,558	201,703	3.44	206
203	Kirinyaga	Kirinyaga	1,479	457,105	528,054	154,220	3.42	357
204	Murang'a	Muranga North, Muranga South, Thika East, Gatanga	1,968	736,273	969,151	262,931	3.69	492
205	Kiambu	Kiambu East, Kikuyu, Kiambu West(Limuru), Lari, Githunguri, Thika West, Ruiru, Gatundu	3,162	1,389,723	1,623,282	462,009	3.51	513
301	Mombasa	Mombasa,Kilindini	177	665,018	939,370	268,700	3.50	5,307
302	Kwale	Kwale, Kinango, Msambweni	8,301	496,133	649,931	122,047	5.33	78
303	Kilifi	Kilifi, Kaloleni, Malindi	12,517	825,855	1,109,735	199,764	5.56	89
304	Tana River	Tana River, Tana Delta	38,376	180,901	240,075	47,414	5.06	6
305	Lamu	Lamu	5,937	72,686	101,539	22,184	4.58	17
306	Taita/Taveta	Taita, Taveta	17,330	246,671	284,657	71,090	4.00	16
401	Marsabit	Marsabit, Chalbi, Laisamis, Moyale	66,502	174,957	291,166	56,941	5.11	4
402	Isiolo	Isiolo,Garbatula	25,201	100,861	143,294	31,326	4.57	6
403	Meru	Meru Central,Imenti North,Imenti South,Igembe, Tigania	6,952	1,102,930	1,356,301	319,616	4.24	195
404	Tharaka-Nithi	Meru South,Maara, Tharaka	2,651	306,443	365,330	88,803	4.11	138
405	Embu	Embu, Mbeere	2,830	449,149	516,212	131,683	3.92	182
406	Kitui	Kitui, Mutomo, Mwingi, Kyuso	30,558	819,250	1,012,709	205,491	4.93	33
407	Machakos	Machakos, Mwala, Yatta, Kangundo	6,242	906,644	1,098,584	264,500	4.15	176
408	Makueni	Makueni, Mbooni, Kibwezi, Nzaui,	8,058	771,545	884,527	186,478	4.74	110
501	Garissa	Garissa, Lagdera, Fafi, Ijara	44,071	392,510	623,060	98,590	6.32	14
502	Wajir	Wajir South,Wajir North,Wajir East,Wajir West	56,184	319,261	661,941	88,574	7.47	12
503	Mandera	Mandera Central, Mandera East, Mandera West	25,551	250,372	1,025,756	125,497	8.17	40

Table 3.1.1 Population Change, Household Size, and Density in 2009 (2/3)

(Continuation)

County		Previous District in 2009 Census	Area (km^2)	1999 Census	2009 Census			
Code	Name			Population	Population	No. of Household	Family Size	Density (/km^2)
601	Siaya	Siaya, Bondo, Rarieda	1,540	718,964	842,304	199,034	4.23	547
602	Kisumu	Kisumu East, Kisumu West, Nyando	1,539	804,289	968,909	226,719	4.27	630
603	Migori	Migori, Rongo, Kuria West, Kuria East	2,646	666,784	917,170	180,211	5.09	347
604	Homa Bay	Homa Bay, Suba, Rachuonyo	1,134	751,332	963,794	206,255	4.67	850
605	Kisii	Kisii Central, Kisii South, Gucha, Gucha South	1,474	952,725	1,030,212	218,897	4.71	699
606	Nyamira	Nyamira, Masaba, Manga, Borabu	758	498,102	720,322	157,171	4.58	950
701	Turkana	Turkana Central, Turkana North, Turkana South	66,276	450,860	855,399	123,191	6.94	13
702	West Pokot	West Pokot, Pokot Central, Pokot North	9,115	308,086	512,690	93,777	5.47	56
703	Samburu	Samburu Central, Samburu East, Samburu North	21,014	143,547	223,947	47,354	4.73	11
704	Trans Nzoia	Trans Nzoia East, Trans Nzoia West, Kwanza	2,509	575,662	818,757	170,117	4.81	326
705	Baringo	Baringo Central, Baringo North, East Pokot, Koibatek	10,880	403,141	555,561	110,649	5.02	51
706	Uasin Gishu	Eldoret West, Eldoret East, Wareng	3,364	622,705	894,179	202,291	4.42	266
707	Elgeyo/Marakwet	Marakwet, Keiyo	3,031	284,494	369,998	77,555	4.77	122
708	Nandi	Nandi North, Nandi Central, Nandi East, Nandi South, Tinderet	2,904	578,751	752,965	154,073	4.89	259
709	Laikipia	Laikipia North, Laikipia East, Laikipia West	9,514	322,187	399,227	103,114	3.87	42
710	Nakuru	Nakuru, Naivasha, Molo, Nakuru North	7,410	1,187,039	1,603,325	409,836	3.91	216
711	Narok	Narok North, Narok South, Trans Mara	18,278	536,341	850,920	169,220	5.03	47
712	Kajiado	Kajiado Central, Kajiado North, Loitoktok	22,130	406,054	687,312	173,464	3.96	31
713	Kericho	Kericho, Kipkellion	2,176	785,375	590,690	127,581	4.63	271

Table 3.1.1 Population Change, Household Size, and Density in 2009 (3/3)

(Continuation)

County		Previous Districts in 2009 Census	Area (km^2)	1999 Census	2009 Census			
Code	Name			Population	Population	No. of Household	Family Size	Density ($/km^2$)
714	Bomet	Bomet, Sotik, Buret	2,831	382,794	891,835	174,914	5.10	315
801	Kakamega	Kakamega Central, Kakamega South, Kakamega North, Kakamega East, Lugari, Mumias, Butere	2,707	1,296,270	1,660,651	355,679	4.67	613
802	Vihiga	Vihiga, Emuhaya, Hamisi	889	498,883	554,622	123,347	4.50	624
803	Bungoma	Bungoma South, Bungoma North, Bungoma East, Bungoma West, Mt.Elgon	3,019	1,011,524	1,375,063	270,824	5.08	455
804	Busia	Busia, Teso North, Samia, Bunyala, Teso South	1,552	552,099	743,946	154,225	4.82	479
Kenya			570,044	28,686,607	38,636,667	8,767,954	4.41	68

Source: 1999 Population and Housing Census; 2009 Population and Housing Census 2009, Kenya National Bureau of Statistics

Table 3.1.2 Population Distribution by Catchment Area and by County in 2009

Province	County	Population 2009	Population of County by Catchment Area in 2009					
			LVNCA	LVSCA	RVCA	ACA	TCA	ENNCA
Western	Bungoma	1,375,063	1,375,063	0	0	0	0	0
	Busia	743,946	743,946	0	0	0	0	0
	Kakamega	1,660,651	1,660,651	0	0	0	0	0
	Vihiga	554,622	471,429	83,193	0	0	0	0
Nyanza	Homa Bay	963,794	0	963,794	0	0	0	0
	Migori	917,170	0	917,170	0	0	0	0
	Kisii	1,030,212	0	1,030,212	0	0	0	0
	Nyamira	720,322	0	720,322	0	0	0	0
	Kisumu	968,909	465,076	503,833	0	0	0	0
	Siaya	842,304	783,343	58,961	0	0	0	0
Rift Valley	Baringo	555,561	0	0	555,561	0	0	0
	Kericho	590,690	448,924	141,766	0	0	0	0
	Bomet	891,835	0	891,835	0	0	0	0
	Elgeyo Marakwet	369,998	133,199	0	236,799	0	0	0
	Kajiado	687,312	0	0	247,432	439,880	0	0
	Laikipia	399,227	0	0	39,923	0	0	359,304
	Nakuru	1,603,325	0	256,532	1,346,793	0	0	0
	Nandi	752,965	685,198	67,767	0	0	0	0
	Narok	850,920	0	459,497	391,423	0	0	0
	Samburu	223,947	0	0	49,268	0	0	174,679
	Trans Nzoia	818,757	753,256	0	65,501	0	0	0
	Turkana	855,399	0	0	855,399	0	0	0
	Uasin Gishu	894,179	894,179	0	0	0	0	0
	West Pokot	512,690	0	0	512,690	0	0	0
Central	Kiambu	1,623,282	0	0	129,863	1,006,435	486,985	0
	Kirinyaga	528,054	0	0	0	0	528,054	0
	Muranga	969,151	0	0	0	0	969,151	0
	Nyandarua	596,268	0	0	333,910	0	35,776	226,582
	Nyeri	693,558	0	0	0	0	478,555	215,003
Nairobi	Nairobi	3,138,369	0	0	0	3,138,369	0	0
Eastern	Embu	516,212	0	0	0	0	516,212	0
	Isiolo	143,294	0	0	0	0	14,329	128,965
	Kitui	1,012,709	0	0	0	50,635	962,074	0
	Machakos	1,098,584	0	0	0	725,065	373,519	0
	Makueni	884,527	0	0	0	884,527	0	0
	Marsabit	291,166	0	0	43,675	0	0	247,491
	Meru	1,356,301	0	0	0	0	705,277	651,024
	Tharaka-Nithi	365,330	0	0	0	0	365,330	0
Coast	Kilifi	1,012,709	0	0	0	860,803	151,906	0
	Kwale	649,931	0	0	0	649,931	0	0
	Lamu	101,539	0	0	0	0	101,539	0
	Mombasa	939,370	0	0	0	939,370	0	0
	Taita Taveta	284,657	0	0	0	284,657	0	0
	Tana River	240,075	0	0	0	0	240,075	0
North Eastern	Garissa	623,060	0	0	0	0	417,450	205,610
	Mandera	1,025,756	0	0	0	0	0	1,025,756
	Wajir	661,941	0	0	0	0	0	661,941
Total		38,539,641	8,414,265	6,094,882	4,808,236	8,979,672	6,346,231	3,896,355

Source: 2009 Population and Housing Census, Kenya National Bureau of Statistics; JICA Study Team.

Table 3.1.3 1999 Census and 2009 Census Population by County in Urban and Rural Areas

County		1999 Census Population			2009 Census Population		
Code	Name	Total	Urban	Rural	Total	Urban	Rural
Kenya		28,686,607	9,904,044	18,782,563	38,636,667	12,487,375	26,122,722
110	Nairobi City	2,143,254	2,143,254	-	3,138,369	3,138,369	-
201	Nyandarua	479,902	68,606	411,296	596,268	110,518	485,750
202	Nyeri	661,156	255,971	405,185	693,558	169,617	523,941
203	Kirinyaga	457,105	54,756	402,349	528,054	83,404	444,650
204	Murang'a	736,273	159,292	576,981	969,151	148,672	820,479
205	Kiambu *	1,389,723	584,197	805,526	1,623,282	*1,014,006*	582,706
301	Mombasa	665,018	665,018	-	939,370	939,370	-
302	Kwale	496,133	75,361	420,772	649,931	117,676	532,255
303	Kilifi	825,855	291,915	533,940	1,109,735	285,482	824,253
304	Tana River	180,901	15,430	165,471	240,075	36,065	204,010
305	Lamu	72,686	11,831	60,855	101,539	20,238	81,301
306	Taita/Taveta	246,671	101,200	145,471	284,657	64,289	220,368
401	Marsabit	174,957	41,798	133,159	291,166	64,009	227,157
402	Isiolo	100,861	40,252	60,609	143,294	62,374	80,920
403	Meru	1,102,930	155,492	947,438	1,356,301	115,033	1,241,268
404	Tharaka-Nithi	306,443	7,271	299,172	365,330	83,999	281,331
405	Embu	449,149	113,899	335,250	516,212	82,921	433,291
406	Kitui	819,250	172,985	646,265	1,012,709	139,909	872,800
407	Machakos	906,644	394,590	512,054	1,098,584	571,355	527,229
408	Makueni	771,545	130,091	641,454	884,527	104,297	780,230
501	Garissa	392,510	80,391	312,119	623,060	146,668	476,392
502	Wajir	319,261	54,378	264,883	661,941	96,855	565,086
503	Mandera	250,372	65,412	184,960	1,025,756	185,568	840,188
601	Siaya	718,964	145,759	573,205	842,304	90,627	751,677
602	Kisumu	804,289	397,802	406,487	968,909	507,720	461,189
603	Migori	666,784	421,220	245,564	917,170	311,512	605,658
604	Homa Bay	751,332	190,562	560,770	963,794	138,051	825,743
605	Kisii	952,725	295,078	657,647	1,030,212	181,359	848,853
606	Nyamira	498,102	132,387	365,715	720,322	158,663	561,659
701	Turkana	450,860	59,882	390,978	855,399	121,719	733,680
702	West Pokot	308,086	67,200	240,886	512,690	42,696	469,994
703	Samburu	143,547	36,763	106,784	223,947	38,664	185,283
704	Trans Nzoia	575,662	86,282	489,380	818,757	167,420	651,337
705	Baringo	403,141	62,313	340,828	555,561	61,551	494,010
706	Uasin Gishu	622,705	266,412	356,293	894,179	345,559	548,620
707	Elgeyo/Marakwet	284,494	22,710	261,784	369,998	53,186	316,812
708	Nandi	578,751	126,243	452,508	752,965	102,281	650,684
709	Laikipia	322,187	113,668	208,519	399,227	99,117	300,110
710	Nakuru	1,187,039	555,543	631,496	1,603,325	735,025	868,300
711	Narok	536,341	46,213	490,128	850,920	58,494	792,426
712	Kajiado	406,054	87,422	318,632	687,312	284,862	402,450
713	Kericho	785,375	154,183	631,192	590,690	228,318	362,372
714	Bomet	382,794	94,999	287,795	891,835	132,255	759,580
801	Kakamega	1,296,270	227,755	1,068,515	1,660,651	252,611	1,408,040
802	Vihiga	498,883	175,797	323,086	554,622	174,105	380,517
803	Bungoma	1,011,524	267,719	743,805	1,375,063	298,696	1,076,367
804	Busia	552,099	186,742	365,357	743,946	122,190	621,756

Note: * In Kiambu, the total population in 2009 does not match the total figure of urban and rural population.

Source: 1999 and 2009 Kenya Population and Housing Census, Kenya National Bureau of Statistics

Table 3.1.4 Population in Urban Centres in 2009 (1/6)

No.	M/P (*)	Urban Centre	Previous Districts in 2009	Status	Male	Female	Total	Urban & Peri-urban
1	○	NAIROBI	Nairobi East/West/ North/ Westlands	City	1,602,104	1,531,414	3,133,518	3,133,518
2	○	MOMBASA	Mombasa/ kilindini	City	486,208	451,923	938,131	938,131
3	○	KISUMU	Kisumu East/ West/ Nyando	City	204,234	205,694	409,928	388,311
4	○	NAKURU	Nakuru/ Nakuru North	Municipality	155,881	152,109	307,990	307,990
5	○	ELDORET	Eldoret East/West/ Wareng	Municipality	146,596	142,784	289,380	289,380
6	○	KEHANCHA	Kuria East/west	Municipality	125,938	130,148	256,086	30,109
7	○	RUIRU	Ruiru	Municipality	119,147	119,711	238,858	238,858
8	○	MALINDI	Malindi/ Kilifi	Municipality	103,079	104,174	207,253	118,265
9	○	NAIVASHA	Naivasha	Municipality	91,371	90,595	181,966	169,142
10	○	KITUI	Kitui	Municipality	75,741	80,155	155,896	109,568
11	○	MACHAKOS	Machakos	Municipality	74,294	75,747	150,041	150,041
12	○	THIKA	Thika West/ Gatanga	Municipality	69,697	70,156	139,853	136,917
13	○	MAVOKO	Machakos	Municipality	76,056	63,324	139,380	137,211
14	○	NYERI	Nyeri North/ South	Municipality	62,648	62,709	125,357	119,353
15	○	VIHIGA	Vihiga	Municipality	56,807	61,889	118,696	118,696
16	○	MUMIAS	Mumias	Municipality	56,783	59,575	116,358	99,987
17	○	BOMET	Bomet/Sotik	Municipality	55,090	55,873	110,963	83,729
18	○	KITALE	Trans Nzoia West	Municipality	54,065	52,122	106,187	106,187
19	○	LIMURU	Kiambu West	Municipality	52,111	52,171	104,282	79,711
20	○	KERICHO	Kericho/kipkelion	Municipality	53,452	50,459	103,911	101,808
21	○	KIMILILI	Bungoma North	Municipality	46,007	48,920	94,927	94,927
22	○	KAKAMEGA	Kakamega Central	Municipality	46,068	45,700	91,768	91,768
23	○	KAPSABET	Nandi Central	Municipality	45,420	45,610	91,030	86,803
24	○	KIAMBU	Kiambu East	Municipality	43,524	45,345	88,869	84,155
25	○	KISII	Kisii Central/ Kisii South	Municipality	41,948	41,512	83,460	81,801
26	○	BUNGOMA	Bungoma South	Municipality	40,086	41,065	81,151	55,867
27	○	WEBUYE	Bungoma East/ Lugari	Municipality	31,954	33,326	65,280	41,344
28	○	BUSIA	Busia/ Teso South	Municipality	29,927	31,788	61,715	51,981
29	○	RUNYENJES	Embu	Municipality	30,268	31,336	61,604	19,548
30	○	MIGORI	Migori	Municipality	29,527	31,522	61,049	53,100
31	○	EMBU	Embu	Municipality	29,768	30,905	60,673	60,673
32	○	HOMA BAY	Homa Bay	Municipality	28,501	31,343	59,844	58,936
33	○	LODWAR	Turkana Central*	Municipality	28,497	29,721	58,218	48,316
34	○	MERU	Imenti North	Municipality	26,418	27,209	53,627	53,627
35	○	NYAHURURU	Laikipia West	Municipality	25,183	26,251	51,434	36,450
36	○	NANYUKI	Laikipia East	Municipality	25,046	24,187	49,233	38,198
37	○	MAUA	Igembe	Municipality	24,027	24,985	49,012	17,226
38	○	VOI	Taita	Municipality	23,611	21,872	45,483	17,152

Table 3.1.4 Population in Urban Centres in 2009 (2/6)

(Continuation)

No.	M/P (*)	Urban Centre	Previous Districts	Status	Male	Female	Total	Urban & Peri-urban
39	○	SIAYA	Siaya	Municipality	21,575	23,778	45,353	22,586
40	○	CHUKA	Meru South	Municipality	21,266	22,204	43,470	43,470
41	○	KERUGOYA/KUTUS	Kirinyaga	Municipality	16,766	17,248	34,014	19,422
42	○	MURANGA	Muranga North	Municipality	14,069	14,706	28,775	28,775
43	○	KABARNET	Baringo Central	Municipality	12,813	14,465	27,278	25,346
44	○	KARATINA	Nyeri North	Municipality	3,738	4,761	8,499	8,499
45	○	NGONG	Kajiado North	Other center	54,040	53,148	107,188	107,188
46	○	AWASI	Nyando/Kisumu East	Other center	44,934	48,435	93,369	93,369
47	○	WAJIR	Wajir East*	Other center	43,684	39,116	82,800	82,800
48	○	KAKUMA	Turkana North*	Other center	34,560	31,254	65,814	36,875
49	○	UKUNDA	Msambweni	Other center	32,011	30,518	62,529	62,529
50	○	WUNDANYI	Taita	Other center	31,400	31,004	62,404	62,404
51	○	KITENGELA	Kajiado North	Other center	30,088	28,079	58,167	58,167
52	○	MTWAPA	Kilifi	Other center	24,134	24,491	48,625	48,625
53	○	ISIOLO	Isiolo/ Imenti North	Other center	22,827	23,301	46,128	45,989
54	○	JUJA	Thika West	Other center	20,488	19,958	40,446	40,446
55	○	ONGATA RONGAI	Kajiado North	Other center	19,271	20,907	40,178	40,178
56	○	MOYALE	Moyale	Other center	18,916	18,471	37,387	37,387
57	○	GILGIL	Naivasha	Other center	18,570	16,723	35,293	35,293
58	○	RHAMU	Mandera Central*	Other center	18,142	12,909	31,051	26,367
59	○	WANGURU	Kirinyaga	Other center	12,225	12,707	24,932	23,983
60	○	ELWAK	Mandera Central*	Other center	13,125	11,243	24,368	24,368
61	○	NJORO	Molo	Other center	11,332	12,219	23,551	23,551
62	○	MOI'S BRIDGE	Lugari/ Eldoret West	Other center	10,698	11,467	22,165	14,596
63	○	LOKICHOGIO	Turkana North*	Other center	11,583	10,573	22,156	17,695
64	○	TAKABA	Mandera West*	Other center	11,835	9,639	21,474	21,474
65	○	AWENDO	Homabay/Rongo	Other center	10,388	10,499	20,887	17,992
66	○	LAMU	Lamu	Other center	9,977	9,488	19,465	18,382
67	○	CHWELE	Bungoma West	Other center	9,119	10,044	19,163	7,206
68	○	KISERIAN	Kajiado North	Other center	9,024	9,072	18,096	18,096
69	○	HOLA	Tana River	Other center	8,470	8,867	17,337	17,337
70	○	USENGE	Bondo	Other center	7,820	8,115	15,935	10,098
71	○	MADOGO	Tana River	Other center	8,152	7,672	15,824	15,824
72	○	MARSABIT	Marsabit	Other center	7,525	7,382	14,907	14,907
73	○	MASALANI	Ijara	Other center	7,374	6,638	14,012	14,012
74	○	BUTERE	Butere	Other center	5,998	6,782	12,780	12,780
75	○	MSAMBWENI	Msambweni	Other center	5,819	6,166	11,985	11,985
76	○	KIMININI	Trans Nzoia West	Other center	5,367	6,292	11,659	11,659
77	○	MAI MAHIU	Naivasha	Other center	5,617	5,613	11,230	11,230
78	○	LOITOKTOK	Loitoktok	Other center	5,617	5,447	11,064	11,064
79	○	LUMAKANDA	Lugari	Other center	5,259	5,321	10,580	10,580

Table 3.1.4 Population in Urban Centres in 2009 (3/6)

(Continuation)

No.	M/P (*)	Urban Centre	Previous Districts	Status	Male	Female	Total	Urban & Peri-urban
80	○	MATUNDA	Eldoret West/Lugari	Other center	4,756	5,275	10,031	10,031
81	○	WATAMU	Malindi	Other center	5,167	4,863	10,030	10,030
82	○	GITHUGURI	Githunguri	Other center	4,843	5,164	10,007	10,007
83		KILGORIS	Trans Mara	Other center	4,926	4,939	9,865	9,865
84		MAIRO_INYA	Nyandarua North	Other center	4,792	5,066	9,858	9,858
85		WAMBA	Samburu East	Other center	4,817	4,805	9,622	6,226
86		NAMANGA	Kajiado Central	Other center	4,684	4,382	9,066	9,066
87		SORI	Migori	Other center	4,478	4,486	8,964	8,964
88		MAKINDU	Kibwezi	Other center	4,183	4,700	8,883	8,621
89		ISINYA	Kajiado North	Other center	4,765	3,905	8,670	8,670
90		HABASWEIN	Wajir South/ West	Other center	4,594	3,906	8,500	8,500
91		TIMAU	Imenti North	Other center	4,177	4,156	8,333	8,333
92		BARAGOI	Samburu North	Other center	3,825	4,167	7,992	7,992
93		KINANGO	Kinango	Other center	3,895	4,063	7,958	7,958
94		CHEMELIL	Nyando/Kisumu East	Other center	4,331	3,557	7,888	7,888
95		MAJENGO	Kilifi	Other center	3,892	3,896	7,788	7,788
96		NKUBU	Imenti South	Other center	3,770	3,781	7,551	7,551
97		SUBUKIA	Nakuru North	Other center	3,460	3,849	7,309	7,309
98		MARIGAT	Barigo	Other center	3,557	3,603	7,160	6,661
99		EMALI	Nzaui	Other center	3,494	3,530	7,024	7,024
100		MAZERAS	Kaloleni	Other center	3,259	3,627	6,886	6,886
101		SULTAN HAMUD	Nzaui/Kajiado central	Other center	3,427	3,209	6,636	6,636
102		MERTI	Isiolo	Other center	3,103	3,429	6,532	6,532
103		KALOLENI	Kaloleni	Other center	3,202	3,236	6,438	5,573
104		SINDO	Suba	Other center	2,980	3,382	6,362	6,362
105		ARCHERS POST	Samburu	Other center	3,226	3,049	6,275	6,275
106		MUHURU BAY	Migori	Other center	3,016	3,238	6,254	6,254
107		KAPSOKWONY	Mt.Elgon	Other center	3,035	3,117	6,152	6,152
108		MAGARINI	Malindi	Other center	2,936	3,115	6,051	6,051
109		NJABINI	Nyandarua South	Other center	3,003	3,039	6,042	6,042
110		MARERENI	Malindi	Other center	2,869	3,080	5,949	5,949
111		NAIRAGIE ENKARE	Narok North	Other center	2,915	2,992	5,907	5,907
112		KIBWEZI	Kibwezi	Other center	2,892	2,979	5,871	5,871
113		NARO MORU	Nyeri North/Laikipia East	Other center	2,965	2,840	5,805	5,805
114		DADAAB	Lagdera	Other center	3,075	2,648	5,723	5,723
115		MWATATE	Taita	Other center	2,761	2,812	5,573	5,573
116		GATUNDU	Gatundu	Other center	2,580	2,970	5,550	5,550
117		BISSIL	Kajiado Central	Other center	2,509	2,867	5,376	5,376
118		DUNDORI	Nakuru North	Other center	2,528	2,693	5,221	5,221

Table 3.1.4 Population in Urban Centres in 2009 (4/6)

(Continuation)

No.	M/P (*)	Urban Centre	Previous District	Status	Male	Female	Total	Urban & Peri-urban
119		LOIYANGA LANI	Laisamis	Other center	2,272	2,845	5,117	4,208
120		SOLOLO	Moyale	Other center	2,543	2,561	5,104	5,104
121		MASENO	Kisumu West	Other center	2,506	5,103	5,103	5,103
122		KINNA	Garbatulla	Other center	2,427	2,440	4,867	4,867
123		SALGAA	Nakuru	Other center	2,390	2,350	4,740	4,740
124		LARE	Igembe	Other center	2,350	2,264	4,614	4,614
125		KAPSOWAR	Marakwet	Other center	2,189	2,303	4,492	4,492
126		MAU NAROK	Molo	Other center	2,112	2,245	4,357	4,357
127		MAJI MAZURI	Koibatek	Other center	2,193	2,072	4,265	4,265
128		KABUTI	Kericho	Other center	2,144	2,093	4,237	4,237
129		CHEPTAIS	Mt.Elgon	Other center	1,852	2,047	3,899	3,899
130		BAHATI	Nakuru North	Other center	1,806	2,027	3,833	3,833
131		GARBATUL A	Garbatulla	Other center	1,931	1,843	3,774	3,774
132		KIRIA_INI	Muranga North	Other center	1,733	1,978	3,711	2,457
133		MOGOTIO	Koibatek	Other center	1,808	1,893	3,701	3,701
134		LUNGA LUNGA	Msambweni	Other center	1,847	1,823	3,670	3,670
135		MWEIGA	Nyeri North	Other center	1,698	1,885	3,583	3,583
136		BUMALA	Busia	Other center	1,611	1,893	3,504	3,504
137		KAGUMO	Kirinyaga	Other center	1,585	1,864	3,449	3,449
138		JUA KALI	Eldoret West	Other center	1,633	1,794	3,427	3,427
139		MATUNGUU	Imenti South	Other center	1,690	1,712	3,402	3,402
140		KATHIANI	Machakos	Other center	1,598	1,767	3,365	3,365
141		KAGIO	Kirinyaga	Other center	1,548	1,809	3,357	3,357
142		KAPCHERO P	Marakwet	Other center	1,559	1,609	3,168	3,168
143		TIMBOROA	Koibatek	Other center	1,551	1,599	3,150	3,150
144		KABATI	Muranga	Other center	1,529	1,599	3,128	3,128
145		ENDARASH A	Nyeri North	Other center	1,429	1,620	3,049	3,049
146		GARSEN	Tana Delta	Other center	1,484	1,420	2,904	2,904
147		TURBO	Eldoret West	Other center	1,419	1,412	2,831	2,831
148		KANGARI	Muranga South	Other center	1,395	1,415	2,810	2,810
149		TONGAREN	Bungoma North	Other center	1,340	1,453	2,793	2,793
150		SIAKAGO	Mbeere	Other center	1,319	1,375	2,694	2,694
151		LOLGORIAN	Trans Mara	Other center	1,373	1,316	2,689	2,689
152		LAISAMIS	Laisamis	Other center	1,370	1,273	2,643	2,643
153		MOGONGA	Gucha	Other center	1,268	1,277	2,545	2,545
154		NDORI	Rarieda	Other center	1,223	1,299	2,522	2,522
155		MACHINER Y	Kibwezi	Other center	1,310	1,195	2,505	2,505
156		MASII	Mwala	Other center	1,188	1,313	2,501	2,501
157		KINAMBA	Laikipia West	Other center	1,142	1,177	2,319	2,319
158		RONGAI	Nakuru	Other center	1,105	1,110	2,215	2,215

Table 3.1.4 Population in Urban Centres in 2009 (5/6)

(Continuation)

No.	M/P (*)	Urban Centre	Previous District	Status	Male	Female	Total	Urban & Peri-urban
159		OLENGURU ONE	Molo	Other center	1,096	1,023	2,119	2,119
160		ENGINEER	Nyandarua South	Other center	1,026	1,007	2,033	2,033
161	○	KIKUYU	Kikuyu	Town Council	114,781	119,272	234,053	233,231
162	○	KANGUNDO -TALA	Kangundo	Town Council	107,968	110,589	218,557	218,557
163	○	KARURI	Kiambu East	Town Council	64,883	65,051	129,934	107,716
164	○	KILIFI	Kilifi	Town Council	60,042	62,857	122,899	48,826
165	○	GARISSA	Garissa/Tana river	Town Council	61,793	57,903	119,696	116,317
166	○	MOLO	Molo	Town Council	53,442	54,364	107,806	40,651
167	○	LITEIN	Buret	Town Council	51,766	52,834	104,600	9,103
168	○	MARIAKANI	Kaloleni/Kinango	Town Council	43,423	45,898	89,321	24,055
169	○	MANDERA	Mandera East	Town Council	46,022	41,670	87,692	87,692
170	○	NYAMIRA	Nyamira	Town Council	40,531	43,708	84,239	41,668
171	○	MWINGI	Mwingi	Town Council	40,245	43,558	83,803	15,970
172	○	RONGO	Rongo	Town Council	39,328	42,738	82,066	82,066
173	○	AHERO	Nyando/Kisumu East	Town Council	36,813	40,015	76,828	50,730
174	○	NANDI HILLS	Nandi Central/East	Town Council	37,999	35,627	73,626	10,120
175	○	MAKUYU	Muranga South	Town Council	35,610	36,303	71,913	44,007
176	○	KAPENGURI A	West Pokot	Town Council	35,604	35,873	71,477	34,046
177	○	NAROK	Narok North	Town Council	34,662	32,843	67,505	38,653
178	○	TAVETA	Taveta	Town Council	34,905	32,600	67,505	19,865
179	○	OL KALOU	Nyandarua North	Town Council	32,382	33,633	66,015	66,015
180	○	MALABA	Teso North/South	Town Council	30,963	32,361	63,324	21,477
181	○	MBITA POINT	Suba	Town Council	30,559	32,415	62,974	11,989
182	○	MALAVA	Kakamega North	Town Council	29,567	31,264	60,831	4,070
183	○	SUNEKA	Kisii South	Town Council	29,158	31,572	60,730	50,818
184	○	OGEMBO	Gucha	Town Council	29,237	31,052	60,289	3,475
185	○	UKWALA	Siaya	Town Council	26,400	30,681	57,081	5,187
186	○	KEROKA	Kisii Central/ Masaba	Town Council	25,796	28,859	54,655	41,654
187	○	MATUU	Yatta	Town Council	26,173	26,971	53,144	50,750
188	○	OYUGIS	Rachuonyo	Town Council	24,768	27,586	52,354	35,451
189	○	KIPKELION	Kipkelion	Town Council	24,791	25,148	49,939	46,760
190	○	LUANDA	Emuhaya	Town Council	23,734	25,612	49,346	49,346
191	○	ELDAMA RAVINE	Koibatek	Town Council	22,810	22,989	45,799	17,872
192	○	NYANSION GO	Borabu	Town Council	22,575	22,738	45,313	5,637
193	○	LONDIANI	Kipkelion	Town Council	22,360	22,593	44,953	43,152
194	○	ITEN/TAMB ACH	Keiyo	Town Council	21,671	22,777	44,448	42,312
195	○	MALAKISI	Bungoma South	Town Council	20,202	21,582	41,784	17,083
196	○	BONDO	Bondo	Town Council	18,734	20,490	39,224	33,468
197	○	MARALAL	Samburu Central	Town Council	17,502	17,970	35,472	15,860
198	○	NAMBALE	Busia/ Teso South	Town Council	16,860	17,875	34,735	5,541

Table 3.1.4 Population in Urban Centres in 2009 (6/6)

(Continuation)

No.	M/P (*)	Urban Centre	Previous Districts	Status	Male	Female	Total	Urban & Peri-urban
199	○	TABAKA	Gucha South	Town Council	16,781	17,943	34,724	15,351
200	○	MUHORONI	Nyando/Kisumu East	Town Council	17,892	16,565	34,457	34,457
201	○	UGUNJA	Siaya	Town Council	15,760	18,118	33,878	7,242
202	○	YALA	Siaya	Town Council	15,992	17,654	33,646	6,412
203	○	RUMURUTI	Laikipia West	Town Council	15,956	17,037	32,993	10,064
204	○	BURNT FOREST	Eldoret East/ Wareng	Town Council	16,364	16,285	32,649	4,925
205	○	MARAGUA	Muranga South	Town Council	15,772	16,543	32,315	26,374
206	○	KENDU BAY	Rachuonyo	Town Council	15,279	16,420	31,699	15,103
207	○	CHOGORIA	Maara	Town Council	15,850	15,773	31,623	28,415
208	○	KWALE	Kwale	Town Council	13,671	14,581	28,252	19,880
209	○	SAGANA	Kirinyaga	Town Council	13,274	13,873	27,147	10,195
210	○	MTITO ANDEI	Kibwezi	Town Council	13,086	12,833	25,919	4,520
211	○	SOTIK	Sotik	Town Council	11,234	10,763	21,997	8,366
212	○	PORT VICTORIA	Bunyula	Town Council	10,438	11,263	21,701	6,561
213	○	OTHAYA	Nyeri south	Town Council	8,974	9,969	18,943	5,137
214	○	KAJIADO	Kajiado Central	Town Council	9,283	8,998	18,281	14,860
215	○	WOTE	Makueni	Town Council	4,887	4,988	9,875	9,875
Total					6,882,529	6,842,046	13,722,069	11,546,351

Note: * ○ : Urban Centres subject to urban water supply development in the NWMP 2030.

Source: 2009 Population and Housing Census.

Table 3.2.1 Projected Population Distribution by County and Catchment Area in 2030

Old Administration 1992		County	Population Projection, 2030 (thousand)						
Province	District		LVNCA	LVSCA	RVCA	ACA	TCA	ENNCA	Total
Western	Bungoma	Bungoma	2,383	0	3	0	0	0	2,385
	Busia	Busia	791	0	0	0	0	0	791
	Kakamega	Kakamega	2,183	0	0	0	0	0	2,183
		Vihiga	1,101	92	0	0	0	0	1,193
Nyanza	South Nyanza	Homa Bay	0	1,382	0	0	0	0	1,382
		Migori	0	2,053	0	0	0	0	2,053
	Kisii	Kisii	0	2,420	0	0	0	0	2,420
		Nyamira	0	452	0	0	0	0	452
	Kisumu	Kisumu	34	2,443	0	0	0	0	2,476
	Siaya	Siaya	848	187	0	0	0	0	1,035
Rift Valley	Baringo	Baringo	0	1	622	0	0	0	623
	Kericho	Kericho	0	1,444	1	0	0	0	1,446
		Bomet	0	1,295	0	0	0	0	1,295
	Elgeyo Marakwet	Elgeyo Marakwet	310	0	220	0	0	0	530
	Kajiado	Kajiado	0	0	148	1,270	0	0	1,417
	Laikipia	Laikipia	0	0	38	0	3	707	747
	Nakuru	Nakuru	0	278	3,727	0	0	1	4,006
	Nandi	Nandi	857	200	0	0	0	0	1,057
	Narok	Narok	0	459	494	0	0	0	953
	Samburu	Samburu	0	0	62	0	0	223	285
	Trans Nzoia	Trans Nzoia	1,813	0	68	0	0	0	1,882
	Turkana	Turkana	0	0	831	0	0	0	831
	Uasin Gishu	Uasin Gishu	1,858	15	13	0	0	0	1,885
	West Pokot	West Pokot	183	0	423	0	0	0	606
Central	Kiambu	Kiambu	0	0	78	3,716	681	0	4,475
	Kirinyaga	Kirinyaga	0	0	0	0	785	1	786
	Muranga	Muranga	0	0	3	0	1,344	0	1,347
	Nyandarua	Nyandarua	0	0	695	3	48	208	954
	Nyeri	Nyeri	0	0	0	0	1,163	122	1,285
Nairobi	Nairobi	Nairobi	0	0	0	6,085	0	0	6,085
Eastern	Embu	Embu	0	0	0	0	779	0	779
	Isiolo	Isiolo	0	0	0	0	19	360	379
	Kitui	Kitui	0	0	0	22	1,408	0	1,431
	Machakos	Machakos	0	0	0	2,428	430	0	2,858
		Makueni	0	0	0	1,161	0	0	1,161
	Marsabit	Marsabit	0	0	21	0	0	297	317
	Meru	Meru	0	0	0	0	1,255	572	1,827
		Tharaka-Nithi	0	0	0	0	437	0	437
Coast	Kilifi	Kilifi	0	0	0	1,730	70	0	1,799
	Kwale	Kwale	0	0	0	920	0	0	920
	Lamu	Lamu	0	0	0	0	1,318	0	1,318
	Mombasa	Mombasa	0	0	0	2,651	0	0	2,651
	Taita Taveta	Taita Taveta	0	0	0	555	0	0	555
	Tana River	Tana River	0	0	0	2	235	0	237
North Eastern	Garissa	Garissa	0	0	0	0	394	241	635
	Mandera	Mandera	0	0	0	0	0	1,021	1,021
	Wajir	Wajir	0	0	0	0	0	642	642
Total			12,361	12,719	7,446	20,543	10,369	4,395	67,833

Source: JICA Study Team based on GIS data from Kenya National Bureau of Statistics and Population Projection in the study

Table 4.1.1 Gross Domestic Product by Activity/Industry between 2007 and 2011

(Unit: KSh million, constant price)

Industry	2007	2008	2009	2010	2011
Agriculture And Forestry	397,057	470,753	555,288	545,927	726,160
Growing of Crops and Horticulture	289,595	345,841	399,474	405,265	546,616
Farming of Animals	82,868	99,697	127,704	109,535	144,804
Agricultural and Animal Husbandry Services	8,573	8,764	9,571	10,934	12,580
Forestry and Logging	16,021	16,452	18,539	20,193	22,159
Fishing	7,127	9,450	9,903	14,637	15,091
Mining and Quarrying	12,904	14,930	12,083	17,650	20,621
Manufacturing	190,497	228,304	234,556	252,122	285,698
Manufacturing of Food, Beverages and Tobacco	57,865	65,123	75,615	79,162	97,053
All Other Manufacturing	132,632	163,181	158,941	172,960	188,645
Electricity and Water Supply	26,633	43,767	44,185	35,592	26,071
Electricity Supply	14,728	31,136	28,866	17,929	5,463
Water Supply	11,904	12,631	15,318	17,663	20,608
Construction	69,556	80,407	97,445	109,146	125,046
Wholesale And Retail Trade	177,609	214,022	233,001	260,869	320,950
Hotels and Restaurants	29,612	23,745	39,421	42,546	50,557
Transport and Communication	194,093	216,052	234,752	253,958	292,601
Transport and Storage	139,128	159,296	172,244	189,426	227,373
Post and Telecommunications	54,964	56,756	62,508	64,532	65,228
Financial Intermediation	88,018	97,806	128,732	143,471	193,044
Real Estate, Renting and Business Services	96,273	107,323	116,657	123,173	134,746
Dwellings, Owner Occupied and Rented	49,120	53,338	58,291	61,598	65,098
Renting and Business Services	47,153	53,985	58,366	61,575	69,648
Public Administration and Defense	107,508	106,431	118,662	141,648	151,321
Education	123,498	132,229	142,235	158,738	176,537
Health and Social Work	45,318	51,591	60,196	65,170	74,979
Other Community, Social and Personal Services	63,207	71,586	79,423	84,415	96,423
Private Household With Employed Persons	7,176	8,207	10,171	11,217	13,227
Less: Financial Services Indirectly Measured	-20,074	-18,231	-25,762	-21,652	-31,787
All Industries at Basic Prices	1,616,010	1,858,371	2,090,948	2,238,630	2,671,285
Taxes Less Subsidies on Products	217,501	249,218	276,036	311,195	353,497
GDP at Market Prices	1,833,511	2,107,589	2,366,984	2,549,825	3,024,782

Source: Economic Survey 2012

Table 4.1.2 Wholesale Prices of Major Agricultural Commodities between 2006 and 2012

(Unit: KSh)

Commodity	Unit	Annual Whole Prices, 2006- 2011							Growth	Average
	(kg)	2006	2007	2008	2009	2010	2011	2012*	08/12	08/12
Avocado	90	992	679	1,044	1,555	1,405	1,524	2,080	18.8%	1,522
Banana Cooking	22	304	958	365	395	386	473	646	15.3%	453
Banana Ripe	14	314	328	391	562	482	557	496	6.1%	498
Beans Canadian	90	3,700	3,045	4,911	5,077	4,781	5,716	5,500	2.9%	5,197
Beans Dolichos	90	4,472	3,131	5,251	6,857	8,358	6,561	6,825	6.8%	6,770
Beans Mwezi moja	90		2,573	4,691	5,382	4,465	5,010	4,650	-0.2%	4,840
Beans Mwitemania	90	3,194	2,716	5,088	5,347	4,351	5,425	5,250	0.8%	5,092
Beans Rose coco	90	3,357	3,109	5,052	5,217	4,629	5,661	5,630	2.7%	5,238
Brinjals	44	1,138	1,017	1,220	1,347	1,454	1,305	1,550	6.2%	1,375
Cabbages	99	1,347	1,178	1,269	1,971	1,528	1,618	1,600	6.0%	1,597
Capsicumus	50	1,214	1,478	1,606	2,120	2,169	2,391	2,280	9.2%	2,113
Carrots	138	1,916	1,529	2,464	3,522	2,583	3,067	1,800	-7.5%	2,687
Cassava Fresh	99	1,176	2,859	1,145	1,716	1,471	1,609	1,967	14.5%	1,582
Cauliflower	39	1,265	1,370	1,930	2,028	1,887	1,779	1,885	-0.6%	1,902
Chilies	38	987	1,301	1,257	2,010	1,505	1,952	2,685	20.9%	1,882
Cowpeas	90	4,228	3,351	4,523	6,231	5,263	5,662	6,190	8.2%	5,574
Cucumber	50	943	692	1,418	1,568	1,672	1,733	1,700	4.6%	1,618
Eggs	Tray	161	279	223	232	323	400	304	8.1%	296
Finger Millet	90	2,870	2,107	3,890	4,693	4,462	4,927	6,274	12.7%	4,849
Fresh Peas	51	1,803	1,333	2,259	2,970	2,457	2,755	1,840	-5.0%	2,456
Green Grams	90	5,560	3,433	5,093	6,979	7,050	8,619	7,240	9.2%	6,996
Groundnut-shell	110	5,461	4,979	7,190	7,921	8,674	9,928	11,180	11.7%	8,979
Irish Potatoes	110	1,801	1,747	2,308	2,874	2,503	3,279	4,460	17.9%	3,085
Kales	50	978	598	676	1,116	799	773	860	6.2%	845
Lemons	95	760	829	1,009	967	1,110	1,953	1,450	9.5%	1,298
Lettuces	51	980	1,500	1,611	2,240	1,613	1,994	2,300	9.3%	1,952
Limes	13	619	1,228	1,094	869	891	581	930	-4.0%	873
Maize Dry	90	1,368	1,118	2,016	2,667	1,652	2,907	2,900	9.5%	2,428
Maize Green	115	2,018	1,514	2,110	2,644	2,237	2,466	2,610	5.5%	2,413
Mangos, local	126	1,036	901	1,013	1,141	1,183	1,424	2,480	25.1%	1,448
Mangos, Ngowe	126	766	1,538	710	899	848	807	1,413	18.8%	935
Onion, dry	13	409	780	583	738	736	621	848	9.8%	705
Onion, spring	142	1,097	1,669	1,770	1,931	1,773	2,131	1,380	-6.0%	1,797
Oranges	93	1,560	1,493	1,726	2,070	2,168	2,631	2,920	14.0%	2,303
Passion fruits	57	1,680	1,414	1,825	2,313	2,962	3,140	3,534	18.0%	2,755
Paw paw	54	718	1,017	923	1,031	983	1,201	1,724	16.9%	1,172
Pineapples	13	453	925	587	667	738	769	742	6.0%	701
Sorghum	90	1,899	1,544	2,257	3,275	2,590	3,064	3,750	13.5%	2,987
Sweet potatoes	98	1,522	1,371	1,909	2,428	1,904	2,668	2,900	11.0%	2,362
Tomatoes	64	1,453	1,797	1,796	2,133	2,486	2,752	4,040	22.5%	2,641
Wheat	90		1,009	4,113	3,656	3,477	4,055	2,900	-8.4%	3,640

Note: * indicates the wholesale price as of November 1, 2012

Source: Economic Review of Agriculture 2012, Ministry of Agriculture; Business Daily, November 2, 2012

Table 6.1.1 Percentage Distribution of Household by Main Source of Drinking Water (1/2)

(Unit: %)

County		Previous District in 1992	Piped into Dwelling	Piped into Plot	Public Tap	Borehole with Pump	Tanker/ Truck/ Vendor	River/ Pond	Others
Code	Name								
KENYA			7.6	13.7	11.2	6.2	4.2	20.5	36.6
RURAL			3.8	8.0	7.0	7.7	2.2	26.4	44.9
URBAN			18.8	31.1	24.1	1.9	10.3	2.5	11.3
110	Nairobi City	Nairobi	27.8	40.0	27.2	0.2	2.7		2.1
CENTRAL			7.5	21.6	2.8	4.2	3.5	25.1	35.3
201	Nyandarua	Nyandarua	4.0	10.8	0.4	4.9	2.0	23.0	54.9
202	Nyeri	Nyeri	8.3	29.5	8.5	0.9	1.6	19.6	31.6
203	Kirinyaga	Kirinyaga	19.1	7.6	1.4		0.2	33.8	37.9
204	Murang’a	Murang’a/ Muragua	4.2	10.6	2.2	0.5	1.9	45.5	35.2
205	Kiambu *	Kiambu/Thika	4.6	31.4	3.1	15.6	7.5	20.5	17.3
COAST			8.5	7.7	35.8	3.8	19.9	6.7	17.6
301	Mombasa	Mombasa	10.8	11.1	40.9	0.4	35.4		1.4
302	Kwale	Kwale	2.9	2.5	44.5	12.1	4.3	1.8	31.9
303	Kilifi	Kilifi/Malindi	13.5	3.9	37.1		21.2	9.2	15.2
304	Tana River	Tana River	1.1	2.3	2.2	20.7	8.0	23.7	42.0
305	Lamu	Lamu	11.4		2.3	2.8	32.1	9.3	51.4
306	Taita/Taveta	Taita Taveta	4.6	19.2	27.4		0.5	23.0	25.3
EASTERN			3.5	13.4	11.8	5.3	1.5	28.1	36.4
401	Marsabit	Marsabit/ Moyale	1.5	8.3	12.5	16.5	9.0	18.1	34.2
402	Isiolo	Isiolo		20.4	17.5		0.6	11.8	49.7
403	Meru	Meru Central/ Meru North	9.0	48.5	12.9		0.2	15.0	14.4
404	Tharaka/ Nithi	Tharaka/ Nithi	1.9	3.2	5.0	15.9	2.3	52.9	18.8
405	Embu	Embu/ Mbeere	3.2	21.7	2.4	6.1	0.7	35.8	30.3
406	Kitui	Kitui/Mwingi	0.9	0.2	9.7	1.8	1.0	58.6	27.9
407	Machakos	Machakos	2.9	2.4	14.3	13.0	3.4	14.6	49.4
408	Makueni	Makueni		4.6	12.6	5.1	0.8	22.1	54.8
NORTH EASTERN			0.1	5.0	1.2	18.8	12.1	15.0	47.8
501	Garissa	Garissa		11.7	2.6	10.7	5.2	10.0	59.8
502	Wajir	Wajir		0.1		31.6	13.2	7.6	47.5
503	Mandera	Mandera	0.2	1.8	0.6	13.8	20.7	32.2	30.7
NYANZA			2.2	2.9	9.6	7.6	2.9	17.1	57.7
601	Siaya	Siaya/ Bondo	1.8	3.6	19.9	7.8	1.6	31.3	34.2
602	Kisumu	Kisumu/ Nyando	6.4	4.2	25.6	10.7	6.5	15.4	31.4
603	Migori	Migori/ Kuria	0.3	0.4	2.1	9.4	4.1	17.8	66.1
604	Homa Bay	Homa Bay/ Rachuonyo/ Suba	0.5	2.4	4.2	11.8	1.1	30.6	49.6
605	Kisii	Kisii Central/ Gucha (S. Kisii)	0.9	4.4	1.2	1.9	1.4	3.8	86.5
606	Nyamira	N. Kisii (Nyamira)	0.4	0.8	0.1		0.7	7.1	90.9
RIFT VALLEY			8.3	12.5	6.4	7.5	2.8	30.5	32.0
701	Turkana	Turkana		5.5	16.3	18.9		35.4	23.9
702	West Pokot	West Pokot	0.3	5.8	0.3	15.8		63.6	14.2
703	Samburu	Samburu			18.0	10.1		44.5	27.4
704	Trans Nzoia	Trans Nzoia	2.0	4.5	13.8	13.3		22.6	43.8
705	Baringo	Baringo/ Koibatek	2.2	14.0	2.9	2.3	1.2	52.1	25.5
706	Uasin Gishu	Uasin Gishu	6.0	3.4	14.4	0.9	5.1	15.3	54.9
707	Elgeyo/Marakwet	Marakwet/ Keiyo	2.6	16.6	2.5	0.8	0.9	43.8	32.9
708	Nandi	Nandi	2.4	7.4	1.2	0.4	0.3	35.6	52.7

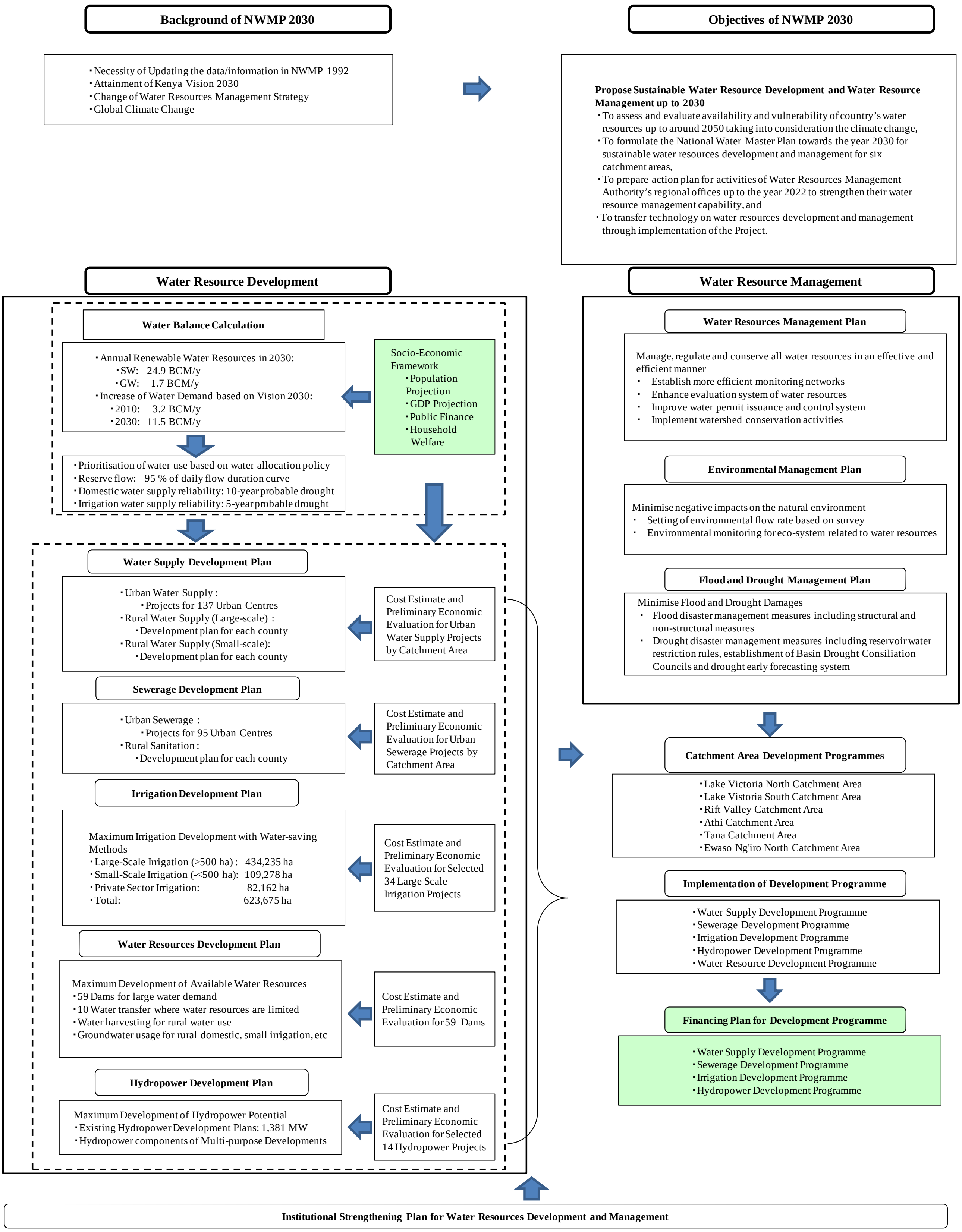
Table 6.1.1 Percentage Distribution of Household by Main Source of Drinking Water (2/2)

(Continuation) (Unit: %)

County		Previous District in 1992	Piped into Dwelling	Piped into Plot	Public Tap	Borehole with Pump	Tanker/ Truck/ Vendor	River/ Pond	Others
Code	Name								
709	Laikipia	Laikipia	16.1	21.9	0.9		1.7	24.1	35.3
710	Nakuru	Nakuru	7.5	25.2	5.6	16.8	8.9	16.3	19.7
711	Narok	Narok/ Trans Mara	0.7	0.9	6.5		0.7	41.8	49.7
712	Kajiado	Kajiado	4.9	28.4	10.7	19.6	6.0	35.6	-5.2
713	Kericho	Kericho/ Buret	48.7	8.9	3.4	0.3	0.1	24.4	14.2
714	Bomet	Bomet	11.3	10.9	2.0	0.6	0.8	31.9	42.7
WESTERN			1.1	3.5	2.5	9.7	1.1	17.5	64.6
801	Kakamega	Kakamega/ Lugari/ Butere/Mumius	1.7	2.5	0.2	14.7	1.2	20.4	59.5
802	Vihiga	Vihiga	0.5	7.2	2.2	1.4	2.0	7.7	79.0
803	Bungoma	Bungoma/ Mt. Elgon	0.4	1.6	4.0	12.9	0.9	18.6	61.6
804	Busia	Busia/ Teso	1.0	1.2	3.9	18.9	0.3	12.9	61.9

Source: Kenya Integrated Household Budget Survey 2005/06

Figures

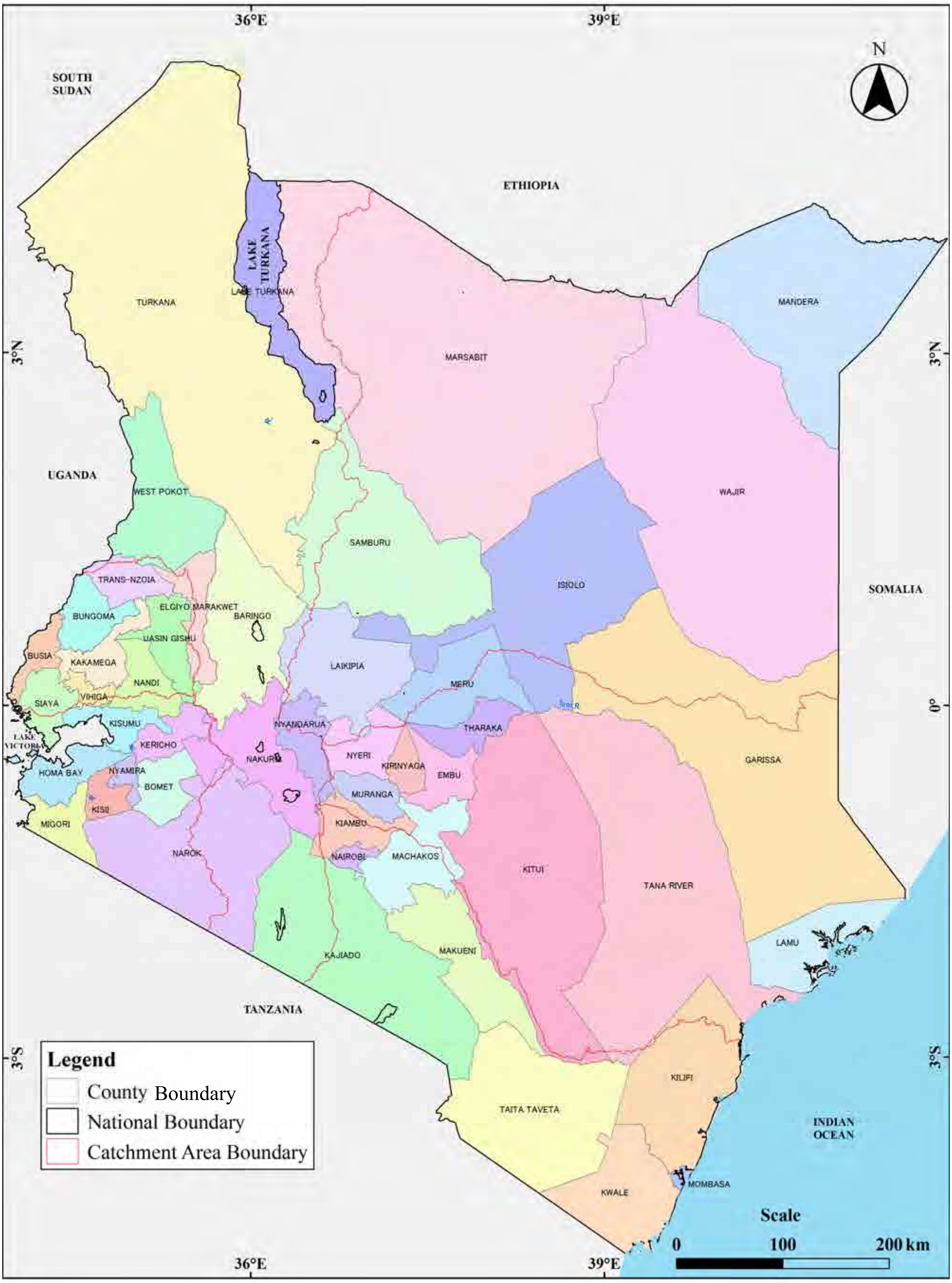


Source: JICA Study Team

THE DEVELOPMENT OF
THE NATIONAL WATER MASTER PLAN 2030

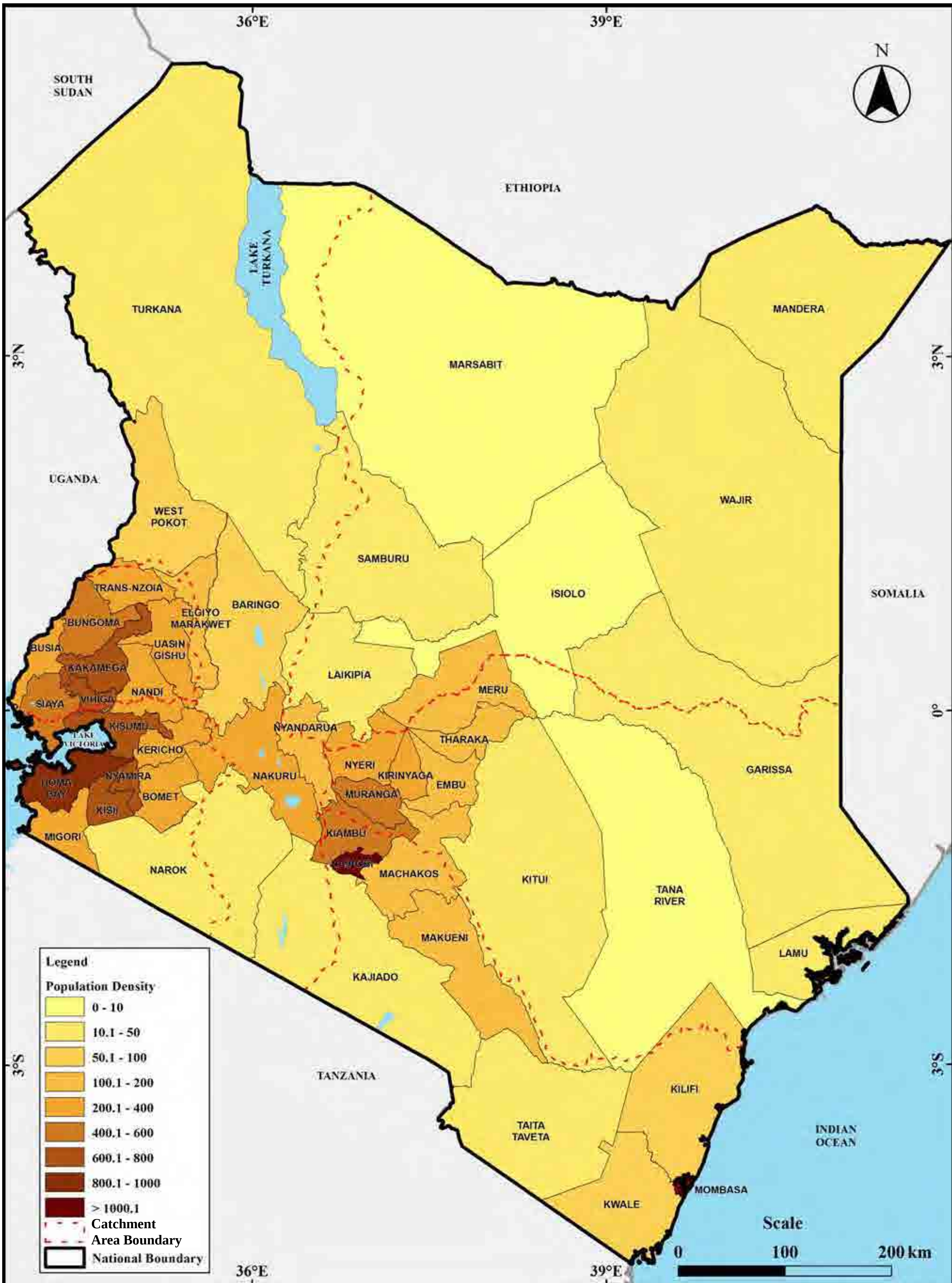
JAPAN INTERNATIONAL COOPERATION AGENCY

Figure 1.1.1
Study Flow of Socio-Economy, Economic Evaluation, and Financing Plan



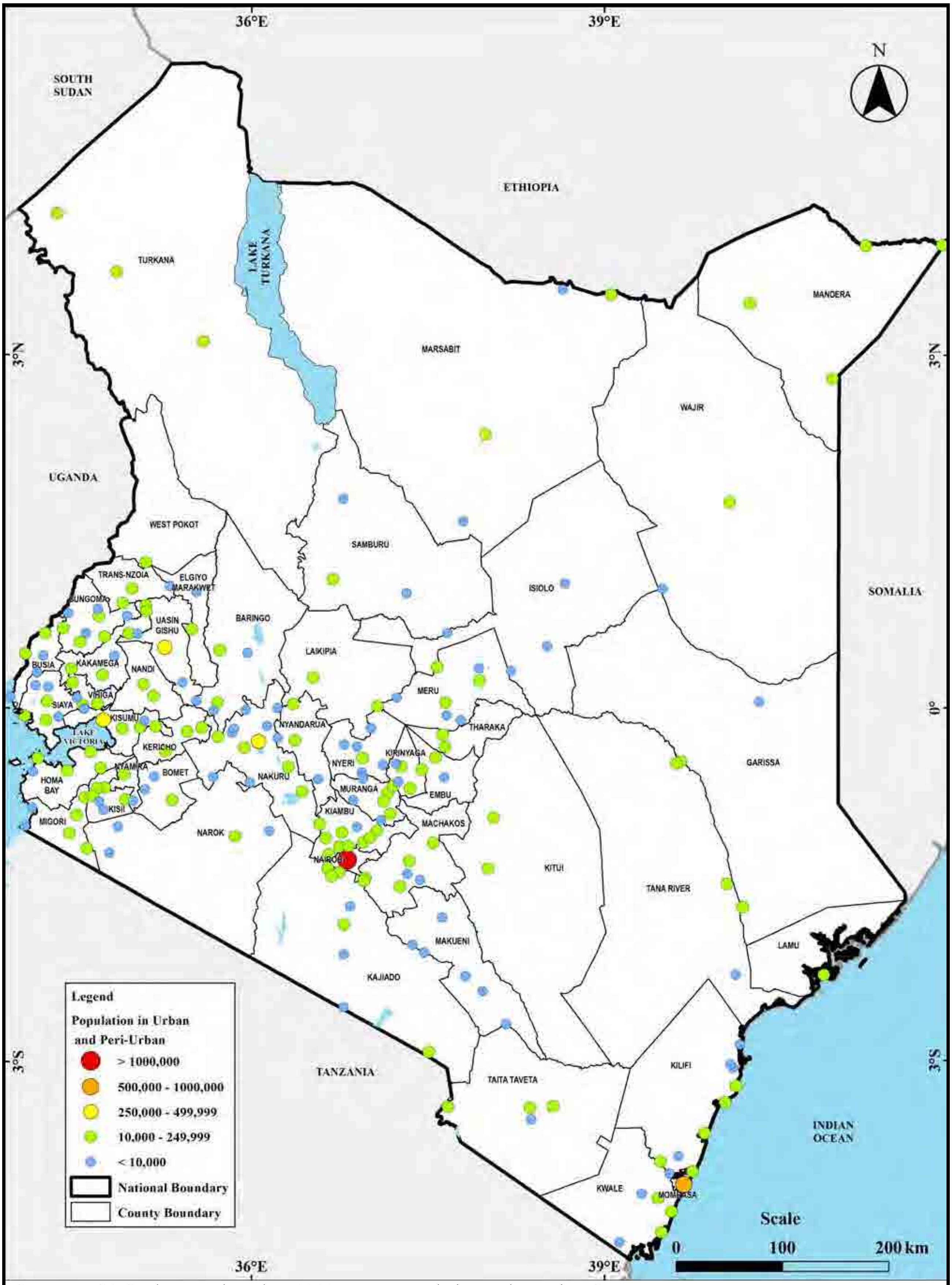
Source: JICA Study Team based on GIS data from Kenya National Bureau of Statistics

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 2.1.1 Administrative Boundary by County and Catchment Area in 2012**
JAPAN INTERNATIONAL COOPERATION AGENCY	



Source: JICA Study Team based on Statistical Abstract 2011

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 3.1.1** **Population Density by County**
JAPAN INTERNATIONAL COOPERATION AGENCY	



Source: JICA Study Team based on 2009 Kenya Population and Housing Census

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 3.1.2 Population in Urban and Peri-urban Centres**
JAPAN INTERNATIONAL COOPERATION AGENCY	

Sectoral Report (B)
Meteorology and Hydrology

THE PROJECT
ON
THE DEVELOPMENT OF
THE NATIONAL WATER MASTER PLAN 2030
IN
THE REPUBLIC OF KENYA

FINAL REPORT
VOLUME – IV SECTORAL REPORT (1/3)

B: METEOROLOGY AND HYDROLOGY

Abbreviation

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List of Abbreviations and Acronyms

AR4	:	Fourth Assessment Report
ASAL	:	arid and semi-arid land
CBS	:	Central Bureau of Statistics
CDF	:	Cumulative Distribution Function
CMIP3	:	Phase 3 of Coupled Model Intercomparison Project
CMS		Catchment Management Strategy
DEM	:	digital elevation model
DIAS	:	Data Integration and Analysis System
EDITORIA	:	University of Tokyo Earth Observation Data Integration and Fusion Research Initiative
ENN	:	Ewaso Ng'iro North
ENSO	:	El-Niño/Southern Oscillation
ESRL PSD	:	Earth System Research Laboratory Physical Sciences Division
FAO	:	Food and Agriculture Organization
GCM	:	General Circulation Model
GEV	:	Generalized Extreme Value Distribution
GEWEX	:	Global Energy and Water Cycle Experiment
GPCP	:	Global Precipitation Climatology Project
GW	:	Groundwater
GWEVT		Groundwater Evapotranspiration
IPCC	:	Intergovernmental Panel on Climate Change
ITCZ	:	Inter Tropical Convergence Zone
JICA	:	Japan International Cooperation Agency
KMD	:	Kenya Meteorological Department
LN3	:	Log Normal Distribution
LP3	:	Log Pearson III Distribution
LVN	:	Lake Victoria North
LVS	:	Lake Victoria South
MWI	:	Ministry of Water and Irrigation
NASA	:	National Aeronautics and Space Administration
NCEP	:	National Centers for Environmental Prediction
NOAA	:	National Oceanic and Atmospheric Administration
NWMP	:	National Water Master Plan
OAR	:	Office of Air and Radiation
OLR	:	Outgoing Longwave Radiation
PCMDI	:	Program for Climate Model Diagnosis and Intercomparison
PDF	:	Probability Density Function
PET	:	potential evapotranspiration
RFA	:	rainfall frequency analysis
RGB	:	Red Green Blue
RGS		river gauging station
RMS	:	root mean square
RMSE	:	root mean square error
RV	:	Rift Valley
SHER	:	Similar Hydrologic Element Response

SLSC	:	Standard Least-squares Criterion
SQL	:	Structured Query Language
SQRT-ET	:	Square-Root Exponential Type
SRES	:	Special Report on Emission Scenarios
SRTM	:	Shuttle Rader Topography Mission
SWIR	:	short wave infrared
TAR	:	Third Assessment Report
TC	:	Tropical Cyclone
TGICA	:	Task Group on Data and Scenario Support for Impact and Climate Assessment
TM	:	Thematic Mapper
UNEP	:	United Nations Environment Programme
UNESCO	:	United Nations Educational, Scientific and Cultural Organization
UTM	:	Universal Transverse Mercator
VNIR	:	visible and near infrared
WCRP	:	World Climate Research Programme
WGCM	:	Working Group on Coupled Modelling
WHYMAP	:	Worldwide Hydrogeological Mapping and Assessment Programme
WRMA	:	Water Resource Management Authority

Abbreviations of Measures

Length

mm	=	millimeter
cm	=	centimeter
m	=	meter
km	=	kilometer

Area

ha	=	hectare
m^2	=	square meter
km^2	=	square kilometer

Volume

1, lit	=	liter
m^3	=	cubic meter
m^3/s, cms	=	cubic meter per second
CM	=	cubic meter
MCM	=	million cubic meter
BCM	=	billion cubic meter
m^3/d, cmd	=	cubic meter per day
BBL	=	Barrel

Weight

mg	=	milligram
g	=	gram
kg	=	kilogram
t	=	ton
MT	=	metric ton

Time

s	=	second
hr	=	hour
d	=	day
yr	=	year

Money

KSh	=	Kenya shilling
US$	=	U.S. dollar

Energy

kcal	=	Kilocalorie
kW	=	kilowatt
MW	=	megawatt
kWh	=	kilowatt-hour
GWh	=	gigawatt-hour

Others

%	=	percent
o	=	degree
'	=	minute
"	=	second
°C	=	degree Celsius
cap.	=	capital
LU	=	livestock unit
md	=	man-day
mil.	=	million
no.	=	number
pers.	=	person
mmho	=	micromho
ppm	=	parts per million
ppb	=	parts per billion
lpcd	=	litter per capita per day

NOTE

1. The National Water Master Plan 2030 was prepared based on the material and data provided from Kenyan Government and its relevant organisations during field surveys in Kenya carried out until November 2012. The sources etc. of the material and data utilised for the study are described in the relevant part of the reports.

2. The names of ministries and related organisations of Kenyan Government are as of November 2012.

3. Information to be updated

   The following information which is given in the report is needed to be updated properly:

   (1) Information on the proposed development projects

   The features and implementation schedules of the proposed development projects may be changed toward implementation of the project. After the subject projects were clearly featured for implementation, the project features and implementation schedules in this report should be updated.

   (2) Information on the water demand

   The water demand projected in this master plan should be revised when the large scale development plans, other than the projects proposed in this master plan, were formulated, as they will significantly affect to the water resources development and management.

4. Exchange rate for cost estimate

   The costs of the proposed development and management plans were estimated by applying the following exchange rate as of November 1, 2012.

EXCHANGE RATE
US$1.00 = KSh 85.24 = ¥79.98
as of November 1, 2012

CHAPTER 1 GENERAL HYDROMETEOROLOGY

1.1 Climate

1.1.1 General Climate

Kenya lies approximately between latitudes 5°20'N and 4°40'S and between longitudes 33°50'E and 41°45'E. Regional factors, which modify rainfall over most parts of Kenya, include large bodies of water bodies Lake Victoria, complex topography such as the Great Rift Valley, and high mountains such Mt. Kenya and such as Mt. Elgon. Local factors such as land-sea breezes and vegetation further complicates the rainfall distribution.

A relatively wet and narrow tropical belt lies along the coast of the Indian Ocean. Behind the coastline are large areas of semi-arid and arid lands. The land then rises steeply to a highland plateau through which the Rift Valley runs. Kenya generally experiences two seasonal rainfall peaks (bimodal) in most places. However, some stations in the western and central parts of the Rift Valley experience a tri-modal rainfall pattern.

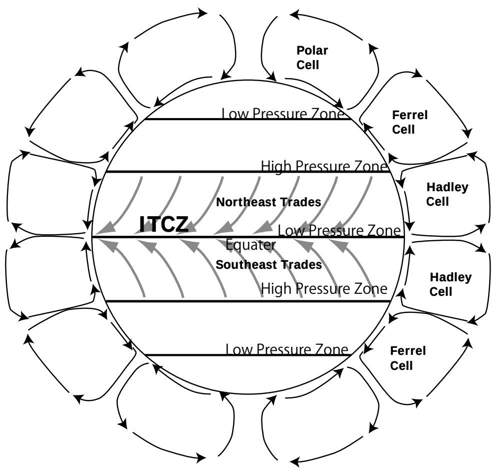
There are four seasons in Kenya as described in the following table.

Month	Season
December – February (DJF)	-
March – May (MAM)	Long Rain
June – August (JJA)	-
September – November (SON)	Short Rain

Source: KMD

1.1.2 Intertropical Convergence Zone

The climate in Kenya is controlled by the northward and southward movement of the Intertropical Convergence Zone (ITCZ). The ITCZ is the area encircling the earth near the equator where winds originating in the northern and southern hemispheres come together.



Source: JICA Study Team

Schematic Image of Global Belts of High and Low Pressure and ITCZ

Variation in the location of ITCZ drastically affects the rainfall in Kenya. Long term changes in the ITCZ may result in severe droughts or floods.

1.1.3 Climatic Zone

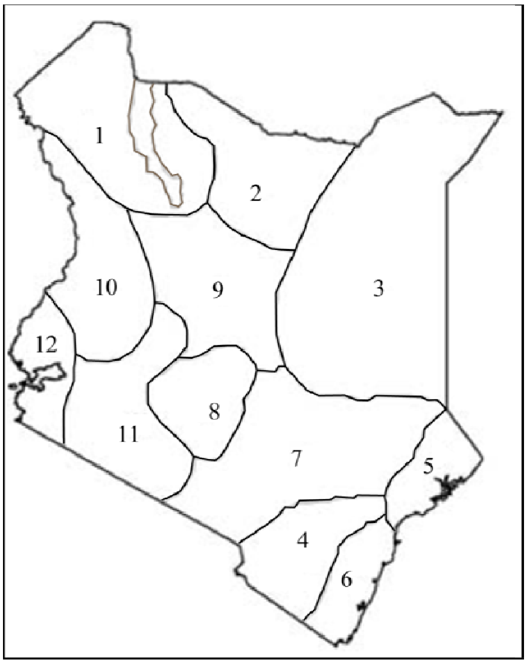
The bimodal nature of rainfall corresponds with the northward and southward migration of the ITCZ. The first peak or season termed as the "long-rains" in the East African region occurs from March to May, while the second season termed as the "short-rains" is observed from October to December. However, the western parts of the country, receive considerable rainfall during the month of June to September season. This is associated with the incursion of the Congo air mass. This period from January to February is generally dry over most parts of the country. Northeasterly monsoons, which are dominant at this time, are difluent and dry (Griffiths, 1972, Anyamba, 1983).

The main synoptic scale systems affecting rainfall in Kenya are the followings:

- The position and strength of subtropical high-pressure systems in the Southwest Indian Ocean (Mascarene High), Southeast Atlantic Ocean (St Helena High), North Atlantic Ocean (Azores/Saharan High), and the Arabian High to the northeast.
- The position and intensity of the ITCZ.
- The position and intensity of tropical cyclones (TCs).
- El-Niño/Southern Oscillation (ENSO).
- The Congo air mass.
- Inter-seasonal annual waves: the quasi-biennial oscillations (QBO).

The moisture availability (ratio of rainfall and potential evaporation) of Kenya is presented in the climatic zones of Kenya as Figure 1.1.1. The moisture availability zones are divided into I-IV: (I) >80-Humid, (II) 65-80-Sub-humid, (III) 50-65-Semi-humid, (IV) 40-50-Semi-humid to Semi-arid, (V) 25-40-Semi-arid, (VI) 15-25-Arid, and (VII) <15-Very arid. The temperature zones are divided into 1-9: (1) 24-30, (2) 22-24, (3) 20-22, (4) 18-20, (5) 16-18, (6) 14-16, (7) 12-14, (8) 10-12, and (9) Less than 10.

Similar to the agro-climatic zones of Kenya, the Kenya Meteorological Department (KMD) defines the climatic zones in Kenya into 12 zones as described in the following table and the figure on right.



Source: KMD

Climatic Zone of Kenya

Climatic Zone of Kenya defined by KMD

Area	Climatic Zone	Representative Station
1 North Western Kenya	Arid (VI) to Very Arid (VII)	Lodwar
2 Northern Kenya	Arid (VI) to Very Arid (VII)	Marsabit, Moyale
3 North Eastern Kenya	Arid (VI) to Very Arid (VII)	Mandera, Wajir, Garissa
4 Southern Lowlands	Semi Arid (V) To Arid (VI)	Voi
5 Northern Coast Strip	Semi-Humid (III) to Semi-Arid (V)	Lamu
6 Southern Coast Strip	Semi-Humid (III) to Semi-Arid (V)	Mombasa, Mtwapa, Malindi, Msabaha
7 South Eastern Lowlands	Semi Arid (V) To Arid (VI)	Machakos, Makindu

Area	Climatic Zone	Representative Station
8 Central highlands including Nairobi	Humid (I) to Semi-Humid (III)	Nairobi, Nyeri, Meru, Embu
9 Highlands North	Sub-Humid(II) to Arid (VI)	Isiolo
10 Highlands West of the Rift Valley	Humid (I) to Semi-Humid (III)	Kericho, Eldret, Kitale, Kakamega
11 Central Rift Valley	Semi-Humid (III) to Semi-Arid (IV)	Narok, Nakuru, Nyahururu, Laikipia Air Base
12 Lake Victoria Basin	Humid (I) to Sub-humid (II)	Kisii, Kisumu

Source: KMD

The KMD provides four-day, seven-day, monthly, and seasonal forecasts based on the above climatic zones.

1.2 Meteorology

1.2.1 Meteorological Observation

The KMD is responsible for the provision of meteorological and climatological services to agriculture, forestry, water resources management, and other sectors for better exploitation and utilization of natural resources for national development.

Currently, the KMD operates a network of 36 synoptic stations. The observed data form these stations are stored in database in their headquarters. The locations of the synoptic and rainfall stations are illustrated in Figure 1.2.1.

The general features of the KMD's synoptic stations are described in Table 1.2.2 Each synoptic station observes rainfall, atmospheric pressure, temperature, relative humidity, sunshine, radiation, evaporation, wind speed, wind direction, etc. The observed items at each synoptic station are presented in Table 1.2.1. The monthly mean maximum and minimum temperatures measured at the synoptic stations from 1979 to 2010 were collected from the KMD.

The evaluation of the climate change impact on Kenya is one of the main themes of the NWMP 2030. A long-term observation data was indispensable for this study in order to make the plan reliable. The history of climatological observation in Kenya is over 100 years. The first climatic data was recorded at the town of Mombasa in 1890.

In order to assess the historical trend of climatic data, the daily rainfall, and annual maximum and minimum temperatures at 24 stations were provided by the KMD for this study.

1.2.2 Temperature

There are 36 synoptic stations in Kenya which observe daily temperature. The daily temperature data of 35 stations from 1979 to 2010, including 20 stations with data from the 1960's were provided by KMD. The locations of synoptic stations are shown in Figure 1.2.1. As shown in the figure, the distribution of the stations is scattered. Furthermore, data availability is low, especially, in the northern and eastern sides of the country.

Temperature at each station is observed four times per day. KMD only records the highest and lowest temperatures in a day and estimates the mean daily temperature as an average value. For trend analysis of temperature, 16 of the 32 stations were selected.

Kenya has a wide variety of temperature which ranges from below the freezing point on the snow-capped Mt. Kenya as a minimum to over 40 °C in the north and northeast arid and semi-arid areas as maximum. The approximate temperature in the coastal town of Mombasa (altitude 17 m) is 30.3 ^{o}C at maximum and 22.4 ^{o}C at minimum; the capital city Nairobi (altitude 1,661 m) 25.2 ^{o}C at maximum and 13.6^{o}C at minimum; Eldoret (altitude 2,085 m) 23.6 ^{o}C at maximum and 9.5 ^{o}C at minimum; and Lodwar (altitude 506 m) and the drier north plain lands 34.8 ^{o}C at maximum and 23.7 ^{o}C at minimum.

1.2.3 Evaporation and Relative Humidity

The mean annual evaporation depth varies from 1,215 mm at Kimakia forest station to 3,945 mm at Lokori in South Turkana. The estimation of evaporation rates from water surface is important for water resources development, especially in arid and semi-arid land (ASAL) regions.

The potential evapotranspiration evaluated using Harmon’s equation and FAO Penman-Monteith method was discussed in Chapter 2.

The highest annual mean maximum and minimum relative humidities were both recorded at the Mombasa station at approximately 90% and 82%, respectively. On the other hand, the lowest annual mean maximum and minimum humidities were recorded at the Lodwar station at approximately 60% and 34%, respectively.

1.2.4 Sunshine Hour

The mean sunshine hours are approximately 7-8 hours. Lodwar has the longest mean monthly sunshine hour with 10.3 hours in September. On the other hand, the shortest mean monthly sunshine hour was recorded in Dagoretti station with 3.0 hours in July.

1.2.5 Rainfall

The average annual rainfall over the country is approximately 680 mm. It varies from 0 to about 250 mm in the ASAL zone areas such as Garissa, Isiolo, Mandera, Marsabit, Moyale, and Turkana to 2,000 mm in high rainfall zones such as Nyeri, Meru, Nyandarua, and Mt. Elgon regions. The high rainfall zone, which receives more than 1,000 mm of annual rainfall, occupies less than 20% of the productive agricultural land and carries approximately 50% of the country’s population. Most of the food and cash crops as well as livestock are produced in this zone under semi-intensive and intensive systems. The medium rainfall zone receives between 750-1000 mm of rainfall annually and occupies between 30-35% of the country’s land area. It is home to about 30% of the population. Farmers in this zone keep cattle and small stock, and grow drought-tolerant crops. The ASALs, which receive 200 to 750 mm of rainfall annually, cover over 80% of the total area. They are not suited for rainfed agriculture due to low and erratic rainfall, although there is cultivation of some crops.

The mean monthly rainfall depth recorded at each station is shown in Figure 1.2.2. An isohyetal map of mean annual rainfall depth for the data from 1981 to 2010 is shown in Figure 1.2.3.

1.3 Hydrology

1.3.1 Rivers, Lakes and Springs

(1) Rivers

The major rivers in Kenya are shown in Figure 1.3.1. Kenya's river system is relatively simple. All the main rivers are consequent on the great dome formed by the Central Highlands.

Kenya has five "water towers", namely, Mt. Kenya (199,558 ha), Aberdares Range (103,315 ha), Cherangani Hills (128,000 ha), Mt. Elgon (73,089 ha), and Mau Forest Complex (400,000 ha). The water towers from the upper catchments of all the main perennial rivers in Kenya. On the other hand, the rivers in ASALS run out seasonally when heavy storm rainfall occurs.

Kenya has limited natural renewable water resources estimated at 76.6 BCM/year, which consists of 20.6 BCM/year of surface water and 56.0 BCM/year of groundwater recharge. The per capita renewable water resources (= precipitation – evapotranspiration) currently estimated at 1,990 m^3 per capita per year for the country's population of 38.53 millions in 2010. Assuming that the sustainable groundwater yield is 10% of the groundwater recharge, the available water resources is estimated at 26.2 BCM/year and the per capita available water resources comes to 681 m^3 per capita per year.

Kenya is delineated into six catchment areas designated as by the National Water Resources Management Strategy and the major rivers of each catchment area are listed as below.

Major Rivers of Six Catchment Areas

Catchment Area	Area (km^2)	Major Rivers
Lake Victoria North	18,374	Nzoia R., Yala R.
Lake Victoria South	31,734	Nyando R., Sondu R., Kuja (Gucha) R., Mara R.
Rift Valley	130,452	Turkwel R., Kerio R., Ewaso Ngiro South R.
Athi	58,639	Athi R., Lumi R.
Tana	126,026	Tana R.
Ewaso Ng'iro North	210,226	Ewaso Ngiro North R., Daua R.
Total	575,451	

Source: WRMA Catchment Management Strategies

(2) Lakes

Kenya has nine major lakes as listed in the table below and shown in Figure 1.3.1.

Of the nine lakes listed below only Lake Victoria has an outlet, while the other lakes have none. Lake Bogoria, Lake Baringo, Lake Naivasha, Lake Elementaita and Lake Nakuru were registered in the Ramsar Convention in 2001, 2002,2004, 2005 and 2006, respectively.

Major Lakes in Kenya

Lakes	Elevation (m)	Area (km^2)	Type of Water
Victoria (Kenyan part)	1,133	3,755	Fresh
Turkana	375	6,405	Saline
Naivasha	1,884	210	Fresh
Baringo	975	129	Fresh
Bogoria	991	34	Saline
Nakuru	1,758	52	Saline
Elementaita	1,776	21	Saline
Jipe	701	39	Fresh
Magadi	579	104	Saline
Total	-	10,749	-

Source: Statistical Abstract, 2009, Kenya National Bureau of Statistics.

(3) Springs

It was said that there are a number of springs in the country. These springs are important sources for water supply of various sectors. According to the "Welfare Monitoring Survey II, 1994, Basic Report, CBS" (the Welfare Monitority Survey II), springs sustain 15% of the total households in Kenya in terms of safe water supply. Unfortunately there are no data presenting the exact the locations of and discharges from the springs. Major springs include the Mzima, Njoro Kubwa, Noltresh, and Kikuyu springs as shown in Figure 1.3.1.

1.3.2 Hydrological Observation

The Ministry of Water and Irrigation (MWI) had been the responsible agency for the management of hydrological data until the Water Resources Management Authority (WRMA) was established in 2005. The hydrological data stored in the server of MWI was transferred to WRMA with the mandate to monitor and assess the country's water resources. Under such circumstances, hydrological data related to surface water was collected from: i) MWI and ii) the headquarters and iii) the regional offices of WRMA.

The following data were collected:

a) Basic information on water level gauging stations (location, identification number, start and end year of operation, category, and present status of operation) ;
b) Daily water level,
c) Rating curve equation, and
d) Daily discharge converted from daily water level.

The station names and coordinator are described in Table 1.3.1.

In NWMP (1992), the observed water levels at 67 river gauging stations (RGSs) between 1959 and 1988 were used for analysis. Such data are shown in Table 1.3.1. Due to physical and financial constraints, some stations have stopped its operations. Hydrological data of 398 stations stored in the MWI database were collected. The collection of recent hydrological data at those RGSs used in NWMP (1992) is on going from the main and the regional office of WRMA. In parallel, the hydrological data at 22 national and 47 management unit stations which were designated by the Catchment Management Strategy was collected from the WRMA database. The details of the hydrological stations which was collected for this study are described in Table 1.3.2.

1.3.3 Streamflow Gauging Network and Hydrological Database

There are existing water level stations at various locations on the main stream and on several major tributaries. However, water level measurements at more than half of the stations has been terminated or abandoned.

Following the start of operation of WRMA in 2005, WRMA established its institutions at the national, regional, and sub-regional levels and developed catchment management strategies (CMSs) to facilitate execution of its mandate.

Based on the CMSs, the surface water monitoring network was prioritised by WRMA and are classified as follows:

- National Station (Priority 1),
- Management Units Stations (Priority 2),
- Inter-Management Units Stations (Priority 3),
- Special purpose stations (Priority 4)

The prioritisation took into consideration the availability of continuous records, accessibility and representativeness of river basins.

The number of streamflow gauging stations in each catchment are summarized in the table below and its location is illustrated in Figure 1.3.2.

Summary of Surface Water Monitoring Network

Catchment Area	Number of River Gauging Stations based on Catchment Management Strategies				Number of Installed Water Level Data Loggers
	National Stations (Priority 1)	Management Units Stations (Priority 2)	Inter-Management Unit Stations (Priority 3)	Special Management Unit Stations (Priority 4)	
Lake Victoria North	5 (5)	6 (6)	10 (10)	6 (6)	5
Lake Victoria South	5 (4)	14 (11)	19 (18)	1 (1)	4
Rift Valley	7 (4)	12 (8)	20 (8)	1 (0)	4
Athi	3 (2)	4 (3)	21 (11)	3 (2)	5
Tana	1 (1)	6 (6)	22 (14)	14 (9)	5
Ewaso Ng'iro North	1 (1)	5 (3)	30 (21)	4 (0)	4
Total	22 (17)	47 (37)	122 (82)	29 (18)	27

Note: Numbers in parenthesis indicate the number of gauging stations in operation as of July 2010
Source: Annual Water Sector Review 2011, February 2011 WRMA

Among the above RGSs, 27 stations have installed data loggers. Staff gauges have been installed for the remaining RGSs. According to an interview in with Tana Regional Office, locals who have signed the contract with WRMA sub-regional office read and record the reading of staff gauges twice a day (usually around 9:00a.m. and 4:00p.m.). The maximum water level or peak discharge against large-scale floods has not been measured at all stations except for stations with installed loggers. A rating curve between water level and discharge (H-Q curve) is available at almost all working stations by periodical reviewing of cross sectional changes due to erosion or sedimentation; however it has not been reviewed at some stations.

Daily water level records are submitted once a month to the sub-regional office where data is inputted into a computer. Inputted data are then sent to the regional office and stored in the database system.

In the NWMP (1992), the computerized hydrological database was renovated in the course of the study. The hydrological database contains meteorological data, rainfall data, river water level data, suspended load monitoring data, water quality monitoring data, etc. Such database were transferred to WRMA in 2005. Through the Kenya Water and Sanitation Program in 2008, MIKE BASIN and SQL Server 2008 were introduced to WRMA for the hydrological database Both the headquarters and regional offices of WRMA have such database system.

1.3.4 Low Flows of Perennial Rivers

The low flows of rivers are one of the essential data needed to understand the characteristics of river and its water resources potential. At this stage of the study, the recorded discharge at the following RGSs were evaluated. These discharges were categorized as a national station and have relatively long recorded discharge period.

Description of Selected River Gauging Stations

Catchment Area	River Name	Station Name	Station Code	Catchment Area (km^2)	Recorded Period (Year)
Lake Victoria North	Nzoia	Ruambwa	1EF01	12,676	1974 – 1988 1990 – 2003 2005 – 2007
	Yala	Yala	1FG02	2,864	1958 – 1964 1966 – 1994 1996 – 1998
Lake Victoria South	Nyando	Nyando	1GD03	2,625	1969 – 1997, 2005 – 2008
Tana	Tana	Garissa	4G01	32,892	1942 – 2009
Ewaso Ng'iro North	Ewaso Ng'iro	Archers' Post	5ED01	15,300	1949 – 2010

Source: WRMA Ewaso Ng'iro North River Catchment Conservation and Water Resources Management Study, 2002

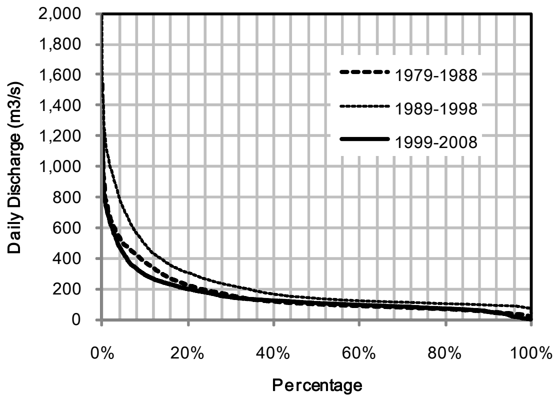
The 50%, 90%, and 95% daily discharges between every ten years from: i) 1979 to 1988, ii) 1989 to 1998, and iii) 1999 to 2008 at the above RGSs are summarized below.

Runoff Characteristics by Percentile Discharge

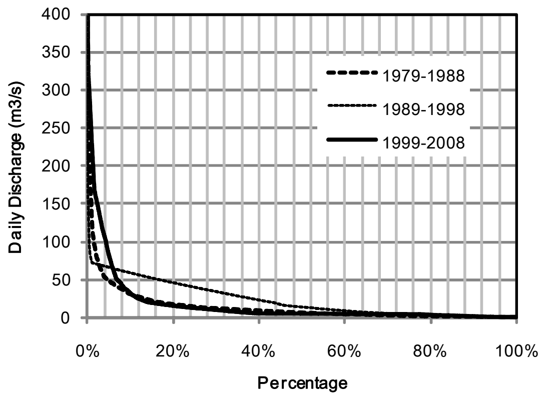
Station Name	Daily Discharge (m^3/s)								
	1979 – 1988			1989 – 1998			1999 – 2008		
	Q50%	Q90%	Q95%	Q50%	Q90%	Q95%	Q50%	Q90%	Q95%
Nzoia	87.0	24.7	19.4	124.9	40.9	30.5	-	-	-
Yala	26.9	10.0	8.1	-	-	-	-	-	-
Nyando	8.0	2.0	1.5	9.7	3.1	2.6	-	-	-
Garissa	98.2	50.3	39.3	134.0	90.1	85.2	107.8	52.0	28.3
Archers Post	6.0	0.6	0.2	14.3	2.1	1.2	4.6	1.1	0.3

Note: Cells with hyphen (-) indicate that the recorded number of data is smaller than 80% of all necessary data
Source: Estimated by JICA Study Team based on the data from WRMA

The flow duration curves of the periods for the Tana River at Garissa RGS and the Ewaso Ng'iro River at Archers' Post RGS are illustrated in the figure below.



Garissa RGS in Tana River



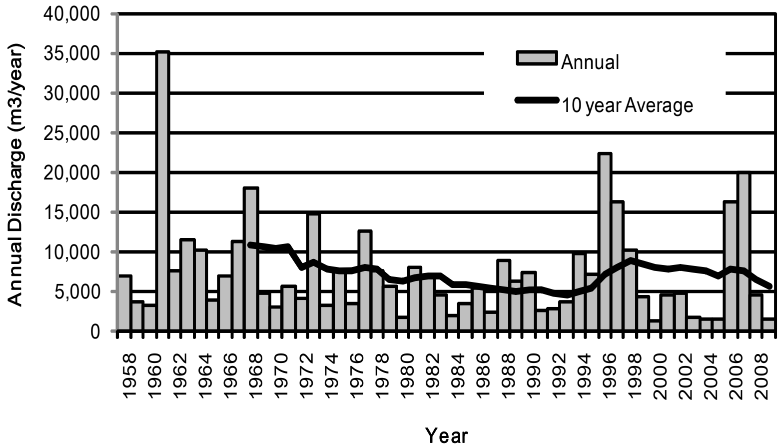
Archers' Post RGS in Ewaso Ng'iro North River

Source: JICA Study Team

Flow Duration Curve for Three Different Periods

As indicated in the above table and figure, the daily discharges at Garissa RGS and Archers' Post RGS are less than 100 m^3/s and 10 m^3/s, respectively, for six months.

The annual discharges and their 10-year trend in the Ewaso Ng'iro North River at Archers' Post RGS were prepared based on the observed discharge and are described in the figure below. The large fluctuation of annual discharge is seen. The figure also indicates that the annual discharge has a decreasing trend for the past 30 years.



Source: JICA Study Team

Annual Discharge of Ewaso Ng'iro North at Archers Post

1.3.5 Flood Flows of Perennial Rivers

The annual maximum daily discharges recorded in the Nzoia River at Ruambwa RGS (1EF01), Nyando River at Nyando RGS (1GD03), Tana River at Garissa RGS (4G01), and Ewaso Ng'iro North River at Archers Post RGS (5ED01) are collected. Based on the recorded discharges, the most severe historical floods in terms of maximum discharge are shown in the table below.

Most Significant Flood Record

Catchment Area	River Name	Recorded Station		Description of Flood	
		Station Code	Catchment Area (km^2)	Date	Maximum Daily Discharge (m^3/s)
Lake Victoria North	Nzoia	1EF01	12,676	2006	928
	Yala	1FG02	2,864	1983	155
Lake Victoria South	Nyando	1GD03	2,625	1988	360
Tana	Tana	4G01	32,892	1961	3,568
Ewaso Ng'iro North	Ewaso Ng'iro	5ED01	15,300	1961	1,655

Note: When the observed daily discharges cover less than 80% of year, the annual maximum daily discharges for the period in that year is not included.

Source: MWI and WRMA

1.3.6 Water Quality

Laboratory equipment for testing water quality and field equipments were procured for the six regional offices and the 26 subregional offices, in order to improve the data on water quality. WRMA has established 51 water quality monitoring stations following the CMS of each catchment. WRMA is currently building a database on water quality that would support the classification of available water as well as, guide future water quality projections, trends and management of water resources in the catchment.

The progress in data the collection of water quality data was hampered by inadequate staff at the subregional level. Training on use of the water quality equipment was limited in the sub-regions because out of the 50 catchment management officers recruited at the sub-regional offices, only eight officers have background on water quality.

The assessment of water quality in six catchments is summarized in Table 1.3.3. Water quality in the catchments has deteriorated in the last 50 years after the introduction of agriculture and related industries.

1.3.7 Sediment Loads

Deforestation, poor land use practices, steep slope and river bank cultivation, all lead to erosion and loss of valuable soil cover, this in turn results in very high sediment loads in streams and rivers which is carried downstream and deposited in reservoirs, lakes, wetlands, and coastal areas. Sedimentation reduces the economic life of reservoirs. It also, reduces the hydraulic capacity of water conveyance facilities, disrupts water supply operations, and affects the ecological functioning of natural areas. The catchment area of the Upper Tana River basin, particularly the Aberdares, have undergone intensive environmental degradation due to the siltation of rivers, reservoirs and irrigation canals, which in turn results in flooding in the lower parts of the basin . Every year, the Tana River and the Sabaki River deposit several million tons of sediment. Sedimentation seriously degrades various coastal resources and reduces the life of reservoirs

Sediment loads are one of the key factors for the formulation of water resources development. In NWMP (1992), the suspended load and sediment deposit volume in the different reservoirs were estimated using limited monitoring data. NWMP (1992) estimated the denudation rate in the Upper Tana River at 350 m^3/km^2/year.

The sediment yield of the Ewaso Ng'iro North and Tana Rivers has increased by 15 times from the previous sediment level in 1970. A recent study on reservoir sedimentation by WRMA says that the sediment yields from the upstream catchment areas of Masinga and Kamburu reservoirs were estimated at 1,095 ton/km^2/year and 508 t/km^2/year, respectively. Assuming the specific gravity of sediment is at 2.65 ton/m^3, the sediment yield from the upstream catchment of Tana is approximately 200 – 400 m^3/km^2/year. This figure needs to be reviewed further, but the rate applied in NWMP (1992) seems to be reasonable.

The study by WRMA also gave estimates of the rates of reduction for the capacity of in Masinga and Kamburu are 3.5% and 5.4% per ten years, respectively.

1.3.8 Transboundary Waters

In Kenya, there are several transboundary waters such as rivers, lakes, and aquifers as shown in Figure 1.3.3. A transboundary water policy is under preparation by MWI, but it has not been finalized at the moment. Bilateral coordination is being made with the neighbouring countries as Uganda, Tanzania and Ethiopia toward the conclusion of memorandum of understanding or cooperative framework for sustainable management of water resources. Among these transboundary waters are the following:

a) Lake Victoria is the world’s second largest fresh water lake, it strides the borders of Kenya, Tanzania and Uganda with a catchment area which extends to the five East African countries. The Lake also forms part of the Nile River System.
b) Lake Turkana, which is the world’s second largest desert lake and whose catchment extends to Ethiopian highlands which Kenya shares with Ethiopia
c) River Daua which Kenya shares with Ethiopia and Somalia
d) Jipe Lake and Chala Lake; Rivers Lumi, Mara, Umba; and Kilimanjaro aquifer shared with Tanzania;
e) Rivers Sio, Lwakhakha, Suam, Malakisi and Malaba are shared with Uganda and,
f) The Merti Aquifer which traverses the Kenya-Somalia border.

CHAPTER 2 ANALYSIS ON CURRENT HYDROMETEOROLOGY

2.1 Temperature Analysis

2.1.1 Data Collection

There are 36 synoptic stations in Kenya which observe daily temperature. The daily temperature data of the 35 stations from 1979 to 2010 was provided to the JICA Study Team from KMD. The distribution and the stations and data availability are shown in the Figure 2.1.1. Data availability for each year is summarized in Table 2.1.1. As shown in the table and the figure, the distribution of the stations is very scattered and data availability is very low, especially at areas, in the half side of the north and east of the country.

2.1.2 Generation of Grid Temperature Data

Temperature is an important factor for this study since drought is a most serious issue that is related to water in Kenya. In order to understand the temperature of areas in the whole country for all duration, grid time series temperature data was created from the point temperature observation records (data at the meteorological stations).

Generally, the distribution of surface temperature has not so much changed in each but locality is dominated by the surface elevation. A temperature lapse rate of 0.6 °C per 100 m was applied. The procedure of the gridded temperature data generation is itemized as follows:

- Select the four nearest stations in the target grid point which has the valid data for the target date.
- Obtain the elevation of the target grid point from SRTM* 90 m DEM data, here Zgrid [El.m] is the elevation.
  *Shuttle Rader Topography Mission
- Correct the temperature of surrounding stations (Ti_observed) at the elevation of the target grid(Zgrid) based from the elevation of the station where it is locates(Zi) using formula the temperature lapse rate;
  $T_{i\_corrected} = T_{i\_observed} + 0.006(Z_i - Z_{grid})$
- The temperature of the target grid (Tgrid) is obtained by spacial interpolation method. Inverse distance weighted method was used; from the temperature data (Ti_corrected) of four stations with corrections based on the elevation of the target grid;

$$T_{grid} = \sum_{i=1}^{4} \frac{T_{i\_corrected}}{l_i} \Bigg/ \sum_{i=1}^{4} \frac{1}{l_i} \qquad \text{(eq. 2.1)}$$

  where, l_i: distance from the station *i* to the target grid.

- The procedures mentioned above were applied for all grids. The size of the grid is 0.1 degree (approximate 11.1 km) in both latitude and longitude, for 30 years from 1981 to 2010.

2.1.3 Temperature in the Kenya

(1) Annual Mean Temperature

The climatology of the annual mean temperature for the period from 1981 to 2010 was calculated for all grids. The distribution is shown in Figure 2.1.2.

The eastern side of the country is hot with an annual mean temperature of around 30°C. The high land area in the centre of the country, which around Mt. Kenya, is cool with an annual mean temperature of less than 10 °C. The western side of Mt. Kenya to Lake Victoria has moderate annual mean temperature from 15 °C to 20 °C. The distribution of temperature in the country does not vary all year around.

(2) Seasonal Temperature

The climatology of the mean temperatures of Kenya's four seasons, namely December – January – February (DJF), March – April – May (MAM), June – July – August (JJA) and September – October – November (SON), were calculated from 1981 to 2010. The charts are shown in Figure 2.1.3.

The climatology of monthly mean temperatures were also calculated for the same period and the charts are shown in Figure 2.1.4.

The distribution of temperature does not vary all year round. Area with cool temperature, which are indicated as green zone in the charts, are smallest in June and largest in February.

2.2 Rainfall Analysis

2.2.1 Data Collection

There were approximately 2000 rainfall stations in Kenya in 1977, of which, collected data from these stations are stored in KMD. The number of rainfall stations has drastically dropped to 1653 by 1988 and to 1497 by 1990. At present, there are only 700 operating rainfall stations left in Kenya.

Data availability from 1981 to 2010 and spatial distribution of the stations were considered for selection of the rainfall stations for this study. The number of stations density is very low in the northern and eastern areas of the country. On the other hand, there are a number of stations in the central and western areas. Therefore, all stations in the northern and eastern areas were selected, even the stations with poor data availability were selected in order to cover the whole nation. Meanwhile, the stations which have good data availability were selected from density area.

The daily rainfall data from 120 stations were obtained from stations KMD database. The distribution of rainfall stations and their data availability are shown in Figure 2.2.1 and Table 2.1.2.

Each rainfall gauging station has a seven digit registration code given by KMD. The first two digits indicate the north polar distance of the latitude circle forming the northern edge of the degree square in which the station is located. The subsequent two digits indicate the meridian of longitude forming the western edge of the degree square. The last three digits are set in ascending order corresponding to the established date of the station.

2.2.2 Generation of Grid Rainfall Data

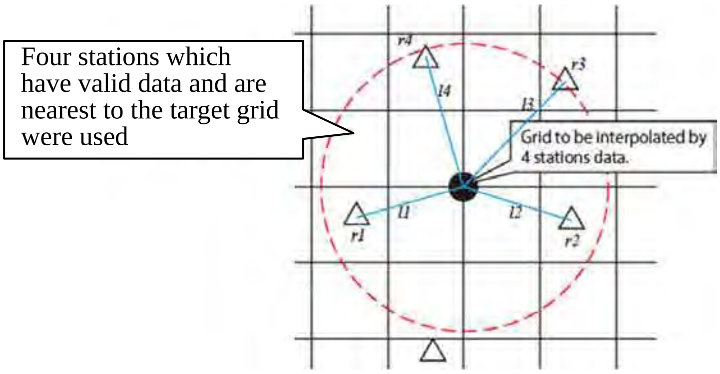
Grid rainfall data with 0.1 degrees in both latitude and longitude was generated from the point rainfall data (observed data at rainfall gauging station). Inverse distance weighted interpolation was applied where the weight factor of averaging is equal to the inverse of distance (linear). The rainfall data from the nearest four stations which have valid data for the target date were used for interpolation. The grid rainfall data was estimated by the equation below:

$$r = \sum_{i=1}^{4} \frac{r_i}{l_i} \Big/ \sum_{i=1}^{4} \frac{1}{l_i} \qquad \text{(eq. 2.2)}$$

where, r = grid rainfall (mm)

r_i= observed daily rainfall at rainfall station i (mm)

l_i= distance between rainfall station i and grid rainfall (km)



The reasons why the grid data is generated for this study are as follows:

- To fulfil the missing data.
- To produce data for areas with no rainfall stations
- To find out the unreliable stations. (fortunately, there are no stations which can be recognized as unreliable)
- To compare with general circulation models (GCMs) which are grid data.

Reliability of the observed data taken by each station was checked with the grid rainfall produced. Any unreliable data obtained were excluded.

2.2.3 Annual Rainfall

The climatology of annual rainfall for the period from 1981 to 2010 is illustrated in Figure 2.2.2. The rainfall of the arid area of the northern half of the country is less than 500 mm per year. The central area around Mt. Kenya, also called the water tower, has over 1,000 mm per year. The western area around Lake Victoria is a humid region. The annual rainfall is over 1,000 mm/year. The coastal area also has much rainfall.

2.2.4 Seasonal and Monthly Rainfall

The climatology of seasonal rainfall for the period from 1981 to 2010 is shown in Figure 2.2.3 and the monthly mean rainfall is shown in Figure 2.2.4.

In Kenya, there are two rainy seasons, namely the short rainy season in November and the long rainy season that usually lasts from the end of March to May. The dry season lasts from June to September.

In western Kenya, especially the Lake Victoria North and South regions, there is no distinctive dry season throughout the year. The maximum rainfall usually occurs in April and November. The double rainy seasons in April and November are well marked in the central Kenya, while the coastal area has a single rainy season in May.

2.2.5 Frequency Analysis

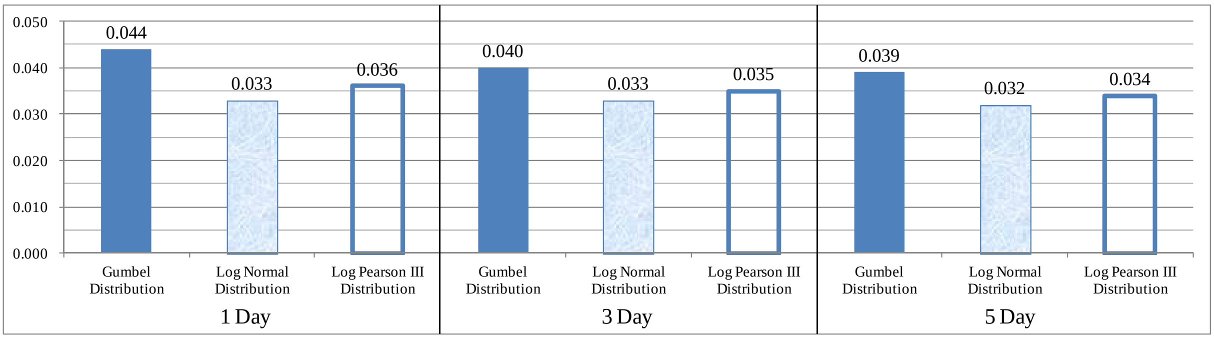
The three probability density functions (PDFs) listed below are often used in Kenya for rainfall frequency analysis:

- Gumbel Distribution (Double Exponential Distribution)
- Log Normal Distribution
- Log Pearson III Distribution

Since rainfall distribution varies by areas, the best fitted PDF also differs according to area. Although the best fitted PDF should be applied for frequency analysis, it is important to select the PDF that has consistency of results.

In order to choose the best fitted PDF, the frequency analysis by said three functions was carried out for one, three, and five-day rainfall of the whole of Kenya. Standard least-squares criterion (SLSC) was used to assess the fitness of the result. A smaller value of the SLSC means the better fitness of the sampled rainfall data. The estimation of the parameters of these three PFDs was computed for all grid data and, then the values were summarized by spatial average. As a result, among the three PDFs, the Log Normal Distribution was chosen.

The results of the comparison of the PDFs are shown below.



Source: JICA Study Team with original data provided by KMD

SLSC Value for Comparison of Appropriate Probable Density Function for Whole Kenya

Rainfall frequency analysis (RFA) was conducted for all grids with log-normal distribution. The result of RFA for the major rainfall stations are tabulated below. The results of RFA for the major stations with three PDFs were plotted on the Log Normal probability paper as shown in Figure 2.2.5. Log-normal distribution has the best fitted among three PDFs on most of the stations.

The distribution of the probable rainfall intensity estimated by log-normal distribution is shown in Figures 2.2.6-8. The highland area around Mt. Kenya and the coastal area are relatively higher than other areas.

Rainfall Frequency Analysis with Log Normal Distribution

(Unit: Daily Rainfall [mm/day])

p (Non-exceedance Probability)	0.5	0.8	0.9	0.95	0.98	0.99	0.995
T (Return Period [years])	2	5	10	20	50	100	200
Monbasa	84.0	119.6	146.6	174.9	214.9	247.5	282.3
Narok	43.6	56.3	64.6	72.4	82.4	89.9	97.4
Nyeri	44.8	60.0	70.9	82.0	97.2	109.2	121.7
Garissa	54.1	79.8	96.5	112.2	132.5	147.6	162.7
Kisumu	56.3	66.2	73.0	79.6	88.4	95.1	102.0
Kitale	43.2	51.1	55.4	59.1	63.4	66.3	69.1
Wajir	47.4	72.8	91.5	110.7	137.5	159.0	181.8
Marsabit	81.4	114.1	132.7	149.0	168.2	181.7	194.4
Lodwar	29.5	44.1	54.5	64.9	79.0	90.1	101.7
Moyale	57.9	81.7	98.5	115.4	138.4	156.4	175.1

Source: JICA Study Team with original data provided by KMD

2.2.6 Number of Rainy Days in a Year

The numbers of rainy days were counted for every grid. The days with rainfall of more than 1mm/day were counted as rainy days. The annual rainy days is shown in Figure 2.2.9.

The western area around Lake Victoria shows a high number of rainy days. The northern area has rainy days of less than 60 to 70 days in a year.

The seasonal climatology numbers of rainy days are shown in the Figure 2.2.10. According to the figure, the seasonal difference of the number of rainy days is recognized.

2.2.7 Annual Rainfall of Drought Year

The drought years with ten-year return period (1/10 drought year) were obtained using the following procedures:

- Compute spatial average of annual rainfall in Kenya for 20 years from 1981 to 2000.
- Sort the annual average rainfall in descending order.
- The second driest year is extracted as the 1/10 drought year.

The distribution of annual rainfall is shown in Figure 2.2.11. The seasonal drought rainfall is obtained by comparing the mean rainfall of each season. The distributions of the seasonal rainfall are shown in Figure 2.2.12. The extraction of the drought year is done by comparing the data for seasonal rainfall. Therefore, the selected year is different from other seasons as a result.

The distribution of rainfall in the drought year is obviously less than the climatology of annual rainfall. Especially, during the dry season (DJF), rainfall is mainly 1mm/day.

CHAPTER 3 TREND ANALYSIS OF METEOROLOGICAL DATA

3.1 Trend Analysis with Observed Data

The climate trend using actual observed data was carried out to understand how the climate has changed in Kenya for the past half century. The future climate change is however difficult to project from the past trend since it is known that the climate has been changing rapidly due to complex factors such as variations in solar radiation, deviations in the Earth's orbit, and amount of greenhouse gas emissions.

3.2 Available Data

(1) Temperature

1) Synoptic Stations

There are 36 ‘synoptic stations’ which observe several meteorological elements. For the trend analysis of temperature, 14 stations which had been established in the early 1900s were selected considering spatial distribution. The selected stations are listed in Table 3.2.1, and the locations of the selected stations are shown in Figure 3.2.1.

2) Data Collection

The daily maximum and minimum temperatures were collected from the KMD database. The availability of temperature data is shown in Figure 3.2.2. The availability was checked using daily mean temperature which was calculated by averaging the daily maximum and minimum temperature and daily minimum temperatures.

Temperature data is available for only 30 years at most of the stations. Considering the established year of the selected stations, more temperature data seems to be available from other sources, i.e. meteorological data book or database of Ministry of Water and Irrigation (MWI).

(2) Rainfall

1) Synoptic Stations

14 synoptic stations were selected for temperature trend analysis. The 14 stations were also used for rainfall trend analysis.

2) Supplemental Stations

Especially in rainfall analysis, station density is important. Around the Lake Victoria, a few stations are included in the 14 selected stations mentioned before. In NWMP (1992), the 22 stations established in the early 1900s were used for evaluation of long term variation of the annual rainfall depth. Therefore, three of the 22 stations were selected to supplement the spatial distribution. The 17 selected stations are listed in Table 3.2.2, and their locations are shown in Figure 3.2.1.

3) Data Collection

Daily rainfall data was collected from the database of KMD. Availability of rainfall data is shown in Figure 3.2.3. There are seven stations among the 17 selected stations with observation periods of more than 50 years. Considering the year of establishment of the selected stations, the more data seems to be available in other sources, i.e. meteorological data book or database of MWI.

3.3 Trend Analysis of Temperature

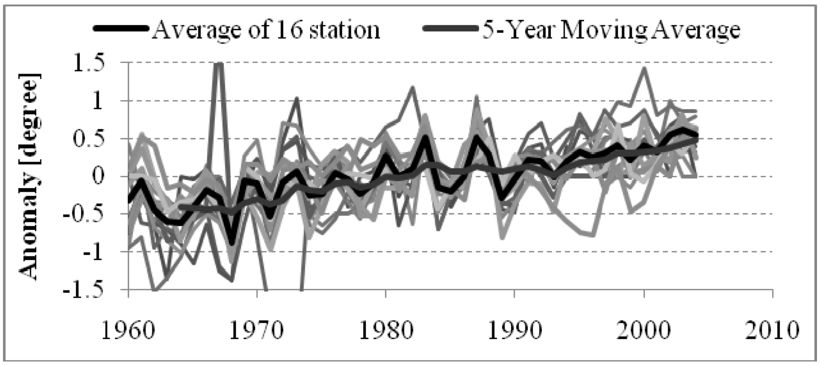
The monthly mean temperature was calculated by averaging the monthly mean maximum and minimum temperature. The annual mean temperature was generated from monthly mean temperature. The annual data with availability of lower than 80% were neglected.

For each item, a five-year moving average calculation and temperature trend analysis were carried out.

T-test was conducted to test the significance of the trend, with the level of significance at 5%. The test statistic *T* follows a *Student*-t distribution with *n-2* degrees of freedom under the null hypothesis.

Results of the trend analysis of temperature are shown in Figure 3.3.1. The increasing trend is seen in the whole country for annual temperature. The increase of annual mean temperature varies from 0.1 to 0.5 ^{o}C per two decades in the Southern Lowland and South Eastern Lowland. In other area, nearly 1.0 ^{o}C of two decades in North Western Kenya, Highland West of the Rift Valley and the Central Rift Valley.

Anomaly of annual the annual mean temperature increase per mean temperature is shown below. A linear increasing trend is seen for the recent 50 years.



Note: The baseline was set at the mean temperature of 1980.
Source: JICA Study Team

Anomaly of Annual Mean Temperature

3.4 Trend Analysis of Rainfall

Annual rainfall and seasonal rainfall were estimated as the total of the daily rainfall for taht specific periods. The numbers of rainy days were counted from the daily rainfall data. The annual maximum daily rainfall was extracted as the maximum value of the daily rainfall. For seasonal rainfall, the following four seasons were taken into account.

Seasonality of Rainfall

Season	Abbreviation	Characteristics
December – February	DJF	Dry season
March – May	MAM	Rain season, called as Long Rain
June – August	JJA	Dry season
September – November	SON	Rain season, called as Short Rain

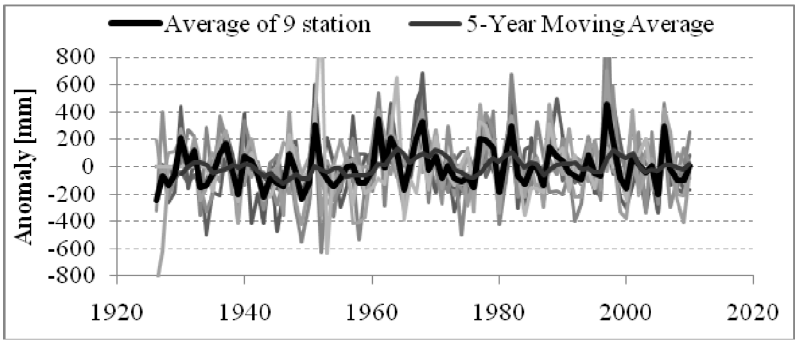
Source: KMD

The five-year moving average rainfall was used for the trend analysis of annual, seasonal rainfall and number of rainy days.

The drought year annual rainfall for the 10-year return period was calculated as the second sample from the bottom of 20 samples. The probable daily rainfall for the 10-year return period was also calculated through frequency analysis using log-normal distribution using 20 samples of the annual maximum daily rainfall.

Anomaly of annual rainfall from the mean annual rainfall is shown below. A decadal cycle is seen on a five-year moving average. The amounts of rainfall in the 1920s, 1930s, 1960s, 1980s and around 2000 are relatively large. On the other hand, the amounts of rainfall in the 1940s, 1950s, 1970s, 1990s and recent several years are relatively small.

No remarkable rainfall trend was seen in contrast to the temperature trend. This is because the anomaly of rainfall is larger than the anomaly of temperature. The differences of rainfall characteristics between each station are also larger than temperature characteristics.



Source: JICA Study Team

Anomaly of Annual Rainfall

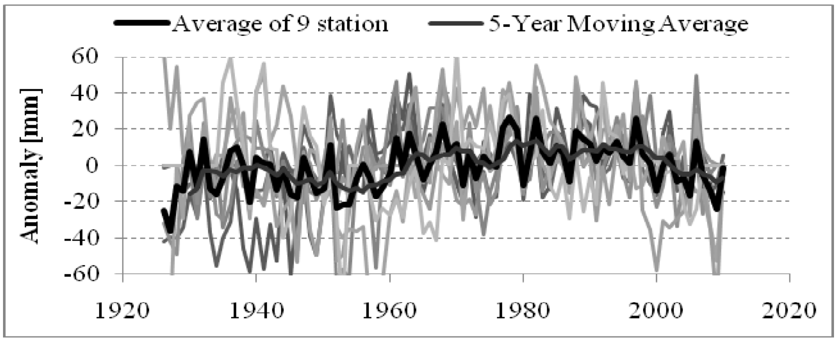
To understand the regional characteristics, the analysis was carried out for each climate zone. The results of the trend analysis of rainfall are shown in Figure 3.3.2 and summarized below.

Summary of Rainfall Trend

Analysis Item	Result	Remark
Annual Rainfall	Increase trend in the whole country	Significant decrease trend at Marsabit
DJF Rainfall (Dry Season)	Increase trend in the whole country	Significant decrease trend at Moyale
MAM Rainfall (Long Rain Season)	Decrease trend in the whole country	Significant increase trend at Lodwar
JJA Rainfall (Dry Season)	Decrease trend in the whole country	Significant increase trend at Makindu
SON Rainfall (Short Rain Season)	Increase trend in the whole country	Significant decrease trend at Marsabit
Number of Rainy Days	Increase trend in the whole country	

Source: JICA Study Team

The anomaly of the annual number of rainy days from the mean annual number of rainy days is shown below. A cycle of about the hundred years is seen for the number of rainfall days. The number of rainy days has been decreasing from around 1980 to the present years following the cycle.



Source: JICA Study Team

Anomaly of Number of Rainy Days

CHAPTER 4 CLIMATE CHANGE ANALYSIS

4.1 Approach to the Analysis

Weather is varied widely every day, every month and every year. Climate is the long-term, average behaviour of weather for a particular region, which is usually considered to be stable. Based on the concept that the climate is stable, hydrological studies have been conducted, and planned values, such as rainfall intensity, have been established through statistical study from observed past records.

Climate is changing naturally. The rate of change has accelerated significantly due to human activities. The target year of this master plan is 2030. Though it is only for a period of 20 years, it may be difficult to consider that future climate conditions will be the same as current conditions. In order to understand the future hydrological condition for development of the master plan, climate change may not be neglected. The impact of climate change on Kenya was evaluated in this study.

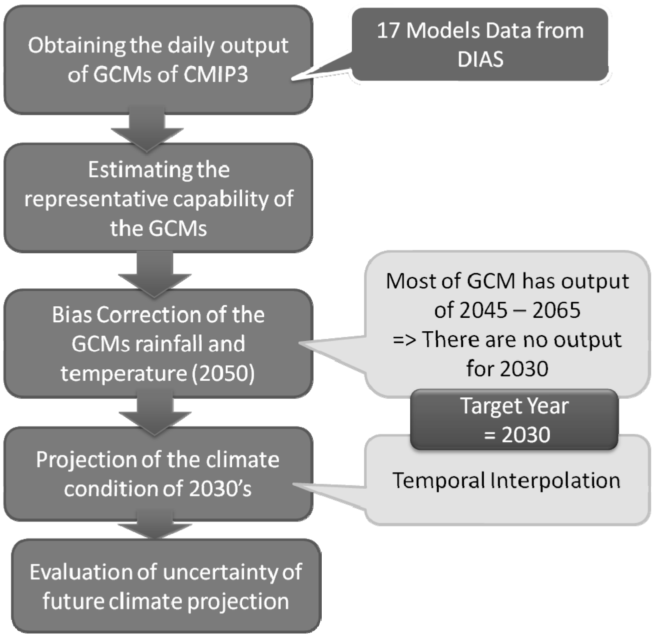
A general circulation model (GCM) is the most hopeful and advanced tool to understand the climate and to project future climate conditions. Many GCMs have been developed in various countries. It was first introduced in the country dudring the Fourth Assessment Report (AR4) conducted by the Intergovernmental Panel on Climate Change (IPCC). Most of those data are archived in the Phase 3 of the Coupled Model Intercomparison Project (CMIP3). In this study, climate change in Kenya was studied using the results of the GCMs.

Although the GCMs are accepted widely as the best physically based tool for devising climate scenarios, there is a considerable gap between local climate conditions and simulation results. These gaps are called bias. In order to apply the GCMs results to the catchment scale, bias corrections were made based on the methodology propounded by Professor Koike of the University of Tokyo.

There are 17 GCMs that are available in the daily data sets. The daily data sets of GCMs are archived in the Data Integration and Analysis System (DIAS) Japan as well as CMIP3. The daily data sets were provided to JICA from DIAS as a part of the cooperation between the University of Tokyo's Earth Observation Data Integration and Fusion Research Initiative (EDITORIA) and JICA.

Every GCM has a future scenario which is different from other GCMs. Even GCMs, equipped with state-of-the-arts of technology, can not project an assured future climate. This uncertainty of the future climate should be evaluated quantitatively. Multi model ensemble analysis was carried out to evaluate the uncertainty of future climate. Such uncertainty should be taken into account in developing NWMP 2030.

The flowchart of climate change analysis is shown below.



Source: JICA Study Team

Work Flowchart of Climate Change Analysis

4.2 Scenario of Greenhouse Effect Gas Emission

In order to study the impact of climate change in the future, the concentrations of greenhouse gases and other pollutants in the atmosphere should be given as boundary conditions for numerical simulation models, to which climate is sensitive.

The Special Report on Emission Scenarios (SRES), published by the IPCC in 2000, describes the emissions scenarios that have been used to make projections of possible future climate change, for the IPCC Third Assessment Report (TAR) and in the IPCC Fourth Assessment Report (AR4). Emission scenarios describe future releases of greenhouse gases, aerosols, and the other pollutants into the atmosphere along with information on land use and land cover. A set of four scenario families (A1, A2, B1, and B2) have been developed. Each scenario describes one possible demographic, political-economic, societal and technological future. The SRES scenario families are described in the table below.

SRES Emission Scenarios (1/2)

Scenario family	SRES Emission Scenarios	CO_2 Stabilization
A1	A future world of very rapid economic growth, global population that peaks in the mid-century and declines thereafter. Rapid introduction of new and more efficient technologies. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. -A1F1: fossil-intensive -A1T: non-fossil energy sources -A1B: balance across all sources	A1F1: Not stabilise A1T:650 ppm A1B:750 ppm
A2	A very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other scenario families.	Not stabilise

Source: Task Group on Data and Scenario Support for Impact and Climate Assessment (TGICA), IPCC

SRES Emission Scenarios (2/2)

Scenario family	SRES Emission Scenarios	CO_2 Stabilization
B1	A convergent world with the same global population as in the A1 storyline but with rapid changes in the economic structure toward a service and information economy, with reductions in materials intensity, and the introduction of clean and resource-efficient technologies.	550 ppm
B2	A world in which the emphasis is on local solutions to economic, social, and environmental sustainability, with continuously increasing population (lower than A2) and intermediate economic development.	650 ppm

Source: Task Group on Data and Scenario Support for Impact and Climate Assessment (TGICA), IPCC

Scenario A1B was selected for this study because it is physically plausible and consistent, with a realistic and the potential range on future regional climate change. In addition, there are a sufficient number of variables on a spatial and temporal scale which allows for impact assessment.

4.3 General Circulation Models

4.3.1 What is a GCM

GCMs are a significant achievement of man toward the assessment of climate change. GCMs representing physical processes in the atmosphere, ocean, cryosphere and land surface are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations. Various GCMs are under development by researchers around the world and the capability of such models is under improvement.

Using GCMs, climatology can be simulated for seasonal and monthly means, but it can not be expected to simulate the actual weather observed at individual locations at specific times or the actual seasonal means for a particular region and, for a particular year.

4.3.2 Available Data Set of GCMs

(1) CMIP3 Multi-Model Dataset

In response to the proposed activity of the World Climate Research Programme (WCRP) Working Group on Coupled Modelling (WGCM), the Program for Climate Model Diagnosis and Intercomparison (PCMDI) volunteered to collect model outputs contributed by leading modelling centres around the world. The climate model output from simulations of the past, present and future climate was collected by PCMDI mostly in 2005 and 2006. This archived data constitutes CMIP3.

The WCRP CMIP3 multi-model dataset now consists of 18 modelling groups from 12 countries which participated with 25 models.

The GCMs and their development institutions are listed in Table 4.3.1.

(2) Acknowledgement

This study on the estimation of climate change is based on the output of the GCMs of CMIP3. The provision of the GCM data to the JICA Study Team was made through the Data Integration and Analysis System (DIAS) under the cooperation of the University of Tokyo Earth Observation and Fusion Research Initiative (EDITORIA) and JICA. The JICA Study Team analysed on the study of the selection of GCMs and the bias correction based on the methodology propounded by Professor

Koike of the University of Tokyo who is the leading academic for the study in the field of climate change adaptation and promoting the project of DIAS.

The JICA Study Team also acknowledges the modelling groups, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the WCRP's Working Group on Coupled Modelling (WGCM) for their roles to make the WCRP CMIP3 multi-model dataset available. Support of this dataset was provided by the Office of Science of the U.S. Department of Energy.

4.4 Selection of General Circulation Models

4.4.1 General

The results of the GCMs have very large diversity, and the diversity can be translated into the uncertainty of the projection of future climate. However, the models with significantly low reproducibility of the current climate conditions should not be considered deselected from the consideration. The reproducibility of GCMs was evaluated by comparing of the climatology of observed climate data and the simulation result of run for the reproduction of the current climate conditions. These simulation cases are called “20c3m” scenario. The observed and the simulated climatology cover the period from 1981 to 2000.

The evaluation of the reproducibility of the GCMs is based on the methodology propounded by Professor Koike of the University of Tokyo.

4.4.2 Methodology of the Selection

The reproducibility of the GCMs was evaluated through the following procedures.

1) The gridded observed data for four variables of climate were obtained from the web site of the National Oceanic and Atmospheric Administration (NOAA). The gridded data were produced based on the observed data and mathematical atmospheric simulation model. The data is called “reanalysis data”. Four variables were chosen as they are considered main climate elements to represent the regional climate conditions. The collected reanalysis data are listed in the table below.

Collected Reanalysis Data

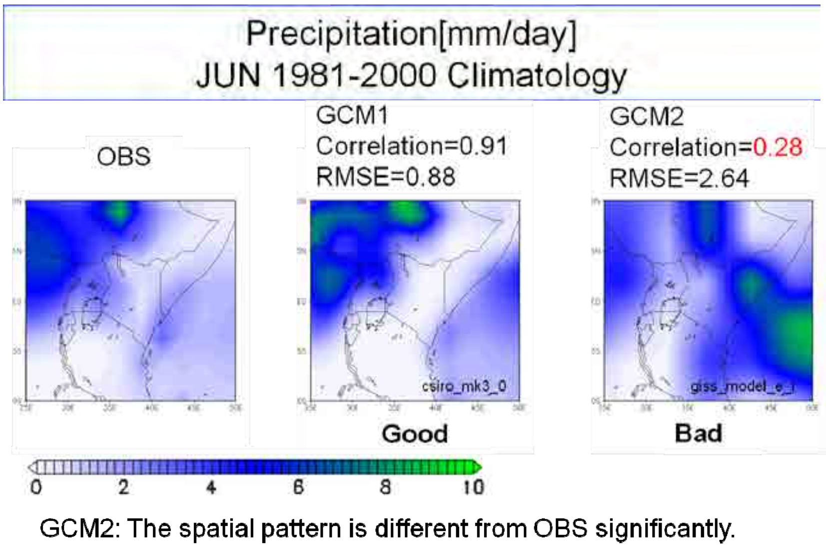
Variable	Standard Name	Notes
pr	Precipitation	Global Precipitation Climatology Project (GPCP) Version 2.2 Climatology Precipitation Acknowledgement: The GPCP combined precipitation data were developed and computed; the NASA/Goddard Space Flight Center's Laboratory for Atmospheres as a contribution to the GEWEX Global Precipitation Climatology Project. from their Web site at http://www.ncdc.noaa.gov/oa/
olr	Outgoing Longwave Radiation (OLR)	20 years(1981-2000) Climatology of OLR from interpolated OLR dataset Created from monthly means of OLR from National Oceanic Atmospheric Administration (NOAA) Acknowledgement: Interpolated OLR data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/
slp	Sea Level Pressure	20 years(1981-2000) Climatology of Sea Level Pressure Created from National Centers for Environmental Prediction (NCEP) Reanalysis monthly Sea Level Pressure Acknowledgement: NCEP Reanalysis Derived data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/
tas	Surface Air Temperature	20 years(1981-2000) Climatology of air temperature Created from NCEP Reanalysis monthly air temperature Acknowledgement: NCEP Reanalysis Derived data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/

Source: JICA Study Team

2) The climatology of monthly mean values of the gridded observed data from 1981 to 2000 were calculated.
3) There are 17 GCMs taht were selected as the daily monthly data are available in the CMIP3 and DIAS, though there are 25 models. The monthly data of the 20c3m experiments of the period from 1981 to 2000 were obtained. The data availability of the GCMs is summarized in Table 4.4.1. There are 17 models collected for this study which are numbered in the table.
4) The climatology of the monthly mean values of the GCMs were calculated for all variables.
5) The correlation factor and root mean square error (RMSE) were applied for comparison.
6) Both the observed data and GCM data are re-gridded into 0.1 degree grid sizes in both latitude and longitude. In order to evaluate in a large scale, the range from 10 º South to 10 º North and from 25 º East to 50 º East were considered.
7) The indexes for comparison were calculated for every grid. Finally, the real average of every index was evaluated.

4.4.3 Selection of GCMs

A comparison of monthly mean climatology between the observed data and GCMs data were made. An example of the results of comparison is shown below.

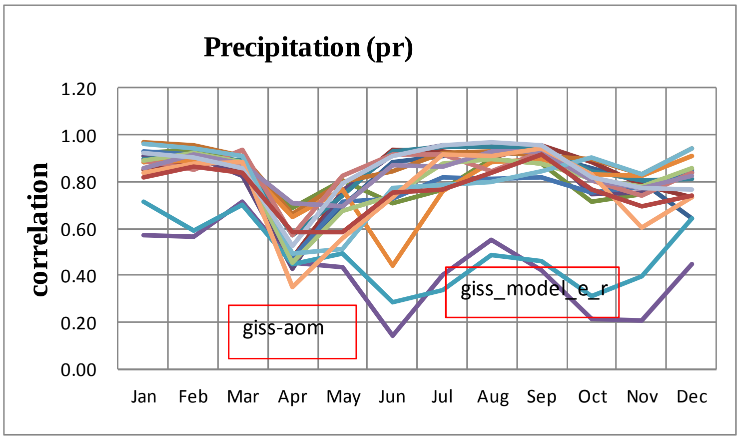


Source: JICA Study Team with following original data
The GPCP Version 2.2 combined precipitation data, the DIAS dataset, and the CMIP3 multi-model dataset.

Comparison of Monthly Mean Precipitation

The left chart shows the observed precipitation climatology. The middle and right charts show the climatology of GCMs data. The distribution of the rainfall intensity in the middle chart is similar to the observed data. Meanwhile, the distribution pattern and rainfall intensity in the right side model are significantly different from the observed data. The correlation factor and RMSE for each model are indicated in the above chart. The correlation factor of the middle model is 0.88, which is it is close to 1.0. It means the climatology of the GCM in the middle chart is similar to the observed one. Therefore, it can be considered that the indexes of correlation factor and RMSE are applicable for evaluation of the reproducibility of the model.

Four variables for all 17 GCMs for 12 months were evaluated in the same manner. All evaluated indexes were summarized in the form of the chart shown below.



Source: JICA Study Team with following original data
The GPCP Version 2.2 combined precipitation data, the DIAS dataset, and the CMIP3 multi-model dataset.

Evaluation of the Reproducibility of the GCMs

According to the chart above, most of the lines show almost the same capability except for two models, giss_model_e_r and giss_aom. The lines of these two models are different from the others. These models are excluded for the further study, because these two models show poor reproducibility of current climatology of Kenya. The evaluated values of correlation factor and RMSE were shown in the Figure 4.4.1 and the names of the models were shown in the charts which are excluded for the further study because of their poor reproducibility. The evaluated values of correlation factor and RMSE are tabulated from Table 4.4.2 to 4.4.9.

Table 4.4.10 summarises the result of selection of GCMs mentioned above. Six GCMs were excluded. The selected 11 GCMs are; Cccma_cgcm3_1, cccma_cgcm3_1_t63, cnrm_cm3, csiro_mk3_0, gfdl_cm2_0, gfdl_cm2_1, ipsl_cm4, miroc3_2_hires, miroc3_2_medres, mpi_echam5 and mri_cgcm2_3_2a.

4.5 Bias Correction

4.5.1 Necessity of Bias Correction

GCMs are effective tools to project future climate conditions. However, GCMs have a bias in simulating 20th century precipitation and temperature. Therefore, GCMs cannot be used directly on hydrological models in order to assess the impact of the projected climate change for the particular basin. This is the reason why bias correction is necessary.

The well-known problems of the GCMs are as follows:

a) Large diversity of the models
b) Low seasonal representation
c) Low extreme heavy rainfall rate
d) Small number of no rainfall day but long drizzle

In order to solve the problems above, statistical bias correction was conducted.

4.5.2 Methodology of Bias Correction

(1) General

Bias is a gap between the observed data and the output of the GCMs for a certain meteorological index such as annual mean rainfall, monthly mean rainfall, rainfall frequency, etc. Although the output of GCMs have dates as if it is along with the actual calendar, the daily rainfall it cannot be compared with the actual record of the same date. For instance in January 1, 1990 GCM output cannot be compared with the actual January 1, 1990 recorded, because the simulation of 20c3m are implemented by giving only the boundary conditions which is not an actual observed data. Therefore, bias correction is made to adjust the simulated climatology to the observed climatology.

For the output of the future A1B simulation, the relationship of the gap correction obtained from the current climate is supposed to be applicable. The difference of A1B and 20c3m is also applied to the projection of the future climate.

The methodology for bias correction that is applied in this study is based on the idea advocated by Professor Koike of University of Tokyo.

(2) Points of View for Bias Correction

Bias correction of rainfall is carried out through the following process.

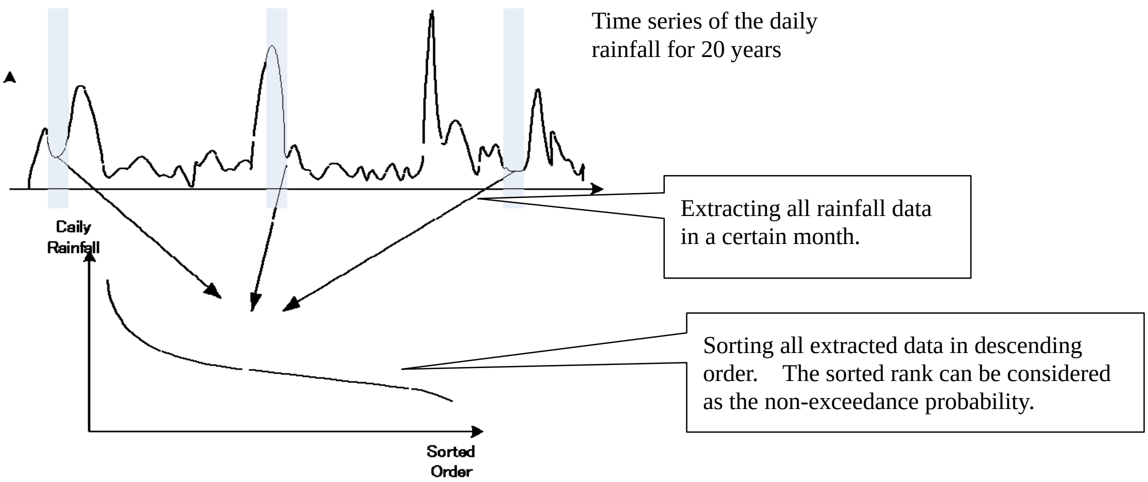
a) Correction to monthly climatology
b) Correction of no rainfall days
c) Correction of high intensity rainfall

The bias correction corresponds with the problems of the GCMs mentioned above.

(3) Correction to Monthly Climatology

The cumulative distribution function based bias correction method (CDF method) was applied to match the rainfall climatology of 20c3m with the observed. Then the relationship of the bias and the 20c3m data is applied to the A1B data. The CDF method is called as sorting method. The procedure for bias correction is as follows;

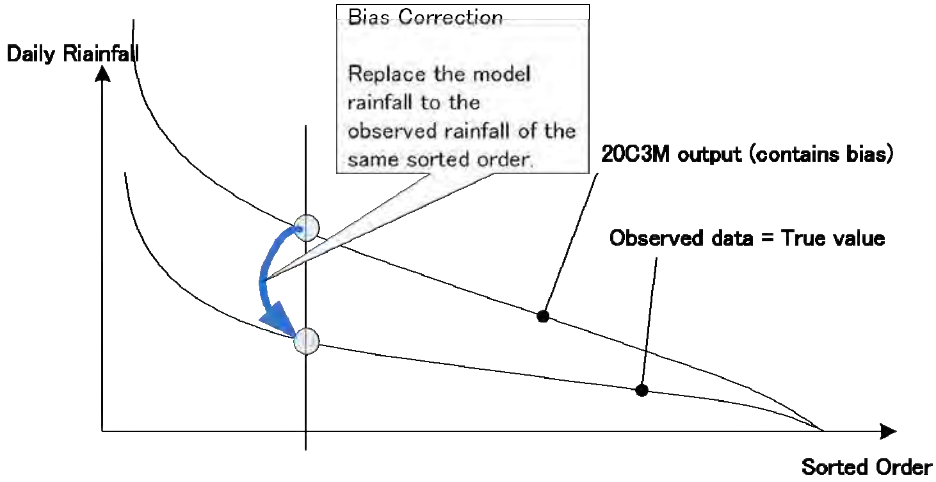
i) The GCMs grid data were re-gridded into the same grid dimension with the gridded observed rainfall data, provided in this study. The grid size is 0.1 degree in both of latitude and longitude directions.
ii) The monthly mean rainfall of the observed and 20c3m are computed for the period from 1981 to 2000.
iii) All daily rainfall data of a certain month are extracted and sorted in descending order. For example, the daily rainfall in April for 20 years is counted as 600. The figure below shows a schematic image of this extraction and sorting work.



Source: JICA Study Team

Schematic Image of Extraction and Sorting for Daily Rainfall of a Certain Month

iv) For a certain rank of rainfall of 20c3m, the bias is considered as the gap between 20c3m and the observed data with the same rank.
v) Rainfall with a certain rank of 20c3m was replaced by that with the same rank of the observed data. Therefore, the bias-corrected climatology of the monthly mean rainfall of 20c3m is to be completely matched with the observed. This procedure is illustrated in the figure below.

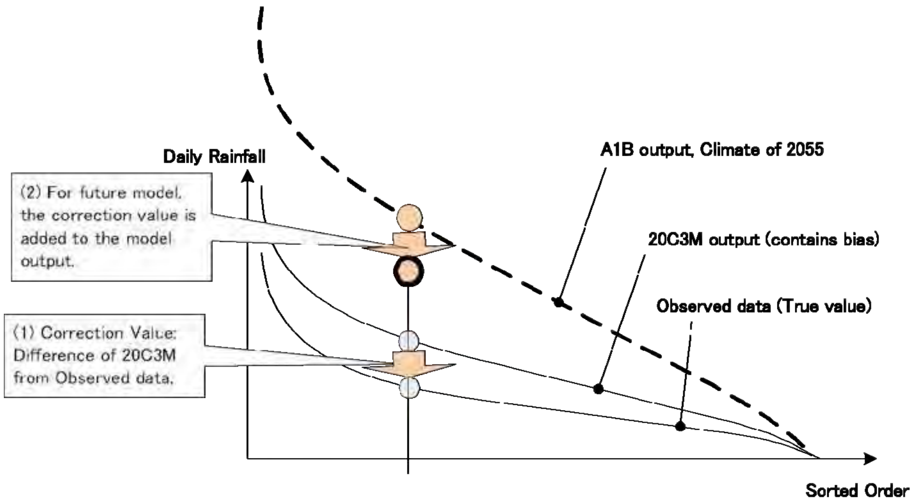


Source: JICA Study Team

Schematic Image of Bias Correction Based on Sorted Rank

vi) The daily rainfall of the A1B for 20 years from 2046 to 2065 was processed in the same manner with the observed data and 20c3m.

vii) To correct the bias of the rainfall of a certain rank, the gap between the 20c3m and the observed data of the same rank is added. The procedure is illustrated in the figure below.



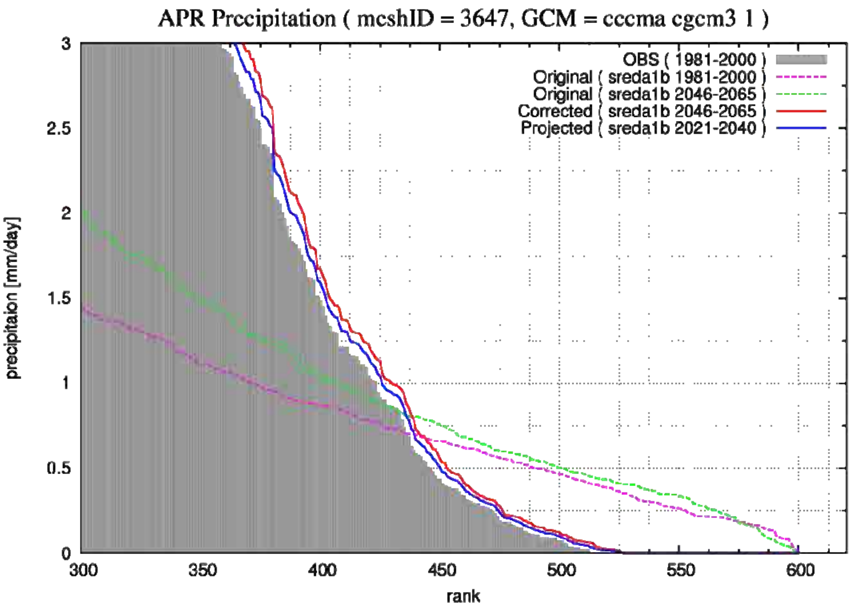
Source: JICA Study Team

Schematic Image of Bias Correction for Output of A1B (2046-2065)

Bias correction for temperature was carried out in the same manner mentioned above. Since the temperature does not have eccentric behaviour temporally, the bias correction procedure is appropriate to match the climatology of temperature.

(4) Correction of No Rainfall Days

The number of no rainfall days of GCMs is less than that of the observed data. The comparison of the observed and the output of GCM are shown below.



Source: JICA Study Team with following original data

Kenya Meteorological Department, the DIAS dataset, and the CMIP3 multi-model dataset.

Tail Part of Sorted Daily Rainfall Data and Bias of No Rainfall Days

The considered duration is 20 years and rainfall for April was extracted and sorted. The rainfall data sets of 600 days were obtained for the observed (gray bar) and simulated. The chart above shows the tail part of the sorted rainfall. The gray coloured area indicates the observed rainfall. This chart is for April having heavy rainfall season in Kenya. Therefore, there are rainfalls around the rank of 500. However, the doted curve, which is sorted for raw rainfall data in the GCMs, indicate that there are rainfalls up to the end of the data. This is a bias of no rainfall days.

The bias correction procedure for no rainfall days is as follows:

i) The rainfall value of 20c3m of the last observed rainfall is made the threshold of no rainfall day.
ii) The rainfall for the A1B scenario that is less than the threshold is corrected as zero.

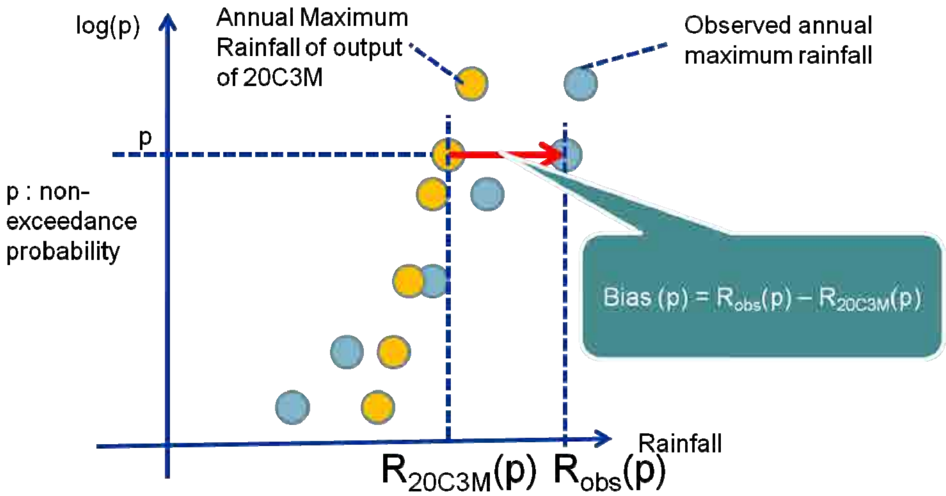
(5) Correction of High Intensity Rainfall

The GCM rainfall of the GCM has low inflection intensity, but problems can be corrected by using the sorting method mentioned above. If there is a heavy rainfall out-of-the season as simulated in the GCM, the result will be rejected because the observed climatology of the month does not have such heavy rainfall. This is the reason why bias correction for high intensity rainfall is necessary.

To cope with the problems of GCMs, plotting position method was applied. The procedure of the method is as follows:

i) The annual maximum daily rainfalls are extracted from the observed and 20c3m data on a certain grid.
ii) Cunnan plot is applied to estimate the non-exceedance probability of the extracted rainfalls.

iii) Bias is considered as the gap between rainfall intensity of the observed and 20c3m with the same probability. The schematic image of the bias of the high intensity rainfall is illustrated below.

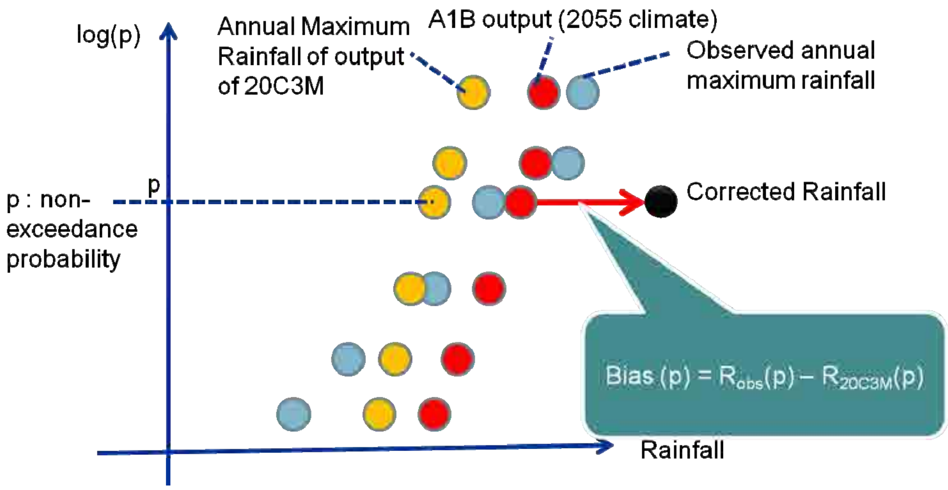


Source: JICA Study Team

Schematic Image of Bias of High Intensity Rainfall

iv) The annual maximum rainfall of A1B (2046-2065) is extracted, and the lowest rainfall is employed as a threshold for this bias correction.

v) The rainfall of A1B larger than the threshold is corrected by adding the gap between observed and 20c3m with the same probability. The bias correction procedure for the A1B data is shown below.



Source: JICA Study Team

Bias Correction for A1B (2046-2065) Rainfall

(6) Result of Bias Correction for A1B 2046-2065

The bias correction for the daily rainfall and daily temperature for the 11 selected GCMs outputs for A1B scenario were carried out. The bias corrected data is a projection of the 2055 climate with a climate period from 2046 to 2065. These results were compared with the observed climate and the projected 2030 climate. The evaluation of the 2055 climate is mentioned in Section 4.8.

4.6 Projection of 2030 Climate

4.6.1 Data Availability Representing 2030 Climate

The target year of this NWMP is 2030. The rainfall and temperature data for the period from 2021 to 2040 are needed for the assessment of the impacts of climate change on Kenya. Actually, the simulations of every GCM for the period around 2030 have been implemented, but the daily output was abolished or could not be obtained due to the huge size of the data. The 2030 climate was projected from the observed climate (1990) and bias-corrected A1B 2055 climate.

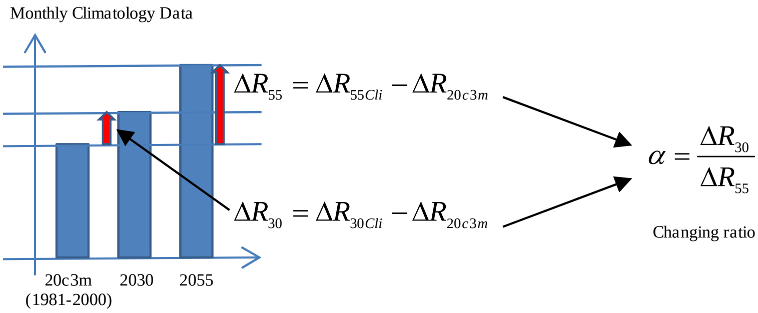
4.6.2 Methodology of the Projection of 2030 Climate

The methodology of the projection is based on simple temporal interpolation. The monthly mean rainfall and temperature data of GCMs can be obtained from the web site of the IPCC Data Distribution Center (http://www.ipcc-data.org). The projection of 2030 climate was made using the following procedures:

i) The monthly mean climatology of the considered GCMs was computed for the 2030 climate, which has uncorrected bias.

ii) The monthly climatology of 20c3m and A1B 2046-2065 is calculated in the same manner with the 2030 data for GCMs.

iii) The changing ratios of the climatology for every month were evaluated. The changing ratio is evaluated as the ratio of the difference from the 20c3m results between the 2055 climate and the 2030 climate from the 20c3m. The schematic image of this procedure is shown in the figure below.



Source: JICA Study Team

Schematic Image of Projection of 2030 Climate (1)

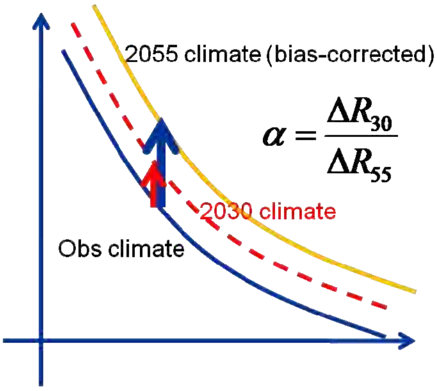
i) The time-series of the observed grid data is a base time-series for the projection of the rainfall and temperature of the 2030 climate.

ii) Preliminary data for, a certain month of the observed and bias-corrected A1B 2055 data are extracted and sorted.

iii) Rainfall or temperature of the 2030 climate can be projected by applying the changing ratio to the difference between values of the bias-corrected 2055 climate and the observed with the same rank.

iv) The evaluated rainfall or temperature for the 2030 climate is re-sorted along with occurrences of the observed data. The projected time-series of every GCM are based on the same time-series data.

The schematic image of the projection of the 2030 climate is shown below.



Source: JICA Study Team

Schematic Image of Projection of 2030 Climate (2)

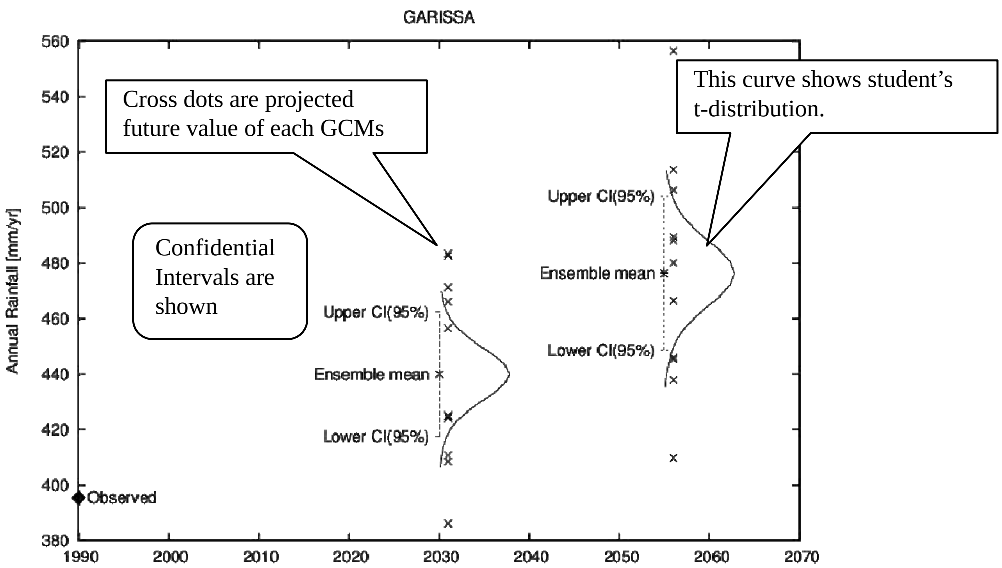
4.7 Evaluation of Uncertainty of Projected Future Climate

The projected daily rainfall and temperature data of 11 GCMs for the 2030 climate and the 2055 climate are obtained from the foregoing processes. One of the problems of GCMs is that the output from each model widely differ among each other. The diversity will be a natural behaviour. It is important for assessment of future climates to consider the uncertainty of the phenomena.

The simplest summarising method of the diversified future is by the use of ensemble mean. Mean values from future projections can be considered as the most expected future.

There are 11 climate data each for the 2030 and 2055 climates. The number of models is not enough to suppose that the data are distributed on normal distribution. Therefore, the student's t-distribution was applied for the evaluation of uncertainty. From the evaluation by the t-distribution, the standard deviation and the confidential interval can be obtained for every index.

The example of the evaluation chart of the uncertainty is shown in the figure below.



Source: JICA Study Team

Evaluation Chart of Uncertainty of Future

This is a result of the annual rainfall climatology at Garissa. The year is plotted on the x-axis and the indexed value (annual rainfall) is plotted on the y-axis. The cross dots on the 2030 and 2055 years are the projected GCM values. The distribution of the probability of the mean value is shown as a curve on the 2030 and 2055 year. From the distribution curve, the range of the uncertainty can be acquired using cognizance. The area of the distribution is the probability. The curve is located above the value of the observed. This means that annual rainfall at Garissa will surely increase.

4.8 Evaluation of Projected Future Climate in Kenya

4.8.1 Annual Precipitation

Figure 4.8.1 shows that the annual rainfall will increase over the country. The distribution of the rainfall will not be changed so much. The annual mean precipitation area of the highland area, which is located on the western south part of the country, will increase from 50 to 100 mm/year in the 2030 climate projection, however, it should be noted that the standard deviation of this area is larger than in the other areas. The probability of increase will be sure for the whole country.

4.8.2 Seasonal Precipitation

1) MAM (March – April – May)

MAM is the heavy rainy season in Kenya. Future rainfall of the highland area will increase, but the rainfall at coastal areas will be unchanged or decreased. The result of the ensemble analysis is shown in the Figure 4.8.2.

2) JJA (June – July – August)

JJA is the long dry season in Kenya. The result of the ensemble analysis is shown in Figure 4.8.3. Future seasonal rainfall of JJA will be almost unchanged over the country. The rainfall of coastal area will decrease.

3) SON (September – October – November)

SON is the short rainy season in Kenya. The result of the ensemble analysis for future seasonal rainfall is shown in Figure 4.8.4. Future rainfall for half of the western area including the upper Rift Valley area, which has a semi-arid climate, will increase. The southern area including the coastal area will be unchanged. The increase of rainfall is probable over the country.

4) DJF (December – January – February)

DJF is the short dry season in Kenya. The result of the ensemble analysis for future seasonal rainfall is shown in Figure 4.8.5. Future seasonal rainfall will increase over the country, especially the rainfall of the half of the southern area including the coast area which willm increase significantly.

4.8.3 Rainfall Frequency

The ensemble analyses for the rainfall frequencies of 10, 50 and 100 years return periods were carried out. The results of rainfall frequency analysis are shown in Figures 4.8.6 to the Figure 4.8.8. The projection for the extreme event rainfall is very difficult. It is important to note that the result is dominated by the methodology. The distributions of rainfall intensity for the future climates in 2030 and 2055 are very similar to that of the current climate. The difference in rainfall intensity for 50-year return period of the future from that of the current is varied by about 50 mm/day less to 50 mm/day more against the current values.

4.8.4 Number of Annual Rainy Days

The days with rainfall larger than 1 mm/day are counted as rainy days. The result of the ensemble analysis over the whole country is shown in Figure 4.8.9. The number of rainy days will increase over the country, especially in the northern area where it will increase significantly. The increase may be almost probable over the country.

4.8.5 Number of Seasonal Wet Days

The results of ensemble analysis for each seasons are shown in Figures 4.8.10 to the Figure 4.8.13.

1) MAM (March – April – May)

The numbers of rainy days will increase or be unchanged. The north Rift Valley area may have significant increase.

2) JJA (June – July – August)

The number of rainy days will increase for most of the country; however, for the coastal area will have slightly decrease in the 2055 climate.

3) SON (September – October – November)

The increase in the number of rainy days in the northern Rift Valley in the 2030 climate and of the southern Rift Valley in the 2055 climate is remarkable.

4) DJF (December – January – February)

Lake Victoria area in the 2030 climate has a high number of rainy days.

4.8.6 Annual Rainfall for the Drought Year in 10-Year Return Period

The evaluation periods for the observed, 2030 and 2055 climate are 20 years. The drought year in the 10-year return period can be obtained as the second driest year of the annual rainfall. This evaluation was done for every grid. The selected year for a certain grid is different from those of the other grids. The evaluated ensemble annual rainfall of the drought year for each grid is shown in Figure 4.8.14.

The rainfall during the drought year will increase in most areas of the country. However, a significant decrease in rainfall for the 2055 climate may happen in coastal areas.

4.8.7 Seasonal Rainfall for the Drought Year in the 10-Year Return Period

The charts of the essential ensemble seasonal rainfall folr the drought year in each grid are shown in Figure 4.8.15 to Figure 4.8.18.

1) MAM (March – April – May)

The rainfall of the 2030 climate will be unchanged from that of the current condition. However, in the 2055 climate, the eastern side of the country may have a remarkable decrease of rainfall.

2) JJA (June – July – August)

The rainfall of the 2030 climate is almost the same with the current climate. However, rainfall may decrease significantly around the Lake Victoria area and the coastal area in the 2055 climate.

3) SON (September – October – November)

The rainfall of the drought year will be unchanged in the 2030 climate. In Kenya’s central of the country in the high land area, the rainfall may decrease in the 2055 climate. There are several dams in the area; therefore the assessment of the impact of the drought in the future climate is important for developing NWMP 2030.

4) DJF (December – January – February)

The distribution of the rainfall in drought year in the 2030 climate will be almost same as the current climate. The rainfall of the high land area may increase in the 2055 climate.

4.8.8 Annual Mean Temperature

The increase in surface temperature seems to be unavoidable in Kenya. The result of the ensemble of the surface temperature is shown in the Figure 4.8.19. In the 2030 climate, the surface temperature will increase by around 1ºC in uniformity from that of the current climate. In the 2055 climate, 2ºC will be increased in uniformity all over the country.

4.8.9 Seasonal Mean Temperature

Seasonal evaluation was carried out for the ensemble analysis of surface temperature. The results are shown in Figure 4.8.20 to Figure 4.8.23. All results are almost the same with that of the annual evaluation. The increase in temperature will occur at any time of the year.

4.9 Climate Change Impact on Kenya

4.9.1 Estimation of Potential Evapotranspiration

(1) Equations for Evapotranspiration Estimation

Evapotranspiration is the sum of evaporation and transpiration. This phenomenon appear to vary widely depending on weather conditions such as temperature, humidity, sunshine hours and intensity, precipitation, soil type, soil saturation, wind, and land slope. The evaluation of evapotranspiration is difficult because it cannot be measured directly. The several equations for the evaluation of evapotranspiration were proposed. The equations can be classified into 2 types; one is an empirical equations and another is a physical based equations.

The empirical type needs only one or two observed parameters and most of this type equation requires air temperature and sunshine duration on site. The most of the empirical type equation was developed through regression analysis and those are based on the assumption that the parameter is correlated highly and dominantly with evapotranspiration.

Meanwhile, the physical based equations require many types of observed parameters. For instance, FAO Penman-Monteith method requires air temperature, daily solar radiation, wind speed, atmospheric pressure and actual vapour pressure. The physical based equation derives reliable evapotranspiration evaluation for anywhere and any seasons, if the sufficient observed parameter is obtained. In other words, the physical based equation is limited for application, since it is difficult to obtain sufficient parameters.

(2) Estimation of Present and Future Potential Evapotranspiration

Daily air temperature data for 35 stations from 1979 to 2010 were provided by KMD for this study and those data availability are shown in Table.2.1.1. Hamon method and FAO Penman-Monteith method (FAO-PM) were applied for estimation of the potential evapotranspiration (PET). The PET by Hamon method for present and future conditions were calculated for entire area of Kenya by using daily air temperature grid data for present and future.

On the other hand, the sufficient observed parameters for application of the FAO-PM method were not obtained for the subjected period. The PET by FAO-PM method had to be calculated indirectly by the procedure described below;

a) The summarized climatology data of various meteorological parameters for 23 synaptic stations were obtained, which are summarized for about 30 years from 1960's to 1990's and the period of summarization of each station was differ from each others. The summarized climatology data for 23 stations could not be placed in this report, because the data was not permitted to be published to public by KMD due to those data policy.
b) From these summarized climatology data, two types of monthly mean PET were calculated by application of Hamon and FAO-PM method, and the PET ratio of FAO-PM to Hamon was calculated for each month.
c) The PET equivalent to FAO-PM was calculated by multiplying the PET ratio grid data by Hamon PET grid data.

The PET by Hamon method was calculated by the following equations (eq.4.1);

Estimation of potential evapotranspiration – Harmon's Equation

$$E_t = 0.14 D_0^{\ 2} P_t \ [mm/day]$$

(eq.4.1)where, E_t is the daily potential evapotranspiration, D_0 is the ratio of day length to 12 hours and P_t is the saturated vapour pressure at daily average temperature t [^{o}C].

Day length D[hr] can be obtained by the following equation;

$$D = 24 - \frac{24}{\pi} \frac{\arccos\left(\sin\left(0.8333 \frac{\pi}{180} \right) + \sin\left(L \frac{\pi}{180} \right) \sin(P) \right)}{\cos\left(L \frac{\pi}{180} \cos(P) \right)} [hr] \qquad \text{(eq.4.2)}$$

$$P = \arcsin\left[0.39795 \cos\left(\begin{array}{l} 0.2163108 \\ + 2.0 \arctan(0.9671396 \tan(0.00860(J - 186))) \end{array} \right) \right] \qquad \text{(eq.4.3)}$$

where, L is the latitude [deg] and J is day of the year.

The PET by FAO-PM method was calculated by the following equation (eq.4.4);

$$E_t = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 u_2)} \qquad \text{(eq.4.4)}$$

Where,	E_t	reference evapotranspiration [mm/day],
	R_n	net radiation at the surface [MJ m^{-2}day^{-1}],
	G	soil heat flux density [MJ m^{-2}day^{-1}],
	T	mean daily air temperature at 2 m height [^{o}C],
	u_2	wind speed at 2 m height [m/s]
	e_s	saturation vapour pressure [kPa]
	e_a	actual vapour pressure [kPa]
	e_s-e_a	saturation vapour pressure curve [kPa
	Δ	slope vapour pressure curve [kPa ^{o}C^{-1}]
	γ	psychrometric constant [kPa ^{o}C^{-1}]

In this study, the PET estimated by Hamon method was considered as base values of PET, because the FAO-PM method could not be applied directly as mentioned before. The PET indirectly estimated by FAO-PM method (simply called as the PET by FAO-PM method) is for reference. The advantages and disadvantages of both methods are summarized as follows:

Advantages and Disadvantages of Hamon and FAO-PM Methods

Items	Hamon Method	FAO-PM Method
Advantage	Only daily average air temperature is required for evaluation.	It can estimate based on physical theory. If sufficient types of parameters are obtained, the evaluation will be reliable for any climate zone.
Disadvantage	If the evapotranspiration at the site is not collelated much with air temperature, the evaluation might be inaccurate, though it is difficult to know the accuracy of the estimated PET.	The sufficient parameters cannot be obtained at most meteorological observation station.
NWMP 2030	Observed air temperature for the subjected period of present and predicted future air temperatures were obtained in this study. The PET by Hamon method was calculated simply apply the equation to the air temperature data. Based on this PET, the runoff model was calibrated as mentioned in Chapter 5.	The FAO-PM method could not be applied for this study, since necessary parameters were not available for the subjected period of present and future. For reference, the PET based on FAO-PM method was calculated by indirect procedure.

The ensemble mean of the annual mean PET estimated by Hamon method is illustrated in Figure 4.9.1. The PET of each season is shown in Figure 4.9.2 to Figure 4.9.5. Similarly, the PET by FAO-PM method is shown in Figure 4.9.6 to Figure 4.9.10.

The PET by Hamon method varies from 800 mm/year to 1,600 mm/year. On the other hand, the PET by FAO-PM method varies up to 2,500mm/year. These figures are not actual evapotranspiration but potential values. If the surface and soil contain sufficient water, the water can be vaporized up to the estimated potential. The actual evapotranspiration will be less than the estimated potential value on most occasions and is dependent on the condition of surface water content.

The potential future evapotranspiration will increase by the raise of air temperature. The increase of evapotranspiration will affect the water resources of Kenya.

4.9.2 Evaluation of Climate Change Impact

Annual rainfall was estimated to be increased and the annual evapotranspiration will increase in the future. These are the impact of the climate change which is derived from analysis using GCM results. These two impacts have opposite vector to the water resources. Then, precipitation minus potential evapotranspiration (P – PET) was estimated. This is one of the results of the climate change impact study.

The annual mean P-PET based on the PET by Hamon method is shown in Figure 4.9.11 and seasonal P-PET is shown in Figures 4.9.12 to 4.9.15. The annual mean P-PET based on the PET of FAO-PM method is shown in Figure 4.9.16 and seasonal P-PET is shown in Figures 4.9.17 to 4.9.20.

The area of the negative P-PET is considered as the place where pressure of the drought is very high. The eastern and northern parts of the country are dry areas at present conditions. Those areas are expected to be drier according to the evaluation of P-PET in the future. Meanwhile, wet areas at the present, particularly the high-land and western part areas will be wetter in the future. According to the P-PET based on the PET by FAO-PM method, most of the Kenya was estimated as negative. The wet season is expected to be wetter and the dry season will be drier.

4.9.3 Conclusion of the Climate Change Impact Study using GCMs

The uncertainty of the climate was evaluated by the ensemble analysis of 11 GCMs. The range of the uncertainty of climate change was estimated. These information will be considered in the development of the water master plan.

The climate change impact in the meteorological condition is concluded as followings;

- The change of climatology of 2030 is not drastic.
- Annual rainfall will increase in the whole country and the probability of the increase was is estimated at 100%.
- Rainfall during dry seasons will decrease in coastal areas.
- Rainfall frequency will increase.
- Annual mean temperature will increase by 1 °C in the 2030 climate.
- Most of areas in the country, in especially ASALs, will be subjected to drought due to climate change.

4.10 Recommendation for Further Study

The water resources in the years 2030 and 2055 were estimated based on the climate change projection of 11 GCMs available for this study. As the climate change projection has a degree of uncertainty, the projection in this study should be reviewed according to the progress of research on climate change.

CHAPTER 5 RAINFALL-RUNOFF ANALYSIS

5.1 Approach to the Analysis

Meteorological conditions in the future were evaluated quantitatively using GCMs in Chapter 4. Rainfall-runoff analysis was carried out in order to evaluate hydrological conditions, including vulnerability and uncertainty.

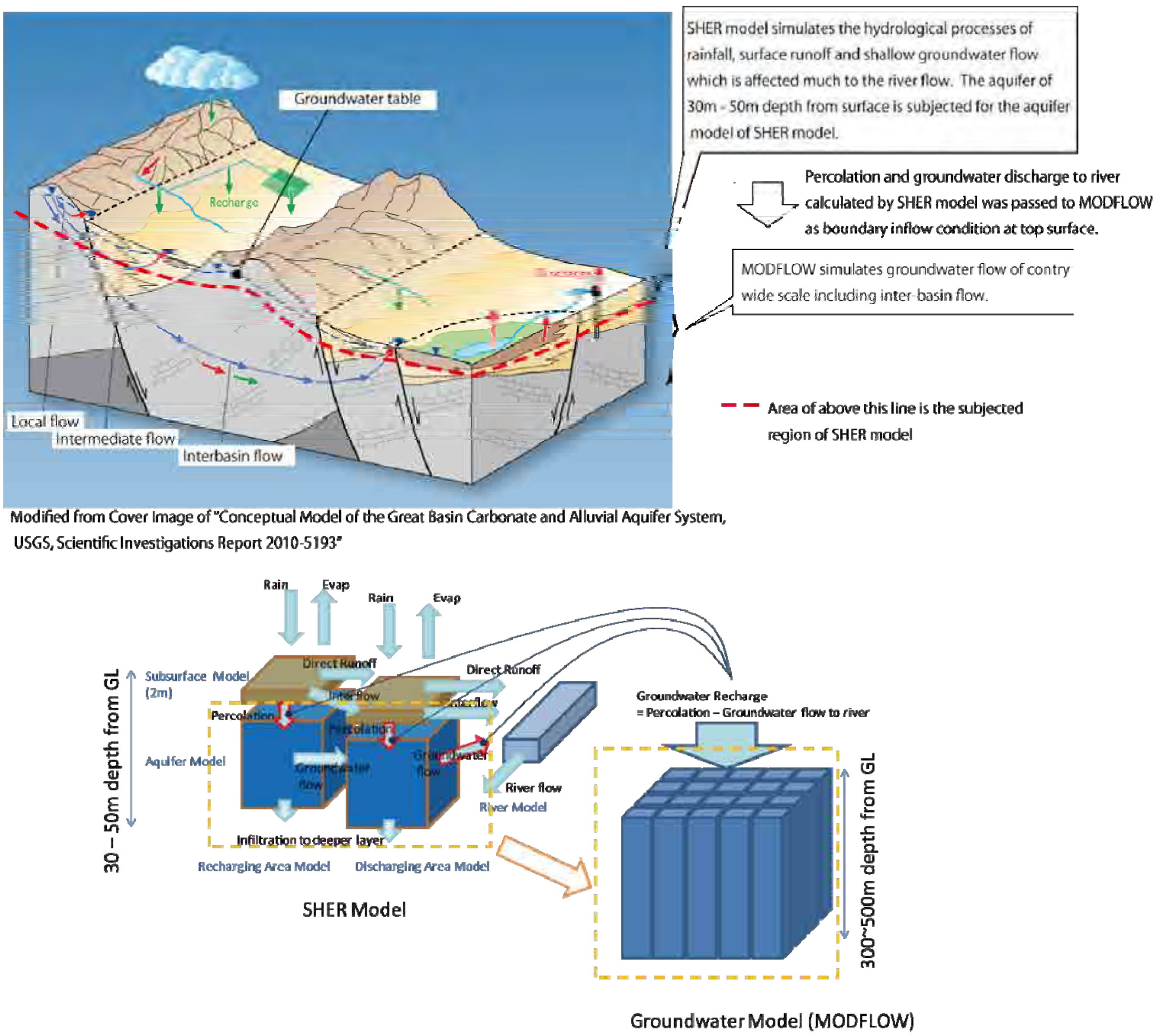
The objective of rainfall-runoff analysis is to estimate the naturalised river flow for present and future condition. The estimated runoff will be used for assessment of renewable water resources as well as for the water balance study. The naturalised flow is defined as the river runoff that is not affected by any water use in the catchment area. A series of naturalised flow is required for the assessment of the water demand and supply balance in the future. The daily runoff of rivers was calculated.

The observed river flow discharge data are obtained from MWI and WRMA. Some of the data have poor quality and many periods have missing data. The distribution of river gauging stations is eccentrically located at populated areas. The physical based rainfall-runoff simulation model was applied in this study in order to overcome the low availability and poor quality of the river flow data.

The climate change impacts to meteorological conditions in Kenya were studied in previous chapter. It was determined that the amount of annual rainfall in the country will increase and that evapotranspiration will increase in the future. In other words, both the cause and outcome of water will increase. The physical based rainfall-runoff model is indispensable in assessing hydrological conditions, river flow and infiltration to groundwater in the future, reflecting on the estimated meteorological conditions, rainfall and potential evapotranspiration derived from GCMs results.

The Similar Hydrological Elements Response model (SHER model) was applied in this study, because the model deals with both of surface runoff and groundwater recharge simultaneously, and it is a kind of physical model which can incorporate the calculations of climate change impact into it. The SHER model was developed with full physical based equations for hydrological processes. The SHER model is one of the best models in evaluating hydrological conditions with physical based approach.

SHER model has very simple aquifer model. The aquifer model of SHER model assumes the catchment area of groundwater is same area as the surface catchment boundary. This might be caused inaccurate analysis for the groundwater flow in view of the country wide scale, since the groundwater flow crosses the boundary of the small topographical surface up and down at some places. Additionally, the aquifer model of SHER model cannot simulates deep groundwater flow. In order to complement the limitation of the SHER model to apply to the country wide groundwater flow analysis, MODFLOW was applied in combination. The schematic image of the application of the combination of SHER model and MODFLOW is illustrated in following figure. Both models simulated the same aquifer layer. The SHER model was calibrated in order to reproduce the river flow and MODFLOW simulated the country wide groundwater flow. The inflow boundary conditions of the top surface of MODFLOW are percolation and groundwater discharge to river which are calculated by SHER model.



Source: JICA Study Team Based on U.S. Geological Survey. 2010. Groundwater Resources Program Conceptual Model of the Great Basin Carbonate and Alluvial Aquifer System. Scientific Investigations Report

Runoff Simulation Models for This Study

In this chapter, the surface runoff simulation using the SHER model is described in detail. The groundwater analysis using MODFLOW is described in Chapter 7.

The SHER model consists of physical based parameters only. Such parameters can be obtained from physical tests or field surveys and there are no conceptual parameters. The main parameters are hydraulic conductivity of subsurface soil and aquifers. The soil and aquifer type distribution was considered in the parameter calibration works. Consecutive parameters were studied to represent all gauged river flow data in the present condition, with observed forcing data, rainfall and potential evapotranspiration. These parameters were applied for evaluation of future conditions.

The actual evapotranspiration and recharging amount to groundwater were estimated from the results of rainfall-runoff analysis. The important advantage of utilizing the physical based model is that the detailed breakdown of hydrological process can be obtained from the analysis. The ensemble analysis was conducted to assess future hydrological conditions and climate change impacts on the water resources.

Considering the objectives of the development of NWMP2030, the years subject to this hydrometeorological study were set as follows:

a) Year 2010(Present): The year represents the present hydrometeorological conditions. The present (2010) climate in this study expresses the climate during 1991 – 2010.

b) Year 2030: Target year for formulation of NWMP 2030. The 2030 climate in this study expresses the climate during 2021 – 2040.

c) Year 2055: The year to evaluate the water resources around 2050 taking into account climate change. The 2055 climate in this study expresses the climate during 2046 – 2065. It can be expressed by Year 2050 in the formulation of NWMP2030.

5.2 SHER Model

5.2.1 Developing Trail

The SHER model was originally developed by Professor Herath of the United Nations University and Professor Musiake of the Tokyo University [1] [2] [3] [4] [5] [6] [7]. This model mainly consists of submodels of surface, subsurface and aquifer. In the surface model, kinematic wave equation is used for surface flow computations. In the subsurface model, the one dimensional Richard's equation was used. Darcy's flow was assumed in the aquifer model.

The model can simulate basin-scale hydrological cycle including river flow, infiltration, groundwater recharging and interflow.

5.2.2 Basic Concept of SHER Model

The subsurface block of the SHER model needs to divide the watershed mainly into two types of blocks. Each block represents similar hydrologic characteristics, namely recharging area and discharging area. A block may have several sub-areas based on the surface soil characteristics. For example, impervious areas such as pavement roads and roofs of buildings shall be separated from other soil types since the hydrological process is completely different. The subsurface soil of paddy

[1] Herath S., Hirose N. and Musiake K. (1990). A computer package for the estimation infiltration capacities of shallow infiltration facilities, Proc. 5ht International Conference on Urban Storm Drainage, Japan, pp.111-118.

[2] Herath S., Musiake K., Hirose N. and Matsuda S. (1992). A process model for basin hydrological modelling and its application, Proc. Japan Annual Conference of Society of Water Resources and Hydrology, pp.146-149.

[3] Herath, S., and Musiake, K., (1992), Modeling basin hydrological changes due to urbanization and remedial measures, Re-discover water; A Priority. Proc. Innovative Technologies in the domain of Urban Drainage, pp 145-154.

[4] Ni, G., Herath, A.S and Musiake, K. (1994), Distributed Catchment Modeling with Efficient Computation of Unsaturated Flow: Proc. 48th Annual Conference, JSCE, pp. 96-97

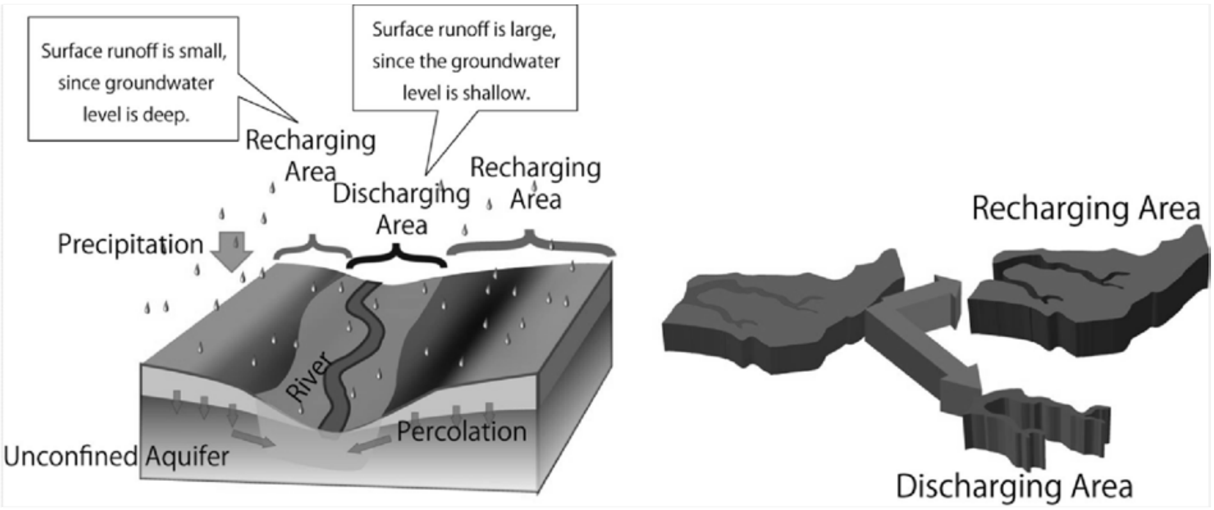
[5] Bhatti, B.M., Herath, A.S. and Musiake, K., (1994), Physically Based Catchment Modeling & Its Application: Proc. of 1994 Annual Conference, Japan Society of Hydrology and Water Resources, pp. 10-11

[6] Ni, G., Herath, S., and Musiake, K., (1994), Numerical Simulation of Hillslope Infiltration and Discharge into River, 38th Annual Journal of Japan Hydraulic Conference, JSCE, pp 191-196

[7] Herath, S., Ni, G., Babar, B., Musiake, K., (1995), Investigation of scaling effect in hydrologic modeling using distributed hydrologic models, Proc. 2nd Study Conference on GEWEX Asian Monsoon Experiment, pp 207 - 211

fields or swamps have very low water permeability as compared to other types of bare soil areas. Several soil types and impervious areas are modelled in the SHER subsurface block.

The aquifer layer model is very simple. The planar shape of the aquifer model is basically the same as that of the subsurface model. The uniformity of hydraulic conductivity and hydraulic gradient of groundwater in an aquifer model are assumed. The point of groundwater modelling is dividing the tributary sub-basin areas into discharging and recharging areas, since the groundwater level relative to the surface is different between the discharging area and recharging area.



Source: JICA Study Team

Basic Concept of Sthe HER Model: Recharging Area and Discharging Area

5.2.3 Model Components of the SHER Model

The SHER model consists of four models, which are discussed below.

(1) Impervious Area Model

The governing equation for the impervious area model is shown below. Rainfall cannot pass through the impervious area. Some amount of water is trapped in depression on surface areas. The depth of the depression storage of the impervious area is generally from 2 to 5 mm. Water trapped in depression storages will be evaporated. Water that overflowed from the depression storage is considered as surface runoff. The surface runoff is routed using the kinematic wave equation (eq. 5.1).

$$\frac{dS_{imp}}{dt} = P - D_{imp} - E_{imp} \qquad \text{(eq. 5.1)}$$

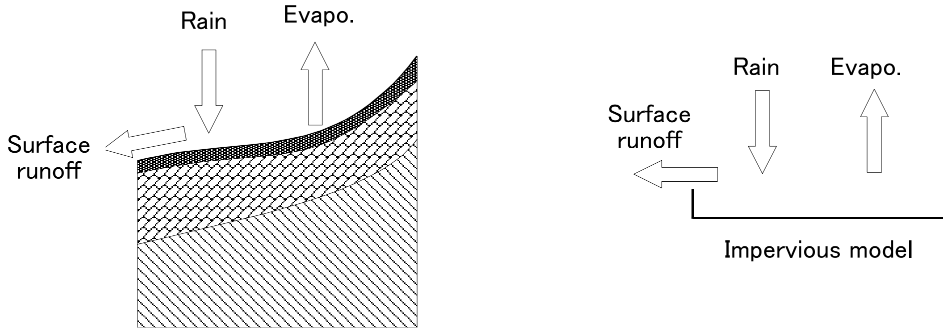
where,

P :rainfall

S_{imp} :water depth (storage) in depression storage pond

D_{imp} :surface runoff from impervious model

E_{imp} :evaporation from depression storage pond



Source: JICA Study Team

Schematic Image of the Impervious Area Model.

(2) Pervious Area Model

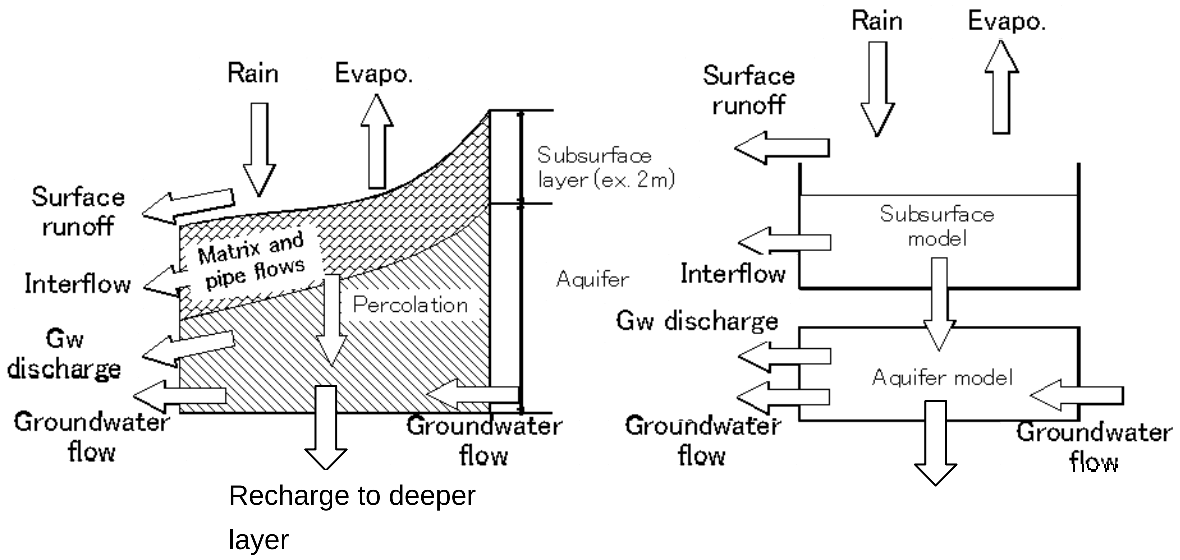
In the pervious area model, three water storage depths were set and computed by the following governing equations.

$$\frac{dS_1}{dt} = U_s - E_1 - D_s \quad \text{(eq. 5.2)}$$

$$\frac{dS_2}{dt} = P - E_2 - R - I - U_s \quad \text{(eq. 5.3)}$$

$$\frac{dS_g}{dt} = R - D_g - R_g \quad \text{(eq. 5.4)}$$

Where
- S_1 : water storage in depression pond
- S_2 : water storage in subsurface layer
- S_g : water storage in aquifer layer
- D_s : surface runoff
- E_1 : evaporation from depression pond
- E_2 : evaporation from subsurface layer
- P : infiltration to subsurface layer (rainfall origin)
- R : recharge to aquifer (percolation)
- I : interflow
- U_s : return flow
- D_g : groundwater discharge to rivers
- R_g : Recharge to deeper layer



Source: JICA Study Team

Schematic Image of the Pervious Area Model

Soil Evapotranspiration

Evapotranspiration potential was estimated by Hamon’s equation as detailed in Section 4.4.4 and the soil evapotranspiration was calculated with the upper limits to the sum of the depression pond and the water content of the subsurface layer.

The procedure of computation is as follows:

a) During rainfall, no evaporation is assumed.

b) Compare the evapotranspiration potential with water storage in the depression pond. The smaller value is to be the actual evapotranspiration from the depression pond in pervious mode.

c) If evapotranspiration potential exceeded the water storage in the depression pond, the rest of the evapotranspiration potential is applied to the subsurface layer. Compare the rest of the evapotranspiration potential with water storage in the subsurface layer. The smaller value is to be the actual evapotranspiration from the subsurface layer.

d) Total actual evapotranspiration computed in B) and C) shall be the evapotranspiration from the pervious soil model.

Infiltration

The amount of infiltration, which water flow penetrated into the subsurface layer through ground surface, vary with moisture content of the subsurface soil because water movement in unsaturated soil depends on unsaturated hydraulic conductivity, suction in soil matrix and others. However, in this model, infiltration is computed so that rainfall water penetrates into the subsurface layer until it is saturated.

Percolation (Recharge to Aquifer)

Water in the subsurface layer goes down to the aquifer which is laid beneath the subsurface layer. This is called percolation. As water in the soil is drained to the aquifer, the water content of the subsurface layer decreases. Along with that, unsaturated hydraulic conductivity also decreases. Therefore, percolation decreases as time elapse. In the model, this mechanism is computed by explicit infinite difference scheme. The steps of the computation are as follows:

a) Calculate unsaturated hydraulic conductivity from current moisture content of the subsurface (eq. 5.5).

b) Assuming that unsaturated hydraulic conductivity is maintained during dT, percolation is computed using the following equation.

c) Update moisture content.

d) Perform A), B), and C) recursively.

$$R = \int_{T}^{T+\Delta T} K_0 \cdot k_r(\theta) dt \qquad \text{(eq. 5.5)}$$

Where,

K_0 : saturated hydraulic conductivity

$k_r(\theta)$: specific unsaturated hydraulic conductivity

θ : moisture content

Interflow

Interflow is also computed by assuming unsaturated flow in the subsurface layer. The difference from vertical water flow in this model is the additional variable in the equation which stands for ground surface slope (hill slope).

$$I = \int_{T}^{T+\Delta T} K_{0I} \cdot kr(\theta) \cdot s dt \qquad \text{(eq. 5.6)}$$

Where,

K_{0I} : saturated hydraulic conductivity

k_r : specific unsaturated hydraulic conductivity

θ : moisture content

s : hill slope

Return Flow

When water content in the subsurface layer exceeds its saturated water content, return flow is generated in the model. The following are computation steps.

a) After finishing the interflow computation, if water content exceeds the saturated water content, put exceeding water up to the depression pond.

b) If water depth in the depression pond exceeds the pond capacity, spill water is counted as surface runoff.

Water Conveyance Characteristics

Water flow in the subsurface layer for both vertical and hill slopes are computed by applying Mualem's equation. The following equations shows Mualem's equation and the vertical and hill slope wise conductivity.

The equation (Harverkamp et. al.) which shows the relationship between bulk moisture content and suction is as follows:

$$\theta = \frac{\alpha(\theta_0 - \theta_r)}{\alpha + \{\ln(\varphi)\}^{\beta}} + \theta_r \qquad \text{(eq.5.7)}$$

Where,

θ : bulk moisture content [cm³/cm³]

θ_0 : saturated moisture content [cm³/cm³]

θ_r : residual moisture content [cm³/cm³]

α, β : parameters

Mualem's function (1978) represents the relationship between water content and hydraulic conductivity.

$$k_r(\theta) = \left(\frac{\theta - \theta_r}{\theta_0 - \theta_r} \right)^n \qquad \text{(eq. 5.8)}$$

$$k = K_0 k_r(\theta) \qquad \text{(eq. 5.9)}$$

$$k = K_{0I} k_r(\theta) \qquad \text{(eq. 5.10)}$$

Where,

k_r : specific hydraulic conductivity

k : unsaturated hydraulic conductivity [cm/s]

K_0 : saturated hydraulic conductivity [cm/s]

K_{0I} : saturated hydraulic conductivity (hill slope wise) [cm/s]

n : coefficient (Mualem's n)

θ : bulk moisture content [cm³/cm³]

θ_0 : saturated moisture content [cm³/cm³]

θ_r : residual moisture content [cm³/cm³]

(3) Groundwater Discharge and Groundwater Flow

Water exchange between river and groundwater is computed using the following equations. If the river water stage is higher than the groundwater's, the first equation is applied (eq. 5.11). However, if the river water stage was lower than the groundwater's, the second equation is applied (eq. 5.12). In the former case, the water which goes to the groundwater is limited by the water in the river at that moment.

The third and the fourth equation are for computing groundwater flow (eq.5.13 and eq5.14).

$$Q_d = k_0 A_{bed} \qquad \text{(eq. 5.11)}$$

$$Q_d = k_0 \frac{h - H_{rivbed}}{b_{bed}} A_{bed} \qquad \text{(eq. 5.12)}$$

Where,

Q_d : water exchange between river and groundwater [m³/s]

k_0 : hydraulic conductivity of riverbed material [m/s]

A_{bed} : permeable area [m²]

b_{bed} : thickness of riverbed material [m]

H_{rivbed} : riverbed elevation [m]

$$Q_g = K_0 \frac{\partial h}{\partial x} \cdot \ell \cdot T \qquad \text{(eq. 5.13)}$$

Where,

Q_g	: groundwater flow
K_0	: hydraulic conductivity
$\frac{\partial h}{\partial x}$	: groundwater slope (hydraulic gradient)
ℓ	: contact line length of two neighboring blocks
T	: averaged aquifer thickness of the block

$$A \cdot S \frac{dh}{dt} = Q_{in} - Q_{out} \qquad \text{(eq. 5.14)}$$

Where,

Q_{in}	: inflow (groundwater) from upper blocks and percolation [m3/s]
Q_{out}	: outflow from this block (groundwater) and other water losses [m3/s]
A	: area of the block [m2]
S	: storage coefficient
h	: groundwater table elevation [m]

(4) River Flow

In the river section, kinematic wave approximation is applied and the governing equations are as shown below. An explicit finite difference scheme has been used in the computer program.

$$Q = \frac{1}{n_r} R_r^{2/3} S_x^{1/2} A_r \qquad \text{(eq.5.15)}$$

$$\frac{\partial Q_r}{\partial x} + \frac{\partial A_r}{\partial t} = q_r \qquad \text{(eq.5.16)}$$

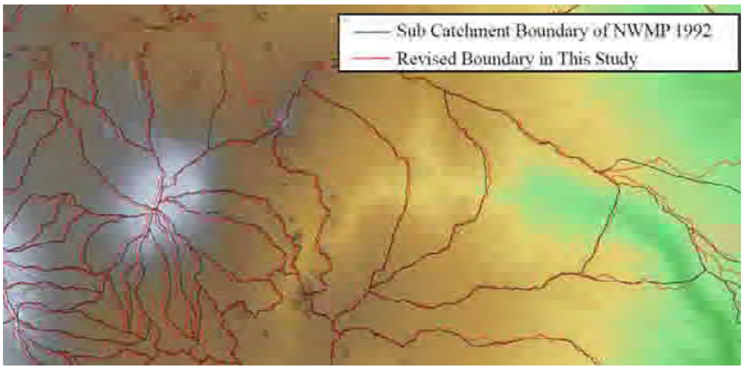
Where,

Q_r	: river flow rate [m^3/s]
n_r	: Manning's roughness coefficient [$s/m^{1/3}$]
h_r	: depth [m]
S_x	: slope
A_r	: cross-sectional area [m^2]
x,t	: independent variables, spatial [m] and time [s]
q_r	: lateral inflow [m^2/s]

5.2.4 Conditions and Parameters

(1) Delineation of SHER Blocks

The subcatchment boundary, which was prepared in the NWMP (1992), was reviewed using detailed river lines data traced from a 1:50,000 topographic map and digital elevation model (DEM) of 90 m resolution grid from Shuttle Rader Topography Mission (SRTM), NASA. Some river lines cross over the subcatchment boundaries. MWI has requested the JICA Study Team to correct the subcatchment boundaries. The reviewed subcatchment boundaries are shown in Figure 5.2.1.



Source: JICA Study Team

Review of Subcatchment Boundaries using Detailed DEM

The discharging area and recharging area are divided for SHER blocks. The recharging area is where water from precipitation is transmitted downward to an aquifer. The discharging area is the opposite of the recharge area. These are located at areas where groundwater moves from the aquifer to the surface. Groundwater discharge occurs where the water table intersects the land surface. River channels appear when the groundwater table is higher than the bottom of the channel. High areas, such as hills or plateaus, are typically where aquifers are recharged. Low areas such as river valleys are where they discharge. However in many cases, the aquifer level is lower than river bed and the river water recharges the aquifer. Such areas also are treated as a discharging area in the SHER model, because the groundwater table is raised during the rainy season and the area becomes a discharging area.

In Kenya, there are many seasonal rivers. There are also many inland rivers in the Rift Valley, which has no river outlet where the river water submerge underground and disappear. It is necessary to define a discharging area for the seasonal rivers and inland rivers on the SHER model. The aerial imagery of Google Earth was referred for the delineation work of discharging and recharging area. Even if the water surface of the seasonal rivers and inland rivers are not visible on the aerial imagery, the unseen channel course can be supposed by the different colour of surface soil or the exuberance of vegetation in linear.

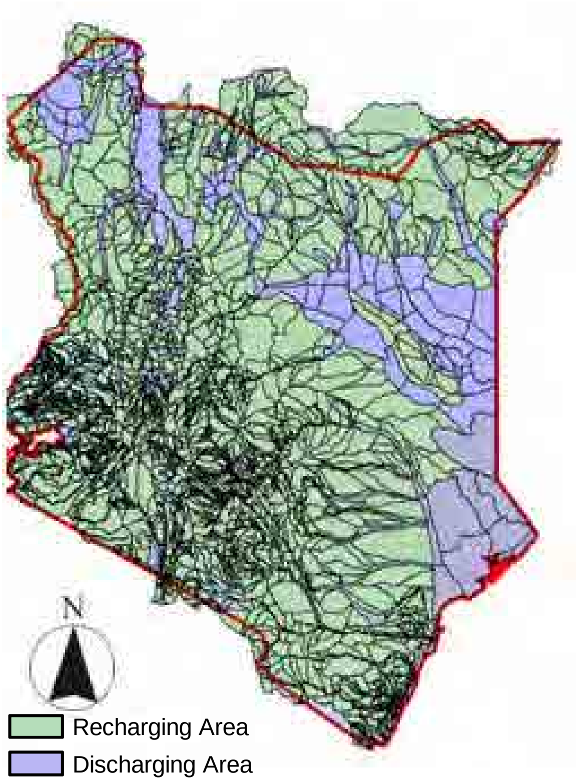
The total number of SHER blocks was 2,977 for the whole country. The calculation was conducted with time step of one day. The area outside of the country where rainfall runs into the inside of the country was modelled. The block numbers of each catchment are shown in the following figure and all block are shown in Figures 5.2.2 to 5.2.33. The sizes of each catchment areas are provided in the table below.

Catchment Area for Calculation

Catchment Area	Inside the country	Including outside of the county	Ratio
	1	2	=1/2
LVN	19,012	19,928	95%
LVS	27,425	29,676	92%
RV	136,848	148,359	92%
Athi	67,469	70,589	96%
Tana	127,463	127,739	100%
ENN	210,573	243,245	87%
Total	588,790	639,537	92%

Note: The catchment area data were as per GIS data provided by WRMA. The above catchment area data were different from the one which were derived from the WRMA Catchment Management Strategies as shown in sub-section 1.3.1.

Source: JICA Study Team



No.	Catchment Area	Blocks
1	Lake Victoria North	354
2	Lake Victoria South	226
3	Rift Valley	795
4	Athi	565
5	Tana	502
6	Ewaso Ng'iro North	535
	Total	2,977

Source: JICA Study Team

Number of SHER Block Prepared for Whole Country

(2) Land Use

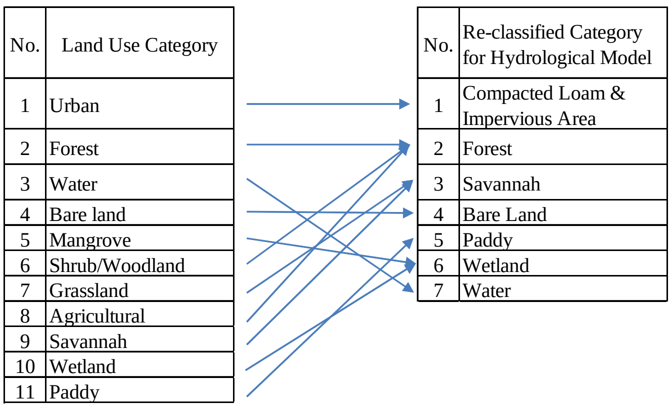
Land use condition is one of the key information to set the soil parameter of surface cover. Land use for the period of 2010 which was produced by remote sensing analysis was utilized for the rainfall-runoff analysis. The details of land use analysis are explained in the subsequent section (refer to Section 8 Land Use Analysis). In addition, the classification of paddy areas was supplemented by land cover information from FAO Africover. The land use classification is shown in the table below.

Land Use Classification

No.	Classes	Definition
1	Urban	Residential, industrial and commercial complexes, transportation, communication and utilities.
2	Forest	Deciduous, evergreen and mixed forest (natural and manmade forests).
3	Water	All areas of open water, including streams, lakes and reservoirs.
4	Bare land	Area of thin soil, sand, or rock, almost has no vegetation.
5	Mangrove	Trees and shrubs growing below the high-water level of spring tides. Their root systems are regularly inundated with saline water. They extend throughout tropical and sub-tropical ecosystems
6	Shrub/Woodland	A woody perennial plant, smaller than a tree, with several major branches arising from near the base of the main stem. It is mostly covered with woods or dense growths of trees and shrubs
7	Grassland	An area in which the natural vegetation consists largely of perennial grasses, characteristic of subhumid and semi-arid climates. It is used for grazing or pasture.
8	Agricultural	Crop fields, vegetable lands and cultivated areas (irrigated and non-irrigated vegetation).
9	Savannah	A flat, grass covered area of tropical or subtropical regions, nearly treeless in some places but generally having a mix of widely spaced trees and bushes.
10	Wetland	Areas of marsh, fen, peat land or water. They could be natural or artificial and the water permanent or temporary, static or flowing, fresh, brackish or saline. Wetlands include areas of marine water whose depth during low tide must not exceed 6 m.
11	Paddy	Paddy field

Source JICA Study Team

The land use classes listed above were reclassified for the hydrological model from the standpoint of surface soil status. For example, soil on forests and agricultural areas can be regarded as the same status of soil in view of hydraulic conductivity because the surface soil on these areas has large porosity. Paddy fields, mangrove areas and wetland areas can be put in the same soil status for hydrological model parameters because the surface soil on such areas are composed of silt or clay and their hydraulic conductivity is very small. The reclassification of the land use category for the SHER model is shown below.



Source JICA Study Team

Reclassification of Land Use Category for Hydrological Model

The ratio of impervious area to the land use category of "Urban" was evaluated by measuring pavement areas and roof areas in urban areas using aerial imagery of Google Earth. The hydrological process on impervious areas is quite different from pervious areas. Although the ratio of urban areas is very small in Kenya, it is important to set the ratio in the SHER model because the runoff ratio is greatly affected by the area of impervious areas. The ratios of measured impervious area to urban area are shown in the table below.

Ratio of Impervious Area to Urban Area

Catchment Area	Catchment Code for SHER	Ratio of Impervious Area to Urban Area [%]
Lake Victoria North	LVN	40
Lake Victoria South	LVS	40
Rift Valley	RV	40
Athi	AT	60
Tana	TN	30
Ewaso Ng'iro North	EN	30

Source JICA Study Team

(3) Subsurface Soil

The modelling of hydraulic conductivity of subsurface soil is the key portion of modelling. Through the modelling of physical characteristics of subsurface soil, the saturated runoff and the subsurface flow can be estimated precisely. In Kenya, subsurface soil can be categorized into three groups: i) Igneous near Mt. Kenya, ii) Metamorphic, and iii) Sedimentary in lowland.

By overlapping with the aforementioned land use distribution, the surface soil type was divided into 11 types. The category list is shown in the table below and the classification of soil types is shown in Figure 5.2.34.

Soil Type Categories for SHER Model

No	Categories for SHER Model	Land Use	Soil Type
1	Compacted_Loam	Compacted	Compacted Soil
2	Igneous_Loam1	Forest, Woodland, Agricultural	Igneous
3	Sedimentary_Loam1		Sedimentary
4	Metamorphic_Loam1		Metamorphic
5	Igneous_Loam2	Savannah, Grassland	Igneous
6	Sedimentary_Loam2		Sedimentary
7	Metamorphic_Loam2		Metamorphic
8	Bare_Sand	Bare Land	Sand
9	Paddy_Silt	Paddy	Silt
10	Wetland_Silt	Wetland, Mangrove	Silt
11	Water_Silt	Water Body	Silt

Source JICA Study Team

(4) Selection of River Gauging Station for Calibration

River gauging stations which will be used for calibration were selected considering the following: i) location of river network (near river mouth, confluence point, etc.), ii) representation of river basin, iii) data availability, iv) data reliability through checking of annual rainfall-annual runoff ratio and specific discharge, and v) soil type, which is one of the key calibration factors. As a result, 23 stations were selected for the calibration of simulated discharges from the collected 47 data stations as shown in Table 5.2.1 and Figure 5.2.35.

5.3 Calibration

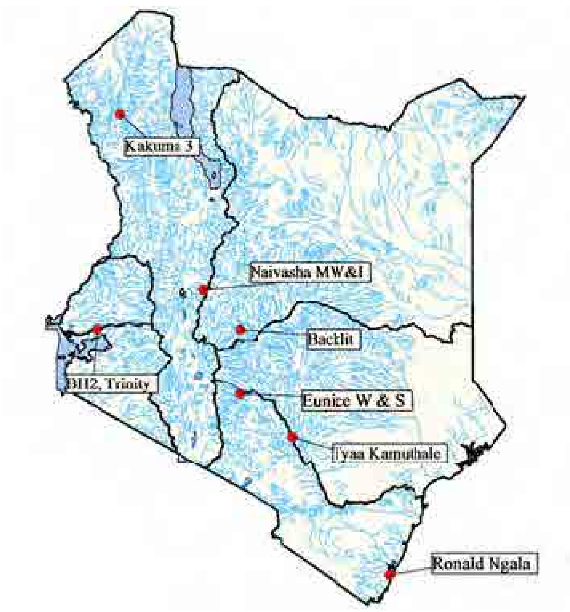
5.3.1 Calibration with Observed River Flow Record

Simulation of the rainfall-runoff model was carried out with the prepared grid rainfall and the potential evapotranspiration which was evaluated by Hamon method for the present climate conditions in order to estimate the naturalized flow for assessment of renewable water resources. The model parameter was calibrated by comparing the observed discharge record at the selected river gauging stations and the simulation result. According to WRMA, the data quality of the river flow gauging after 1990's has been deteriorated and the data before 1990 were recommended for calibration. Therefore, the period for calibration was from 1981 to 1990 for each gauging stations.

The saturated hydraulic conductivity of surface soil and the saturated hydraulic conductivity of aquifers were subjected to calibration in the SHER model. The results of calibrations are summarised in Figure 5.3.1. The comparison of the simulated discharge and observed discharge is shown in Figure 5.3.2. The calibrated parameter lists are shown in Tables 5.3.1 to 5.3.6. The applied efficiency criterion was to match the total annual discharges between the simulated and observed ones, and also to match the low flow discharges during the dry season between the simulated and observed ones.

As there was no flood data for calibration of the model, the simulated and observed values at high flows do not match very well. It is advised for WRMA to procure flood flow measuremet equipment to measure the flood discharge to accumulate data. (Ref. Main Report Part H, 3.2 Proposed Action Plans (2) a) iv))

The parameters for the subsurface soil were calibrated to be consistent and to be within the typical range. The results of the simulated river discharge were agreed with the observed record over the whole selected stations. It is possible to apply the developed rainfall-runoff model for evaluation of the water resources for un-gauging rivers, since the calibrated parameters have physical based meanings. Similarly, the model also can be applied for evaluation of future hydrological conditions and water resources with the bias corrected GCM data.



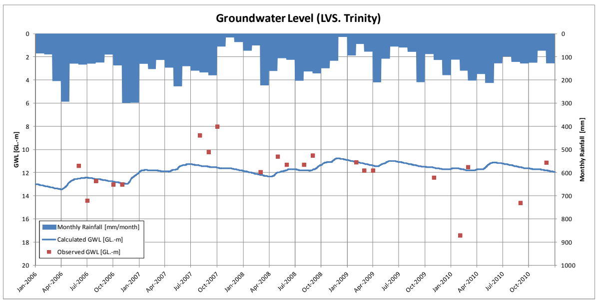
Source: JICA Study Team

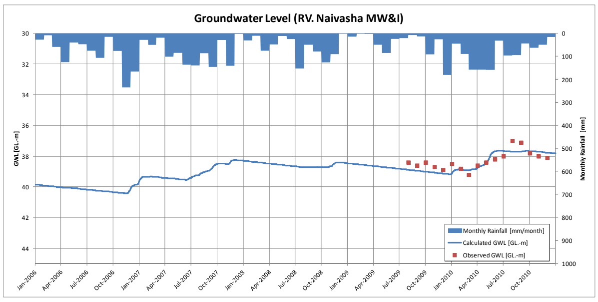
Selected Groundwater Level Gauging Wells for Verification of Calibrated SHER Model

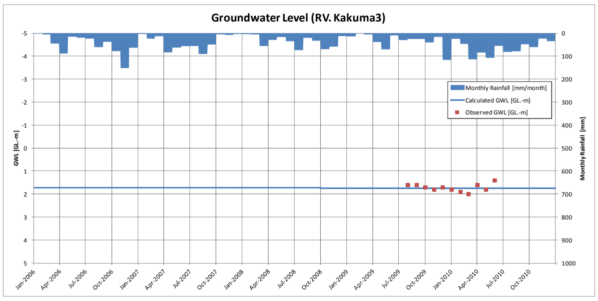
5.3.2 Verification of Calibrated Model

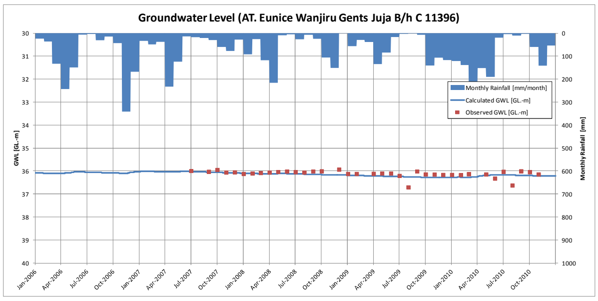
(1) Groundwater Level

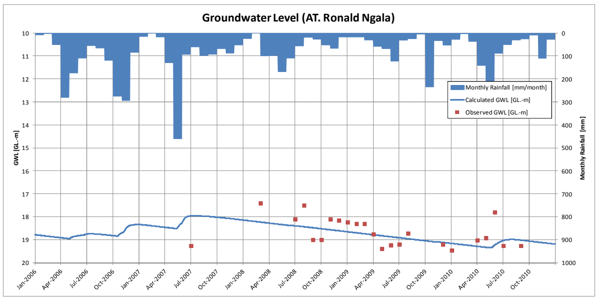
The observed groundwater level records for several wells were collected. Those wells are in use and the observed groundwater levels are affected by water pumping. The observed groundwater level data to which the influence of water pumping seems to be relatively lower than others were selected. The selected number of wells was 7. The comparisons of the simulated groundwater levels by calibrated SHER model and observed groundwater levels are shown in the following charts. They are agreed fairly.

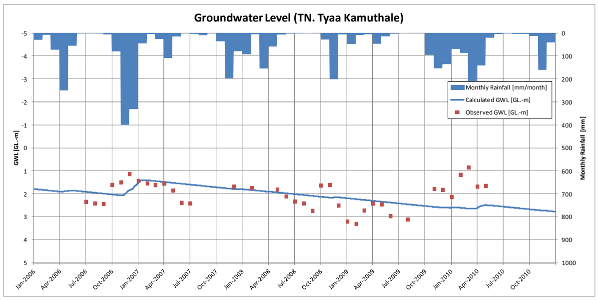


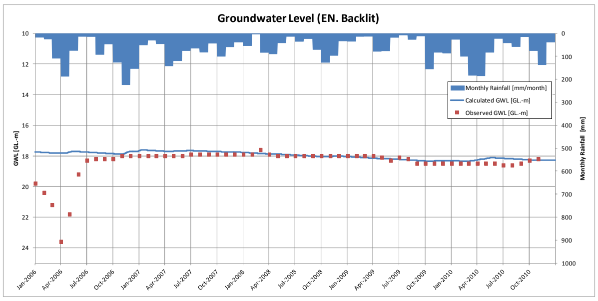












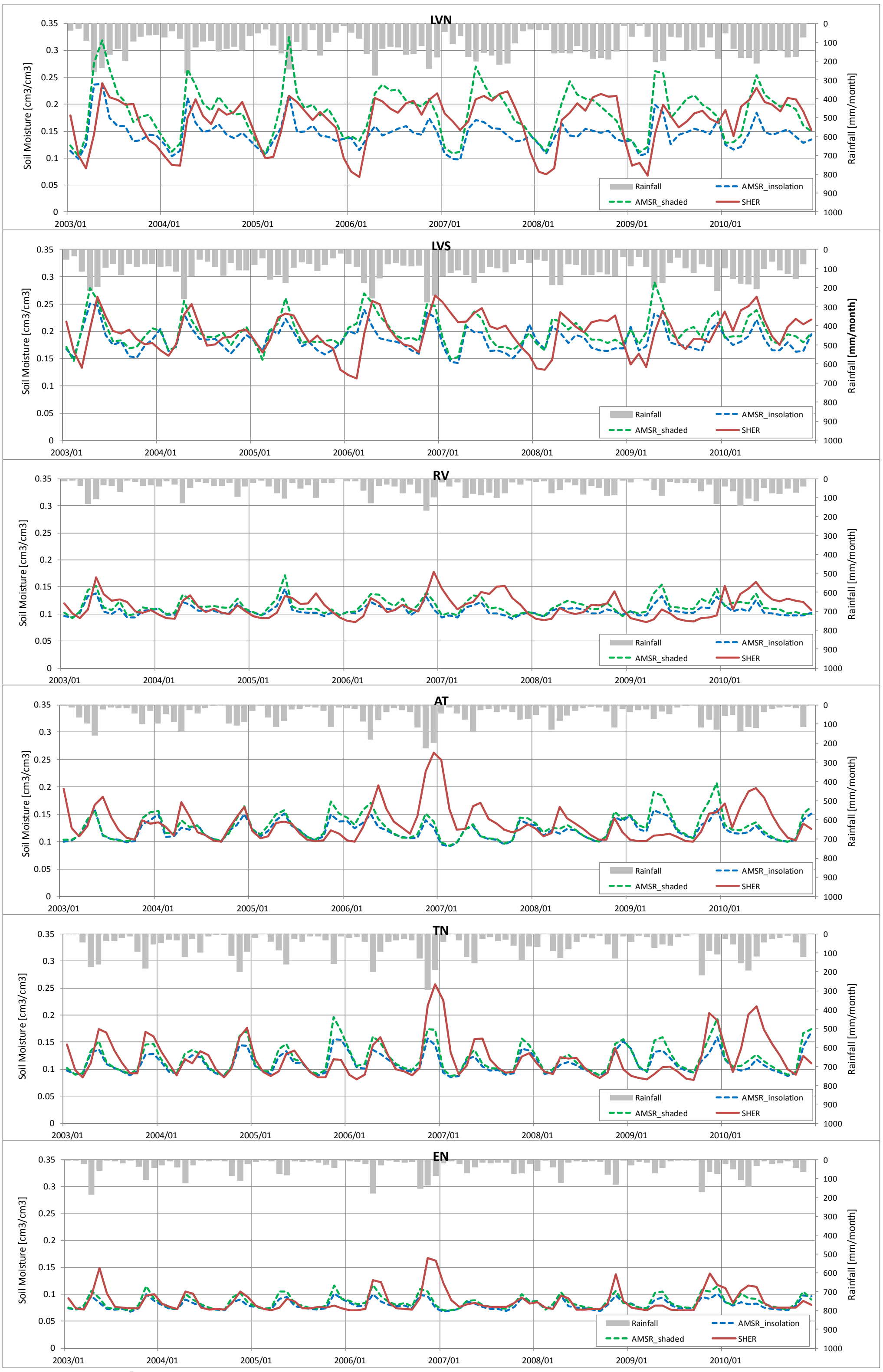
Source: JICA Study Team

Comparison of Groundwater Levels between Observed Record and Calculated by Calibrated SHER Model

(2) Water content of Surface Soil

The Advanced Microwave Scanning Radiometer (AMSR) mounted on satellites which was launched by Japan Aerospace Exploration Agency (JAXA) is a passive sensor that measures weak microwaves radiated from the Earth at several frequencies. Estimated soil moisture data are derived from the observed microwave. The algorithm for transformation to soil moisture was developed by Prof. Toshio Koike of University of Tokyo.

The estimated soil moisture data was obtained from the AMSR web site (http://sharaku.eorc.jaxa.jp/AMSR/index.html) from 2003 to 2010 and the calculated soil moisture by calibrated SHER model were compared with those AMSR data. The calculated soil moisture of sub-surface blocks of SHER model were area averaged for each cachment, LVNCA, LVSCA RVCA, ACA, TCA and ENNCA. On the whole catchments, the calculated soil moistures reproduced the estimated that by AMSR very well. From those comparison, the calibrated SHER model represents the hydrological processes adequately.



Source: JICA Study Team

Comparison of Area Averaged Soil Moisture Data between Calculated and eEtimated by AMSR-E

5.4 Result of Rainfall-Runoff Analysis

5.4.1 Simulation of Present and Future Runoff

The naturalized runoff for the present climate condition was estimated with the present climatology inputs from 1991 to 2010. For the future climate conditions, a rainfall-runoff analysis was carried out for a 20-year time sequence using future climate of 11 GCMs with bias correction. Future runoff was estimated for the 2030 and 2055 climates. The annual catchment area precipitation (rainfall) used for the rainfall-runoff analysis are shown below.

Annual Catchment Area Average Precipitation

(Unit: mm/year)

Catchment Area	Area (km^2)	Present (2010) Climate	2030 Climate	2055 Climate
Lake Victoria North	19,012	1,415	1,505	1,601
Lake Victoria South	27,425	1,277	1,372	1,451
Rift Valley	136,848	509	583	653
Athi	67,469	808	881	916
Tana	127,463	837	899	935
Ewaso Ng'iro North	210,573	510	577	623
Whole Country	588,790	679	750	801

Source: JICA Study Team

The average monthly rainfall by sub-basin is presented in Table 5.4.1 and 5.4.2.

The surface water runoff by catchment area for the years 2010, 2030 and 2055 are shown below.

Annual Surface Water Runoff by Catchment Area

(Unit: MCM/year)

Catchment Area	Area (km^2)	Present (2010) Climate	2030 Climate	2055 Climate
Lake Victoria North	19,012	4,626	4,969	5,455
Lake Victoria South	27,425	4,773	5,749	7,005
Rift Valley	136,848	2,457	3,045	3,794
Athi	67,469	1,198	1,334	1,711
Tana	127,463	5,858	7,261	7,383
Ewaso Ng'iro North	210,573	1,725	2,536	1,361
Total	588,790	20,637	24,894	26,709

Source: JICA Study Team

As shown in the table above, the annual surface water runoff in all catchment areas except the Ewaso Ngiro North Catchment Area (ENNCA) are predicted to increase toward 2055. ENNCA has a trend to increase toward 2030, but would then decrease toward 2055. ENNCA has a climatic characteristic that pressure of dryness is the highest among six catchment areas and 90% of precipitation evaporates even at present.

The impact of future climate change is increase of both precipitation and temperatures, but the difference between precipitation and temperature is small compared with other catchment areas. In 2030, the precipitation exceeds the actual evapotranspiration and in 2055 vice versa. For this the annual surface water runoff in 2055 decreases against that in 2030.

The average monthly surface water runoff by sub-basin are presented in Tables 5.4.3 and 5.4.4.

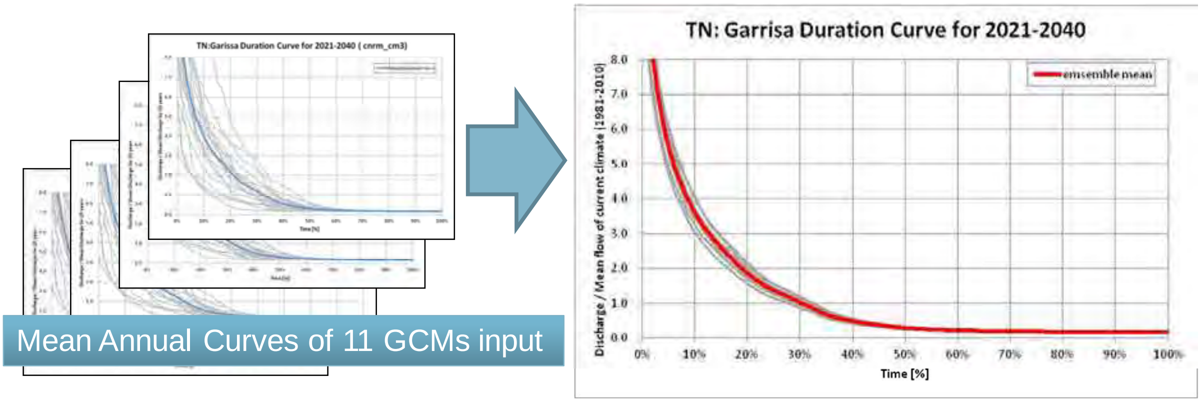
The monthly precipitation and surface water runoff for each year from 1991 to 2010 and from 2021 to 2040 are presented in Databook Part A.

5.4.2 Flow Duration Curve

The flow duration curve was prepared for a 20-year time sequence runoff. The procedure for the preparation of flow duration curve is explained as follows:

i) The simulated runoff results were grouped annually. Then, the flow duration curve for each year was prepared. A total of 20 flow duration curves was produced for one station.
ii) By averaging these curves, one represented flow duration curve was prepared.

For the future climate conditions, the flow duration curve was produced for each GCM output. The ensemble average curve was prepared by averaging the 11 flow duration curves.



Schematic Image of Ensemble Average of Flow Duration Curves

5.4.3 Comparison of Flow Duration Curve

The flow duration curves for the present and future climate conditions were compared as shown in Figure 5.4.1. According to the flow duration curves of the calculated runoff for the present and future climate conditions, high water flow such as runoff in the rainy season increases due to the increase of future rainfall, while low water flow such as runoff in the dry season will not change.

5.5 Impact of Climate Change on Hydrological Conditions

5.5.1 Evaluation of Hydrological Water Budget

All of hydrological process flux can be obtained from the calculation output of SHER model. The hydrological water balance of six catchment areas for present (2010) and future (2030 and 2055) conditions were evaluated. The potential evapotranspiration (PET) estimated by Hamon method was utilized for the hydrological water budget basically as explained in Section 4.9. The groundwater recharge of whole country was estimated at 56 BCM/yr (95mm/year) for present condition. In order to study the amount of the water resources of Kenya more comprehensively, the hydrological water budget was studied by applying the PET estimated by FAO Penman-Monteith (FAO-PM) method. The procedure is as mentioned below:

a) The difference of the both of PETs were calculated; $\Delta ET = ET_{PM} - ET_{Ham}$, where ET_{PM} is potential evapotranspiration evaluated by FAO-PM method and ET_{Ham} is that of Hamon method.

b) The groundwater recharge which is the percolation flux from sub-surface soil layer to aquifer, was corrected by subtraction ΔET from the percolation calculated under the condition of Hamon PET; Rech_corrected = Rech - ΔET

c) The correction processed repeated for every SHER model blocks day by day.

Then, the corrected groundwater recharge under the condition of FAO-PM PET was estimated at 21.5 BCM/yr (36mm/year) for whole country.

There are a certain range of uncertainty on the evaluation of groundwater recharge and soil evapotranspiration. It is very difficult to predict the amount of the groundwater recharge with unfailing accuracy. The groundwater analysis is discussed in Chapter 7 in detail.

The estimated hydrological water budget for the PET by Hamon method illustrated in Figure 5.5.1 and that for the PET by FAO-PM method is shown in Figure 5.5.2. Figure 5.5.3 shows the change of annual surface runoff volume for 2010, 2030 and 2055.

The distribution of groundwater evapotranspiration is discussed in Chapter 7.

5.5.2 Soil Evapotranspiration

The soil evapotranspiration was obtained from the rainfall-runoff model analysis for the present and the future climate conditions of 11 GCMs. The ensemble analysis results of the actual soil evapotranspirations for the potential evapotranspiration estimated by Hamon method are shown in Figure 5.5.4 for annual amount and in Figures 5.5.5 to 5.5.8 for seasonal amount. Those for FAO-PM method are shown in Figures 5.5.9 to 5.5.13. They are tabulated below by catchment area.

Annual Soil Evapotranspiration Estimated under Hamon PET Condition

(Unit: mm/year)

Catchment Area	Area (km^2)	Present (2010) Climate	2030 Climate	2055 Climate
Lake Victoria North	19,012	800	854	898
Lake Victoria South	27,425	784	835	864
Rift Valley	136,847	440	506	565
Athi	67,469	687	756	777
Tana	127,462	671	733	774
Ewaso Ng'iro North	210,573	449	514	566
Whole Country	588,790	549	613	659

Note: The area was measured by the GIS data provided by WRMA.
Source: JICA Study Team.

Annual Soil Evapotranspiration Estimated under FAO-PM PET Condition

(Unit: mm/year)

Catchment Area	Area (km^2)	Present (2010) Climate	2030 Climate	2055 Climate
Lake Victoria North	19,012	1,102	1,178	1,230
Lake Victoria South	27,425	1,019	1,085	1,118
Rift Valley	136,847	482	553	617
Athi	67,469	741	813	837
Tana	127,462	731	791	832
Ewaso Ng'iro North	210,573	475	541	593
Whole Country	588,790	608	675	723

Note: The area was measured by the GIS data provided by WRMA.
Source: JICA Study Team.

The annual evapotranspiration will increase over the whole country. The difference in evapotranspiration in the projected 2030 climate from present conditions was evaluated as 70 mm/year under both of PET evaluation methods, and the difference in the 2055 climate will be increased to 100 to 110 mm/year.

The difference of future evapotranspiration from the present climate of the long rainy season (MAM) will increase all over the country in the future. Meanwhile, the amount of evapotranspiration of the long dry season (JJA) will not change drastically and those of Tana and Athi catchments will decrease in the future.

5.5.3 Precipitation Minus Soil Evapotranspiration

The spatial distribution of the future annual precipitation minus the actual soil evapotranspiration (P-SET) will be almost unchanged from the present distribution. However, the northern part of the Rift Valley Catchment and the northern part of the Ewaso Ng'iro North Catchment are expected to be drier as shown in Figure 5.5.14 for the potential evapotranspiration estimated by Hamon method. The seasonal ensemble analysis are shown in Figures 5.5.15 to 5.5.18. Those for the potential evapotranspiration estimated by Hamon method are shown in Figures 5.5.19 to 5.5.23.

From the seasonal view, even though the increase of water resources is expected in the rainy seasons, most of the country will be drier in the dry season (June–August). Renewable water resources are more unevenly distributed in terms of spatial and temporal viewpoints in the future. The acceleration of unevenness of the temporal and spatial distribution is the impact of climate change on hydrological conditions of Kenya.

5.5.4 Groundwater Recharge

Groundwater is an important water resource for ASALs of Kenya. The groundwater recharge was estimated through rainfall-runoff analysis. The estimated annual groundwater recharges by catchment areas for the years present, 2030, and 2055 are shown below. Groundwater recharge was estimated based on the rainfall – runoff analysis. Considering future climate change, annual rainfall was estimated to be increased and the annual evapotranspiration was estimated to be increased. These are the impact of the climate change which is derived from analysis using GCM results. These two impacts have opposite vector to the water resources.

Annual Groundwater Recharge by Catchment Area under Hamon PET Condition

(Unit: MCM/year)

Catchment Area	Area (km^2)	Present (2010) Climate	2030 Climate	2055 Climate
Lake Victoria North	19,012	7,083	7,412	7,917
Lake Victoria South	27,425	8,743	8,983	9,096
Rift Valley	136,847	6,863	7,467	8,250
Athi	67,469	7,002	7,099	7,686
Tana	127,462	15,298	13,977	13,217
Ewaso Ng'iro North	210,573	10,986	10,642	10,708
Total	588,790	55,975	55,580	56,874

Note: The area was measured by the GIS data provided by WRMA.
Source: JICA Study Team.

Annual Groundwater Recharge by Catchment Area under FAO-PM PET Condition

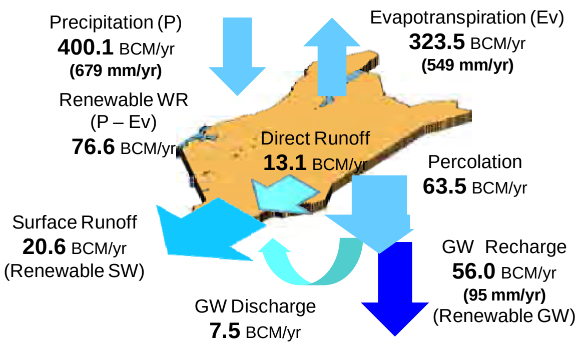
(Unit: MCM/year)

Catchment Area	Area (km^2)	Present (2010) Climate	2030 Climate	2055 Climate
Lake Victoria North	19,012	1,326	1,251	1,612
Lake Victoria South	27,425	2,294	2,112	2,126
Rift Valley	136,847	1,126	1,126	1,209
Athi	67,469	3,345	3,303	3,649
Tana	127,462	7,719	6,520	5,840
Ewaso Ng'iro North	210,573	5,660	5,095	4,851
Total	588,790	21,470	19,407	19,287

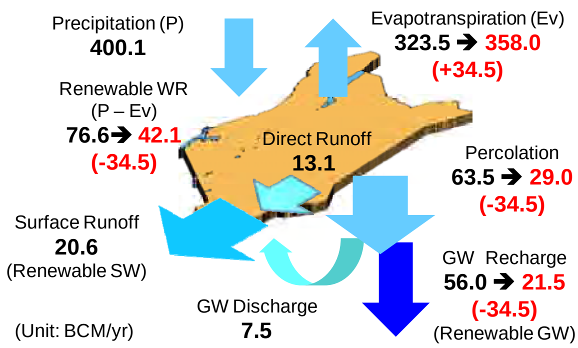
Note: The area was measured by the GIS data provided by WRMA.

Source: JICA Study Team.

The amount of the groundwater recharge estimated under the FAO-PM PET condition is about half of the amount under the Hamon PET condition.



Evapotranpiration estimated with Hamon



Evapotranpiration estimated with FAO Penman

By changing Hamon to FAO Penman, the evapotranspiration increases by 34.5 BCM and becomes 358.0 BCM/yr. (608 mm/year.), meaning about 10% increase from the original 323.5 to 358.0 BCM/year. Because the evapotranspiration increases and a surface runoff value remain unchanged, the groundwater recharge decreases by 34.5 BCM/year (the same amount of evapotranspiration increase) and becomes 21.5 BCM/year (36mm/year.). In this manner, the small increase in evapotranspiration gives large decrease in groundwater recharge which is about 60% of the groundwater recharge estimated by Hamon method (56.0 BCM/year).

The spatial distributions of ensemble mean annual groundwater recharges under Hamon PET condition are shown in Figure 5.5.24 for whole country and in Figures 5.5.25 to 5.5.28 for seasonal change. Those under FAO-PM PET condition are shown in Figures 5.5.29 to 5.5.33.

The amount and distribution of groundwater recharge are expected not to be changed drastically in view of the annual amount and distribution. The recharge volume will be increased at wet areas, particularly in the middle and western area, while the recharge volume at ASALs will decrease.

The change of the recharge amount in the long dry season, from June to August, is shown in Figure 5.5.14, and the groundwater recharge of the dry season will decrease in most parts of the country.

The further unevenness of spatial and temporal can also be expected from the aspect of the groundwater recharge.

The change of groundwater recharge amounts between 2010 and 2055 is small under Hamon PET condition as the difference is only 2% of the groundwater recharge amount, while the difference under

FAO-PM PET condition comes to 10%, but it is considered to be not significant difference considering accuracy of estimation of the evapotranspiration and uncertainty of the climate change analysis. The groundwater recharge amount will remain almost unchanged toward future.

5.6 Evaluation of Water Resources

5.6.1 Annual Renewable Water Resources

Renewable water resources are computed on the basis of the water cycle. The total of annual renewable surface water resources and annual groundwater recharge were estimated by multiplying the values of rainfall minus the soil evapotranspiration by catchment area. The total annual renewable surface water resources and annual groundwater recharge by catchment for the years of present , 2030 and 2055 were estimated, as shown below.

Annual Renewable Water Resources under Hamon PET Condition

(Unit: MCM/year)

Catchment Area	Present (2010) Climate	2030 Climate	2055 Climate
Lake Victoria North	11,709	12,379	13,371
Lake Victoria South	13,516	14,732	16,101
Rift Valley	9,319	10,512	12,045
Athi	8,199	8,434	9,397
Tana	21,156	21,239	20,600
Ewaso Ng'iro North	12,710	13,177	12,069
Total	76,609	80,473	83,583

Note: The area was measured by the GIS data provided by WRMA.
Source: JICA Study Team

Annual Renewable Water Resources under FAO-PM PET Condition

(Unit: MCM/year)

Catchment Area	Present (2010) Climate	2030 Climate	2055 Climate
Lake Victoria North	5,952	6,220	7,067
Lake Victoria South	7,067	7,861	9,131
Rift Valley	3,583	4,171	5,003
Athi	4,543	4,637	5,360
Tana	13,577	13,781	13,223
Ewaso Ng'iro North	7,385	7,631	6,212
Total	42,107	44,301	45,996

Note: The area was measured by the GIS data provided by WRMA.
Source: JICA Study Team

As shown in the above table, the renewable water resources in all catchments except Tana and Ewaso Ng'iro North have an increasing trend. The eastern part of the country, in which Tana and Ewaso Ng’iro North catchments are placed, will be stronger drying pressure rather than the other area. The renewable water resources in Ewaso Ng'iro North Catchment are expected to increase in 2030, but will decrease in 2055 due to the increase of potential evapotranspiration. A contradicted trend was seen due to the sensitive balance of precipitation increase and evaporation increase. From a planning point of view, the present values were decided to be applied considering the uncertainty of GCM projections.

The amount of the renewable water resources under FAO-PM PET condition was estimated as half of that of the Hamon method. In order to avoid the excessive development, it is recommended to use the water resources estimated by the FAO-PM PET condition in this study.

5.6.2 Annual Renewable Surface Water Resources

The renewable surface water resources were estimated by summation of the annual river runoff at most downstream river reaches within the catchment through the rainfall-runoff analysis. The estimated annual renewable surface water resources by catchment for the years of 2010, 2030 and 2055 are shown in the table in Section 5.4.1 as annual surface water runoff. The specific annual renewable surface water resources by sub-basin for the year 2010 are shown in Figure 5.6.1. The difference of annual renewable surface water between 2010 and 2030 is shown in Figure 5.6.2.

5.6.3 Annual Renewable Groundwater Resources

The renewable groundwater resources were estimated as groundwater recharge within the catchment through the rainfall-runoff analysis. The estimated annual renewable groundwater resources by catchment for the years of 2010, 2030 and 2055 are shown in the tables in Section 5.5.4 as annual groundwater recharge. The annual groundwater recharge much varies by variation of the evapotranspiration. As seen in the tables, the amount of the renewable groundwater resources under FAO-PM PET condition comes to 21.5 BCM/year which is less than half of that of Hamon PET condition of 56 BCM/year. The distribution of groundwater recharge is discussed in Chapter 7.

5.7 Recommendation for Further Study

For the hydro-meteorological analysis, a lot of existing rainfall and river discharge data were checked and it was known that the existing data have many gaps in observation. The accuracy of analysis depends on reliability of the data used.

It is recommended to continuously carry out the observation of rainfall and river discharges at the key stations to improve the reliability of the data.

CHAPTER 6 FLOOD ANALYSIS

6.1 Approach to the Analysis

One of the important points of climate change impact on hydrological conditions is that flood flow is expected to increase. The probable flood discharge was evaluated in this chapter.

The data availability of observed flood data of Kenya is not sufficient in view of the number of stations and temporal availability. The stations which have sufficient data availability were selected for the evaluation of probable flood discharge. Several probability density function (PDFs) were examined to estimate probable flood discharge. The standard least-squares criterion (SLSC) is the index for evaluation of fitness of the calibrated PDF to the plotted sample dataset by plotting position method. The most appropriate PDF, which indicates the smallest value of SLSC, was selected.

The output of the rainfall-runoff analysis covered the whole of the country. Simulated discharge data sets were assessed, not only for present conditions but also future conditions, considering climate change impacts. Probable flood discharges at every river point, which were modelled for runoff analysis, were evaluated in the same way as that for observed data. There were 11 scenarios for the future because 11 GCMs were selected for the study of climate change impact. The assessed 11 probable flood discharges were averaged and the ensemble mean and confidential interval for every point were evaluated.

Finally, the assessed probable discharge for the present and the future, particularly in 2030 and 2055, were aligned with the catchment area on a log-log plot. The regression curves for the regional plots were calculated. The regional area-flood discharge curve can be applied for trial evaluation for river planning and dam planning. Although the detailed study for flood discharge would be necessary for the detailed planning.

6.2 Evaluation of Probable Flood Based on Observed Discharge

6.2.1 Data Availability and Extraction of Annual Maximum Discharge

The daily discharge data for 47 river gauging stations were corrected for this study. The data availability for each year was tabulated in Table 5.2.1. For flood analysis, annual maximum discharge is most important and most basic value. It might be difficult to know the maximum discharge for the year that data availability is too low. For evaluating probable quantity by statistical approach, 20 or more samples are necessary. The numbers of valid years for each station were counted. The valid year is defined as the annual data availability is over 80%. The stations with more than 15 valid years were selected for the subjected stations for frequency analysis and the valid year counting result are shown in Table 6.2.1. The hydrographs of selected stations are shown in Figures 6.2.1 to 6.2.18.

Annual maximum floods for the selected stations were extracted from the observed record and are given in Table 6.2.2.

6.2.2 Probable Flood Based on Observed Discharge Record

(1) Probability Density Functions

The probable flood discharges were examined using five PDFs. The applied PDFs are Log Normal Distribution (LN3), Gumbel Distribution, Log Pearson III Distribution (LP3), Generalized Extreme Value Distribution (GEV) and Square-Root Exponential Type Distribution (SQRT-ET). The formulas are described below.

Log Normal Distribution (LN3):

Probability density function

$$f(x)=\frac{1}{(x-a)\sqrt{2\pi}\sigma_y}\exp\left\{-\frac{1}{2}\left[\frac{\ln(x-a)-\mu_y}{\sigma_y}\right]^2\right\},\quad y=\ln(x-a) \qquad \text{(eq. 6.1)}$$

Cumulative distribution function

$$F(x)=\Phi\left(\frac{\ln(x-a)-\mu_y}{\sigma_y}\right),\quad \Phi(z)=\frac{1}{\sqrt{2\pi}}\int \exp\left(-\frac{1}{2}t^2\right)dt \qquad \text{(eq. 6.2)}$$

Where, *a* is a parameter, μ_y is mean, and σ_y is standard deviation of *y*.

Gumbel Distribution:

Gumbel distribution function is also known as the double exponential function.

Probability density function

$$f(x)=\frac{1}{a}\exp\left[-\frac{x-c}{a}-\exp\left(-\frac{x-c}{a}\right)\right],\quad -\infty<x<\infty \qquad \text{(eq. 6.3)}$$

Cumulative distribution function

$$F(x)=\exp\left[-\exp\left(-\frac{x-c}{a}\right)\right] \qquad \text{(eq. 6.4)}$$

Where, *a* and *c* are parameters of the function.

Log Pearson III Distribution (LP3):

Probability density function

$$f(x)=\frac{1}{|a|\Gamma(b)x}\left(\frac{\ln x-c}{a}\right)^{b-1}\exp\left(-\frac{\ln x-c}{a}\right),\quad a>0,\quad \exp(c)<x<\infty \qquad \text{(eq. 6.5)}$$

Cumulative distribution function

$$F(x)=G\left(\frac{\ln x-c}{a}\right),\quad G(\omega)=\frac{1}{\Gamma(b)}\int_0^{\omega}t^{b-1}\exp(-t)dt\quad (a>0) \qquad \text{(eq. 6.6)}$$

Where, *a*, *b* and *c* are parameters of the function.

Generalized Extreme Value Distribution (GEV):

Probability density function

$$f(x) = \frac{1}{a}\left(1 - k\frac{x-c}{a}\right)^{1/k-1} \exp\left[-\left(1 - k\frac{x-c}{a}\right)^{1/k}\right] \quad (k \neq 0) \qquad \text{(eq. 6.7)}$$

Cumulative distribution function

$$F(x) = \exp\left[-\left(1 - k\frac{x-c}{a}\right)^{1/k}\right] \quad (k \neq 0) \qquad \text{(eq. 6.8)}$$

Where, *a, c* and *k* are parameters of the function.

Square-Root Exponential Type Distribution (SQRT-ET):

Probability density function

$$f(x) = \frac{ab}{2}\exp\left[-\sqrt{bx} - a\left(1+\sqrt{bx}\right)\exp\left(-\sqrt{bx}\right)\right] \quad (x \geq 0) \qquad \text{(eq. 6.9)}$$

Cumulative distribution function

$$F(x) = \exp\left[-a\left(1+\sqrt{bx}\right)\exp\left(-\sqrt{bx}\right)\right] \quad (x \geq 0) \qquad \text{(eq. 6.10)}$$

Where, *a* and *b* are parameters of the function.

(2) Probable Flood Discharge

Probable flood discharges were calculated using the five PDFs mentioned above. The five PDFs evaluated the fitness of the estimated PDF to the sampled annual maximum data. The SLSC was applied for the evaluation of the fitness, which is widely used to quantify the fitness of extreme distribution functions to data. The best fitted PDF, which has the lowest SLSC score among the five PDFs, was selected. An SLSC score of 0.04 was used as a criterion of the common fitness validity. The evaluated probable floods which have an SLSC score of more than 0.04 were considered invalid. The evaluated probable floods for the selected river gauging stations are shown in Table 6.2.3.

6.3 Assessment of Probable Flood in Future and Regional Area-Flood Curve

The rainfall-runoff analysis was carried out for the whole country, and the dates for present (1981-2000), as well as the years of 2030 (2021-2040) and 2055 (2046-2065) were evaluated. For the evaluation of future hydrological conditions, all data of the 11 selected GCMs were applied for the input of the runoff analysis. The probable flood discharges of all river reaches in Kenya were evaluated based on the simulated river discharge for all GCMs in the future condition, the same way as the evaluation based on observed data. The 11 probable discharges were averaged and the ensemble mean of probable discharge was calculated for every river reach. The probable flood discharges of ensemble mean were plotted with the catchment area at corresponding river reaches. Then, regression analysis was carried out, and the regression curves were evaluated for every basin. The basin code which was shown in the figure and tables of this chapter is tabulated in Table 6.3.1. This code was numbered for the runoff model. The maps of the basins are shown in Figures 5.2.2 to 5.2.33.

The equations of regression curve of area-flood relation are given in Table 6.3.2. The probable flood discharges of Kenya are expected to increase for the whole region. It is difficult to discuss about the probable discharge in a high degree of accuracy because there are many kinds of problems in the process. Such problems include limited data availability of the observed river flow in terms of spatial and temporal, and low reliability of observed flood discharges. These evaluated results can be used as a rough estimation for the regional flood characteristics. It is highly recommended to further carry out a detailed study for the detailed planning or the design stage.

CHAPTER 7 GROUNDWATER ANALYSIS

7.1 Introduction

Groundwater has played and will continue to play a vital role in the development of various areas in Kenya. For example, the City of Nairobi relies extensively on groundwater to meet domestic, commercial and industrial needs that cannot be met by surface water supply. A number of major towns rely either exclusively or extensively on groundwater such as Malindi and Nakuru. Numerous rural communities across the country use groundwater from boreholes equipped with hand pumps. In the North Eastern Province where deep groundwater is the only perennial source of water for humans and livestock, economic activity is seriously hampered without groundwater. The agricultural export sector has grown rapidly with the help of groundwater development in many areas, notably in the Rift Valley, Athi and Ewaso Ng'iro Catchments. However, groundwater abstraction exceeding sustainable yield is seen, leading to water level decline (depletion) and water quality deterioration (Guidelines for Artificial Groundwater Recharge, WRMA, 2012).

The groundwater analysis in this study was carried out to understand the occurrence, distribution and movement of groundwater in the country. Major outputs of groundwater analysis include evaluation of sustainable yield of groundwater and preparation of the groundwater potential map showing the evaluation results.

The years subject to the groundwater analysis are same as those for the rainfall-runoff analysis in Section 5.1 as below.

a) Year 2010(Present): The year represents the present hydrometeorological conditions. The present (2010) climate in this study expresses the climate during 1991 – 2010.

b) Year 2030: Target year for formulation of NWMP 2030. The 2030 climate in this study expresses the climate during 2021 – 2040.

c) Year 2055: The year to evaluate the water resources around 2050 taking into account climate change. The 2055 climate in this study expresses the climate during 2046 – 2065. It can be expressed by Year 2050 in the formulation of NWMP2030.

As for the depth of groundwater, the deepest existing boreholes for water use purpose are at around 400 to 500 m at maximum. Therefore, this depth was regarded as the maximum for exploitation in the study. It was decided not to consider water use deeper than this, such as geothermal water.

7.1.1 Objective

Evaluation of groundwater potential is essential to develop groundwater resources strategically and efficiently. The objective of groundwater analysis is to know the source, distribution and movement of groundwater. The results of the analysis will be illustrated as a groundwater potential map. Groundwater potential was evaluated in the previous master plan; however, groundwater abstraction has been increasing in accordance with economic growth. An evaluation update for groundwater potential is needed, utilizing the latest available data.

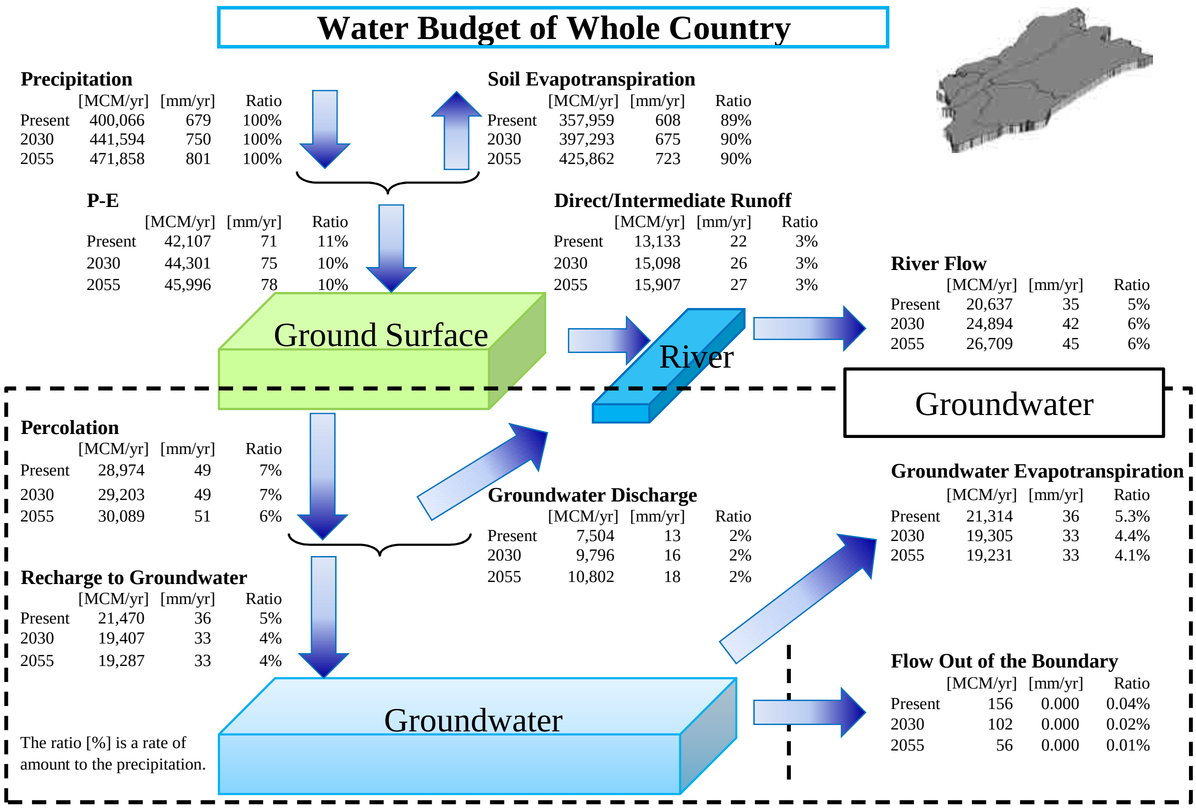
7.1.2 Approach to the Analysis

(1) Definition

There are several definitions of groundwater potential according to previous researches or studies. To avoid misunderstanding the term "groundwater potential", the following definitions were introduced in this study:

1) Renewable Groundwater Resources

Groundwater balance is indicated in the following figure of the annual water budget (similar to Figure 5.6.2). In the figure, renewable groundwater resource is equivalent to annual volume of "percolation", given by hydro-meteorological analysis in Chapter 5. Percolation is the movement of water through fractures or interstices of a rock or soil. The amount of renewable groundwater resources for the years present (2010), 2030 and 2055 are estimated as shown in the table below.



Note: Soil evapotranspiration is estimated by the FAO PM method
Source: JICA Study Team

Groundwater Balance

Renewable Groundwater Resources (Percolation) for Present (2010), 2030 and 2055

(Unit: MCM/year)

Catchment Area	Present (2010) Climate	2030 Climate	2055 Climate
Lake Victoria North	4,543	4,624	5,030
Lake Victoria South	4,763	4,772	4,944
Rift Valley	2,459	2,779	3,244
Athi	3,159	3,232	3,662
Tana	8,533	8,321	8,056
Ewaso Ng'iro North	5,517	5,475	5,153
Total	28,974	29,203	30,089

Source: JICA Study Team

2) Renewable Groundwater Recharge

Renewable groundwater recharge is equivalent to "annual volume of "Recharge to groundwater'' in the above figure. Recharge to groundwater is net amount of water added to an aquifer and is estimated as the rest of deriving "groundwater discharge" from "percolation". The amount of renewable groundwater recharge for the years present (2010), 2030 and 2055 are estimated through rainfall-runoff analysis by SHER model as shown in the table below.

Recharge to Groundwater for 2010, 2030 and 2050

(Unit: MCM/year)

Catchment Area	Present (2010) Climate	2030 Climate	2055 Climate
Lake Victoria North	1,326	1,251	1,612
Lake Victoria South	2,294	2,112	2,126
Rift Valley	1,126	1,126	1,209
Athi	3,345	3,303	3,649
Tana	7,719	6,520	5,840
Ewaso Ng'iro North	5,660	5,095	4,851
Total	21,470	19,407	19,287

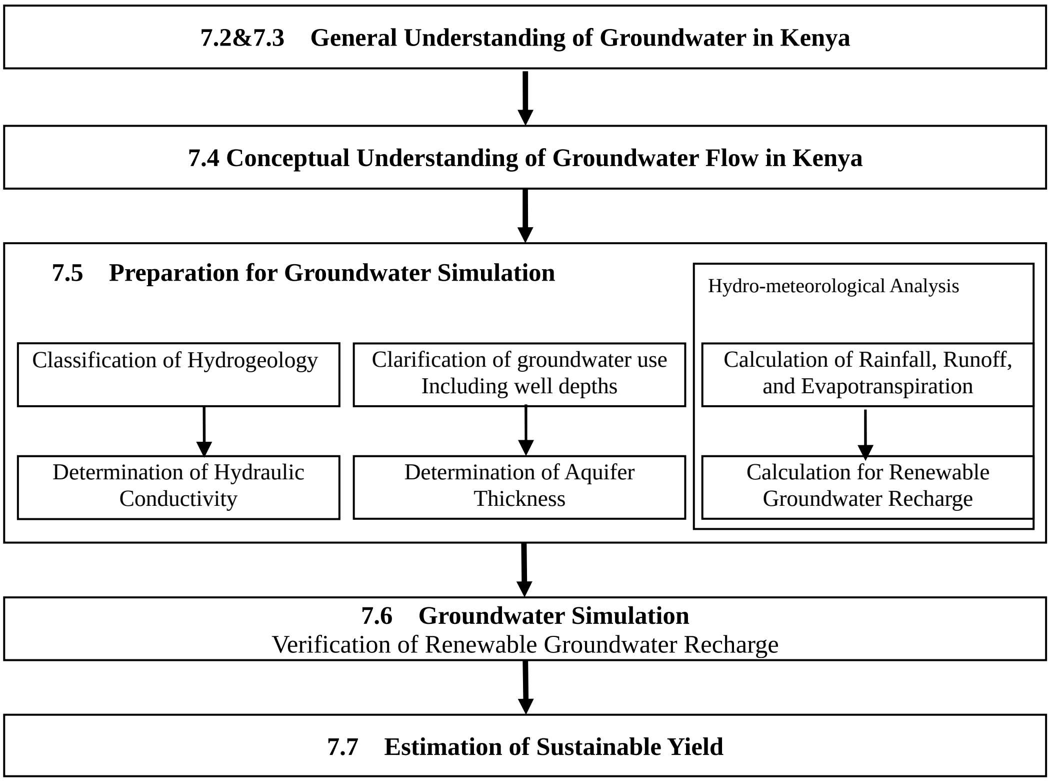
Source: JICA Study Team

3) Sustainable Yield

Sustainable yield is defined as the amount of groundwater which could be developed sustainably without an undesirable impact.

(2) Flow of Groundwater Analysis

The flow of the analysis to estimate the sustainable yield of groundwater is shown in the following chart. To verify how renewable groundwater recharge flows in the aquifer as groundwater and analyses the mechanism of groundwater flow, a groundwater flow simulation for the whole of Kenya is made using MODFLOW, originally developed by U.S. Geological Survey, and then the sustainable yield is estimated.



Flow of Groundwater Analysis

7.2 Geology and Hydrogeology

7.2.1 Geology

(1) Overview

From the Precambrian to the Cenozoic Eras, there consist of four major geological series which represent the complex geologic formation of Kenya. These four are the Precambrian, the Karoo, the Mesozoic and the Cenozoic. The Precambrian series, the lower portion of the geologic formation, is represented by volcanic rocks as well as the igneous and metamorphic rocks. The Paleozoic series is represented by the sedimentary rocks known as the Karoo System which is distributed in the south eastern part. The Mesozoic series is well developed in the north-east and the south-east. It represented by the sedimentary rocks. The Cenozoic series is probably the best developed and most important in terms of surface coverage and is represented y sedimentary and volcanic rocks of Tertiary and Quaternary deposition. The geological map of Kenya is shown in Figure 7.2.1.

(2) Precambrian Rocks

The Precambrian series are distributed in south western and central part of Kenya. It consists of four geological systems: Basement, Nyanzian, Kavirondian, and Bukoban. Detailed description of each system is summarised as follows;

a) The Basement system is composed of sedimentary rocks (grits, sandstones, shale, limestone) and volcanic rocks metamorphosed by heat, pressure and hydro thermal fluids

b) The Nyanzian system is composed of volcanic rocks (rhyolite, andesite, basalt and greywackes).

c) The Kavirondian System is composed of sedimentary rocks (alternating bands of grits, sandstones and shale which are only slightly metamorphosed).

d) The Bukoban system is composed of volcanic rocks (quartzite and volcanic product).

(3) Paleozoic series

The Paleozoic series is distributed in south eastern part of Kenya. It is mainly represented by the Toru grits, a monotonous series of grits, sandstones, shales and traces of coal.

(4) Mesozoic series

The Mesozoic series is distributed in northeastern and southeastern part of Kenya. It is divided into three ages: Triassic, Jurassic and Cretaceous. Triassic age is consists of upper unit system and lower unit system. The Upper unit system is represented by the Mazeras sandstone and the Shiiaba grits overlain by the Mariakani sandstones. The lower unit system is resented by sandstone. The Jurassic age system is composed of shales, sandstones in the south-east, whereas in the north-east it is chiefly limestone. The Cretaceous age system occurs in north eastern Kenya, where a lower series of siltstones and flaggy, fine-grained sandstones are overlain by a thick formation of cross-bedded sandstones, both of which are together known as Marihan series.

(5) Cenozoic series

The Cenozoic series is distributed in central and eastern part of Kenya. It is divided into two ages, Tertiary and Quaternary. The Tertiary age system is composed of volcanic rocks (basalt and trachyte) in the western part and sedimentary rocks (sandstone and limestone) in the eastern part.

The Quaternary age series is composed of the volcanic rocks (basalt, pyroclastics and trachyte) and alluvial and colluvial deposits in the western part, and sedimentary rocks (sandstone and limestone) and, alluvial and colluvial deposits in the eastern part.

(6) Tectonics

Mountain building, chiefly folding and faulting, began during the Precambrian or early Cambrian and continued until the Tertiary period, with varying degrees of intensity. Tectonic movements consisted mainly of uplifts with long periods of almost continued denudation, leading to peneplanation of much of Kenya in later Jurassic times. During the Cretaceous and early Tertiary, vertical and tilting movements were dominant and their effects are most readily evident along the coast as well as the Rift Valleys.

7.2.2 Hydrogeology

Hydrogeology in Kenya is classified into three geological categories, i.e. sedimentary rock, volcanic rock and basement rock. Detailed characteristics of each category are given below.

(1) Sedimentary Rock

Eastern sedimentary rock area covers about 30% of the country. It comprises of alluvial, beach sand, coral reef and limestone. Main aquifers appear to be made of coral limestone and Pleistocene sands underlain by Jurassic shale. Spring discharge is common, particularly along the shore. The aquifer is generally shallow and unconfined.

Sediments of Palaeozoic and Mesozoic systems occur in the south eastern and north eastern areas of Kenya. The lithology varies widely and three major sedimentary rock types of sandstone, limestone and shale are represented in the area. Aquifers in this area are typically confined and deep. The water generally includes chloride.

(2) Volcanic Rock

Volcanic rock covers about 25% of the country and is represented more commonly in the western area. For volcanic rocks outside the Rift Valley, the lithology is widely variable and includes phonolite, trachyte, and basalt. Groundwater storage in both the Tertiary and Quaternary is similar. Groundwater is stored typically in the old weathered zone between basement complexes. Fractures, faults and contraction joints are also suitable for water storage. Groundwater may occur within the volcanic formation mainly in zones between volcanic rocks of different types. Yield, depth and static water level varies enormously within the volcanic rocks. Aquifers are usually confined. Water quality is generally of bicarbonate type.

For volcanic rocks inside the Rift Valley, lithologic conditions are similar to those prevailing in adjacent areas. The complex structural character of the area has modified its water storage properties. Its geology is dominated by Tertiary volcanic, while the Quaternary volcanic represent the second most widespread rock type. A few pockets of basement rocks and quaternary sediments are also found. Groundwater resources in this area seems to be large in terms of depth to the groundwater, therefore, yield cannot be predicted with certainty because rock displacements can be of the order of a hundred meters. The complex pattern of faulting and cross-faulting can be resolved into a simple system trending SE-NW in the southern parts of the area. These faults affect not only water storage, but also the pattern of its migration and consequent discharge.

Hot springs and geysers occur commonly in this region evidencing active geothermal activity. The water is typically of bicarbonate type. Fluoride content is high in places which is believed to be of volcanic and fumarotic origin.

(3) Basement Rock

Rocks of basement complex are widely distributed throughout the country. These rocks occur mainly in the central, western and north eastern parts of Kenya, with small exposures in other parts. This hydrogeological zone covers 25% of the country. The lithology is dominated by granites, granitic rocks, schists and less metamorphosed sediments. They are deeply weathered, although the depth of weathering is not uniform. The aquifers are shallow and discontinuous, both vertically and laterally. Perched aquifers are typical as they are in most crystalline rocks where the faulting and fracture zones are extensive, and the groundwater table occurs. Water quality in this zone is generally good.

7.3 Current Situation of Groundwater Use

A water resources database was established through the previous water master plan study in 1992. Registered borehole data were stored on a database which is being managed by MWI. Since the reform of the water sector in 2003, WRMA has been responsible in the management of the database. The latest borehole data were collected from MWI. The database stores borehole data up to 2005 only, thus no data have been stored after. The location map of boreholes as stored in the database is shown in Figure 7.3.1.

Histograms of borehole numbers of each catchment by construction year are shown in Figure 7.3.2. The numbers of boreholes have been increasing for all catchments. The Athi Catchment has the largest cumulative number of boreholes, while Lake Victoria South Catchment has the smallest cumulative number.

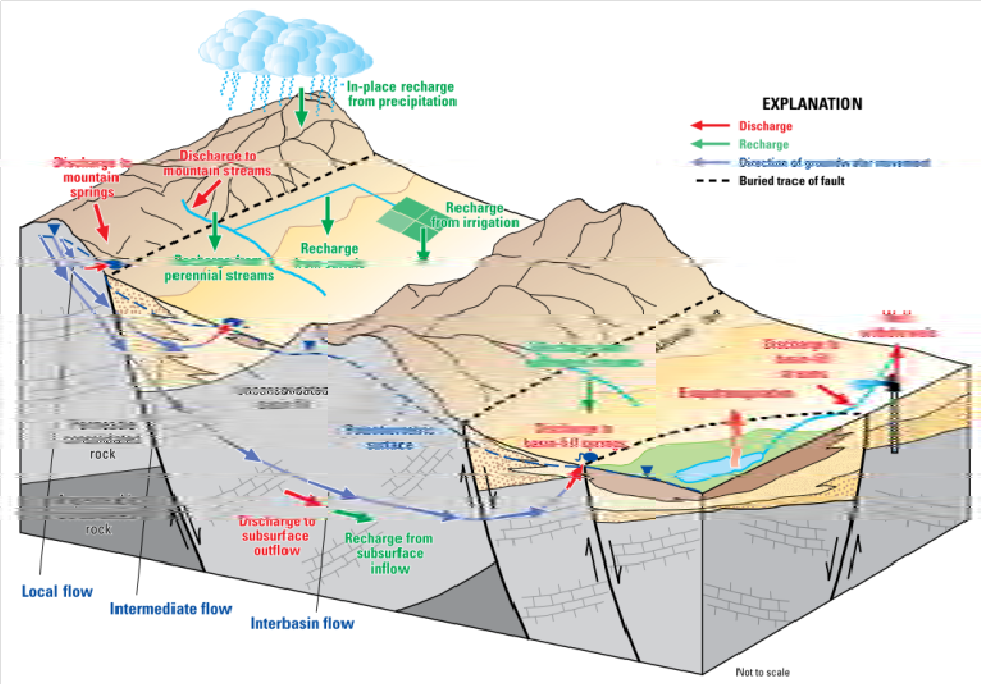
Histograms of borehole numbers of each catchment by depth are shown in Figure 7.3.3. Depth of boreholes varies for each catchment. In the Lake Victoria North, Lake Victoria South and Tana Catchments, the depths of almost all boreholes are less than 100 m. In other catchments, deeper boreholes are distributed. Histograms of borehole numbers of each catchment by depth are shown in Figure 7.3.3. Depth of boreholes varies for each catchment. In the Lake Victoria North, Lake Victoria South and Tana Catchments, the depths of almost all boreholes are less than 100 m. In other catchments, deeper boreholes are distributed but the depths of most wells are less than 500 m.

Histograms of borehole numbers of each catchment by yield are shown in Figure 7.3.4. The yields of boreholes seem to be almost the same for all catchments. It was determined that 5 L/min is the most dominant unit yield.

7.4 Conceptual Understanding of Groundwater Flow in Kenya

7.4.1 Conceptual Groundwater Flow Model for a Regional Aquifer System

A groundwater flow model was prepared after recollecting the related information on groundwater in Kenya. USGS's conceptual model of the Great Basin aquifer system, encompassing in eastern Nevada and western Utah in the United States and including 165 hydrographic basins and 17 regional groundwater aquifers, was referred to for this study. The following figure shows the conceptual model applied for this groundwater flow analysis. Precipitation in mountainous areas percolates underground, and then some moves in the shallow part in the ground and reappear at the outskirt of the mountains as springs (local flow). Deeper flow reaches plain areas in the basin (intermediate flow). Further deeper flow of the groundwater flows across the basin boundaries and reappear in the downstream basins (interbasin flow). In this manner, precipitation percolates underground to recharge groundwater and reappear on the ground mainly following three paths as mentioned above, then discharge into the atmosphere through evapotranspiration.



Source: U.S. Geological Survey. 2010. Groundwater Resources Program Conceptual Model of the Great Basin Carbonate and Alluvial Aquifer System. Scientific Investigations Report

Conceptualized Groundwater Flow of the Great Basin Aquifer

7.4.2 Major Aquifers in Kenya

World Bank conducted a case study on groundwater governance in Kenya (Mumma et al.2011). The four case aquifers, Merti, Nairobi, Tiwi, and Barcho shown in the table below, are picked up for the study. In addition to the case study, the report refers that there exists five significant transboundary aquifer groups: the Rift Valley aquifers, the Elgon aquifer, the Merti aquifer, the Kilimanjaro aquifer, and the Coastal sedimentary aquifers. Figure 7.4.1 shows the location of these transboundary aquifers but there is no further information such as their extents, aquifer type, and lithology, etc. except for Merti. In general, Great Rift Valley and volcanic geography/geology including Mt. Kenya over 5000m in height and the arid or semi-arid climate from the north western region to the south eastern region characterizes groundwater flow in Kenya.

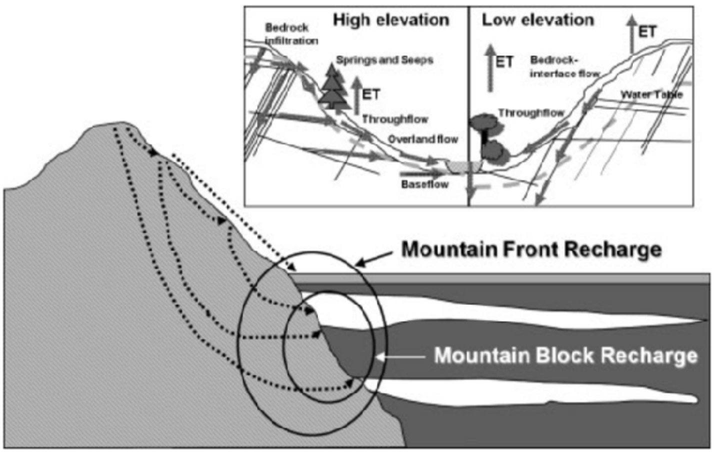
Major Aquifers in Kenya

Parameters	Major Aquifers			
	Merti	Nairobi	Tiwi	Baricho
Aquifer Type	(Semi) - Consolidated Sedimentary	Inter-montane Valley Fill	Major Alluvial	Major Alluvial
Lithology	Clays, Sands, Sandstones, Limestones	Lavas and Lake Sediments	Clays and Sands	Alluvial Sand and Gravel
Scale	Regional/ Transboundary	Regional	Local	Local
Surface Area	60,900 km^2	6,500 km^2	30 km^2	2 km^2
Pollution Vulnerability	Negligible - Low	Negligible - Low	Low - Moderate	High
Depletion Vulnerability	Moderate/Local	Serious/extensive	Low	Low
Dominant Water Use	Refugee Camps Livestock Domestic Public Water Supply	Domestic Commercial Industrial Irrigation Public Water Supply	Public Water Supply	Public Water Supply

Source: KENYA GROUNDWATER GOVERNANCE CASE STUDY, Albert Mumma et al, 2011, World Bank

7.4.3 Groundwater Recharge and Complex Flow in the Mountain Range

In the mountain ranges, infiltration goes down deeply through fractures even though the hydraulic conductivity of the ground itself is low. This deep recharge in the mountain range is called "bedrock recharge" (or mountain block recharge) and differentiated from recharge to the shallow layer. The recent research reported that the bedrock recharge reached 40% of precipitation in some places. The bedrock recharge forms the deep aquifer as groundwater and some of them flow into the downstream basin. In addition, there are a lot of faults around the Great Rift Valley and the mountain ranges around Mt. Kenya due to mountain-building activities. Because the faults disturb the horizontal movements of groundwater in some places, groundwater flow becomes complex there.

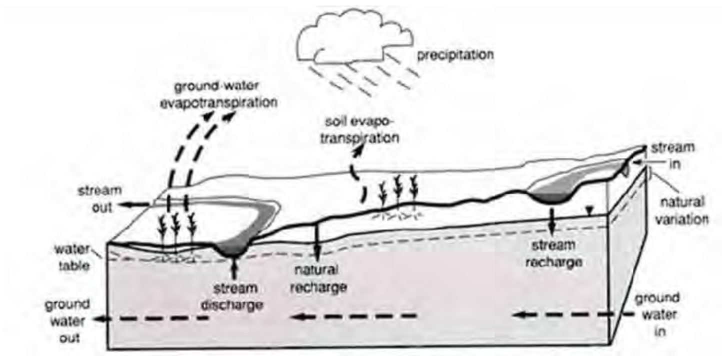


Source: Pam Aishlin and James P MacNamara. 2011. Bedrock infiltration and mountain block recharge accounting chloride mass balance. Hydrological Processes

Bedrock Recharge in the Mountain Ranges

7.4.4 Groundwater Evapotranspiration

Vegetation such as grasses and trees directly absorb groundwater and vapor it into the atmosphere as transpiration in the riparian area such as riversides, lakeshores, and marsh lands where groundwater tables are shallow. This phenomenon, combined with evaporation from the ground surface, is called "groundwater evapotranspiration", differentiated from evapotranspiration where the groundwater table is relatively deep, called "soil evapotraspition" here. The groundwater evapotranspiration is an important component of water balance as a sink especially in arid and semi-arid regions. For example, in the Great Basin aquifer underlying Nevada and Utah f the U.S.A. and consisting of 17 groundwater basins mentioned in 7.4.1, the ratio of groundwater evapotranspiration to total sink in its groundwater balance reaches 69% at most on the basis of the groundwater basin and 43% in the entire aquifer.



Source: Kansas Ground Water,
http://www.kgs.ku.edu/Publications/Bulletins/ED10/07_manage.html

Water Movement near Ground Surface and Groundwater Evapotranspiration

7.4.5 Groundwater in Six Catchment Areas in Kenya

Considering the location of the aquifers, production well locations (present groundwater development and utilization), geography, geology, climate, and hydrology (characteristics of surface water discharge), the groundwater flow conditions in six catchment areas of Lake Victoria North, Lake Victoria South, Rift Valley, Athi, Tana and Ewaso Ng'iro North are grasped and summarised below:

(1) Lake Victoria North Catchment Area

Groundwater discharges to the rivers or flow through the aquifers and reaches Lake Victoria.

(2) Lake Victoria South Catchment Area

Groundwater discharges to the rivers or flow through the aquifers and reaches Lake Victoria.

(3) Rift Valley Catchment Area

Rift valley Catchment Area is characterized with lakes, such as Baringo, Naivasha, Nakuru and Magadi in the south and Turkana in the north. Precipitation falls on the western slopes of the mountain ranges including Mt. Kenya and most water percolates into the aquifer as groundwater and some portion discharges as spring in the shallow layer, flows into the rivers and finally reaches the lakes or stay in a marsh and vapors into the atmosphere. The other is stored in the aquifers of the Rift Valley. The aquifers extend to the north western arid region of Kenya and Ethiopia.

(4) Athi Catchment Area

Because the aquifers underlie the surrounding areas of Mt. Kilimanjaro, there are swamps in Amboseli and Mzima springs discharging plentiful water.

(5) Tana Catchment Area

Precipitation falls on the eastern slopes of the mountain ranges including Mt. Kenya and most water percolates into the aquifer as groundwater and some portion discharges as spring in the shallow layer, flows into the rivers. The other stays in marshes and vapours into the atmosphere. In this basin, Tana River originates from Mt Kenya and flows into the Indian Ocean, and its river flow is very low, compared to the amount of rainfall even. The possible reasons for this low river flow are considered a great amount of evapotranspiration from inundated areas in flood and infiltration from the river bottom but its mechanism is not clear. The middle and downstream of the basin locates in the arid and semi-arid climate, and thus groundwater evapotranspiration is expected to be significant in a location where the groundwater table is shallow. Along the Indean Ocean coasts, the aquifers exist and groundwater has been explored.

(6) Ewaso Ng'iro North Catchment Area

This area has the Merti aquifer, considered as the greatest aquifer in Kenya. Ewaso Ng'iro North River flows into Lorian swamps and disappears before reaching the Indian Ocean. The middle and downstream of the basin locates in the arid and semi-arid climate, similar to the Tana basin.

7.5 Preparation for Groundwater Flow Simulation

7.5.1 Available Data

The following data were collected and utilized for the analysis.

Available Data for Groundwater Analysis

Category	Data	Resources
Geology	Geological map of Kenya	Ministry of Energy and Regional Development
	Groundwater resources map	UNESCO (2008)
Groundwater level	Borehole database	MWI / WRMA
Hydraulic Parameter	Pumping test data	JICA (1992)
Groundwater abstraction rate	Borehole database	MWI / WRMA

Source: JICA Study Team

The geological map of Kenya and the groundwater resources map were utilized to classify the geological formation and to apply hydraulic parameters to each geological classification for analysis. The groundwater level data were utilized to describe the groundwater level contour maps. The borehole data were collected. This data includes groundwater level data when the boreholes were constructed.

Since official statistical data of groundwater abstraction rate in the whole of Kenya is unavailable, the groundwater abstraction rate was estimated using only the available data. The groundwater abstraction rate map of Kenya was prepared in the previous master plan in 1992, but the map showed only data to estimate the groundwater abstraction rate of the whole of Kenya. A borehole database was utilised to estimate the latest amount of groundwater abstraction in the study.

In terms of data accumulation after 1992, the situation before 1992 was better compared with the last 20 years. Some conductivity data were added, but for the groundwater analysis the amount of additional data was not significant.

The spatial distribution of hydraulic conductivity for the upper confined aquifer was determined using the hydrological classification and pumping test results which ware obtained at specific locations in this study. If more detailed hydrological classification and pumping test results are available, it will surely contribute to more accurate analysis.

7.5.2 Hydraulic Conductivities, Aquifer Thickness and Groundwater Contour

(1) Hydrogeological Classification

The Worldwide Hydrogeological Mapping and Assessment Programme (WHYMAP) were undertaken by UNESCO (2008), and the groundwater resources map of the world was produced by the programme. The hydrogeological classification is shown in Figure 7.5.1, which was prepared based on the geological map of Kenya shown in Figure 7.2.1 and the UNESCO's water resources map mentioned above. As seen in this figure, geological setting are classified into three categories, i.e. major basin comprised of sedimentary rock, complex hydrogeological structure comprised of volcanic rook, and local aquifers comprised of metamorphic and intrusive rock.

(2) Hydraulic Conductivity

The hydraulic conductivity value is necessary to evaluate the groundwater flow rate. Pumping test data were evaluated in the previous master plan study. These data results were utilised to determine the hydraulic conductivity for the hydrogeological classification of this study. A histogram of estimated hydraulic conductivity is shown in Figure 7.5.2 and the representative values were determined as follows. The spatial distribution of hydraulic conductivity in the upper unconfined aquifer is determined as shown in Figure 7.5.3, in accordance with the hydrogeological classification.

Hydraulic Parameter for the Groundwater Flow Analysis

Hydrogeological Classification	Geological Era	Hydraulic Conductivity (cm/s)
Quaternary sedimentary rock	Quaternary	1.0×10^{-4}
Volcanic rock Old sedimentary rock	Neogene, Mesozoic	1.0×10^{-5}
Metamorphic rock Intrusive rock	Paleozoic, Precambrian	1.0×10^{-6}

Source: JICA Study Team

(3) Aquifer Thickness

Figure 7.5.4 shows the locations of existing production wells and their average depths on around 110 km x 110 km size cells. The thickness of the upper unconfined aquifer is estimated using these average depths of production wells as shown in Figure 7.5.5.

(4) Groundwater Level Contour Map

Groundwater level distribution was interpolated based on the available information from the borehole database. Borehole data with a total of 5,600 boreholes were used for the interpolation. The groundwater level contour map was prepared as shown in Figure 7.5.6.

7.6 Groundwater Flow Simulation

7.6.1 Numerical Simulation of Groundwater Flow

(1) Steady-state Simulation with MODFLOW

A three-dimensional groundwater flow model, MODFLOW (McDonald & Harbaugh, 1988), was used for the groundwater-flow simulation. Steady-state simulations are made to replicate groundwater flow under a pre-development condition (without any pumping). To reach steady-state conditions, transient-simulation with time-step for 100 years (36500 days) is repeated for 10,000 years.

(2) Model Discretization and Boundary Conditions

Considering the scale of the aquifer and the available computer resource for the analysis, the entire area of Kenya was discretized with 5 km size cells. Its simulation results were good enough to match the observed data. Therefore, the 5 km size cell is considered appropriate. Figure 7.6.1 shows the boundary conditions. Constant-head boundaries are set for Daua River, the national border with Ethiopia, the Indian Ocean coast, Lake Victoria and Lake Turukana and also the national boundary with Somalia and some portion of the national border with Tanzania based on the basin boundaries determined for the SHER model. Figure 7.6.1 shows the boundary conditions. Constant-head boundaries are set for Daua River, the Lake Turukana and also the national boundary with Somalia and some portion of the national border with Tanzania based on the basin boundaries determined for the SHER model. No-flow boundaries are set for other peripheral borders but any no-flow boundaries are set for the inside of Kenya in the groundwater flow model although six surface catchment exist.

(3) Aquifers and Hydrogeological Parameters

As described in 7.4.2, the aquifers are widely distributed in the entire Kenya. Thus, it is assumed that the aquifer system consists of two layers: the upper unconfined aquifer and the lower confined layer here (Figure 7.6.2 case A). The thickness of the upper layer is 300m to 500m and its hydraulic conductivity is 5.0 x 10^{-5} cm/s to 5.0 x 10^{-4} cm/s in accordance with the hydrogeological classification shown in Figure 7.5.1. The conductivities used for this study are determined based on the observed records. The lower layer is assumed as the bedrock containing water in its fractures, and its thickness ranges 200 m to 1800 m, its hydraulic conductivity is constant at 1.0 x 10^{-5} cm/s. Storativity is 0.05 for an unconfined condition and 1.0 x 10^{-5} for a confined condition.

In order to investigate outflow from the boundaries and interflow between the basins (inter-basin flow), the thickness of the lower confined layer is increased from 200 m ~ 800 m to 2000 m ~ 3000 m (Figure7.6.2 case B), and the steady-state simulation was made. However, its increase of outflow from the boundaries and interflow between the basins is only 1.2 times of that of case A. Therefore, the thickness of lower confined aquifer with 200 to 1800 m is adopted for the subsequent simulations.

In addition, the difference of hydraulic conductivities with the range of 10^{-4} to 10^{-6}cm/s does not affect much and there is no large movement of the groundwater between the neighbouring blocks. Amount of evapotranspiration from each block affects more to the analysis results.

As described in Section 7.4.2, the aquifers are widely distributed in the entire Kenya. Thus, it is assumed that the aquifer system consists of two layers: the upper unconfined aquifer and the lower confined layer here (Figure 7.6.2 case A). The thickness of the upper layer is 300 m to 500 m and its hydraulic conductivity is 5.0 x 10^{-5} cm/s to 5.0 x 10^{-4} cm/s in accordance with the hydrogeological classification shown in Figure 7.5.1. The lower layer is assumed as the bedrock containing water in its fractures, and its thickness ranges 200 m to 1,800 m, its hydraulic conductivity is constant at 1.0 x 10^{-5} cm/s. Storativity is 0.05 for an unconfined condition and 1.0 x 10^{-5} cm/s for a confines condition.

In the mountain regions, the groundwater flow becomes complex as described in 7.4.3, but these complexities such as faults are not modelled because the purpose of this simulation is to grasp general (not local) groundwater flow in Kenya.

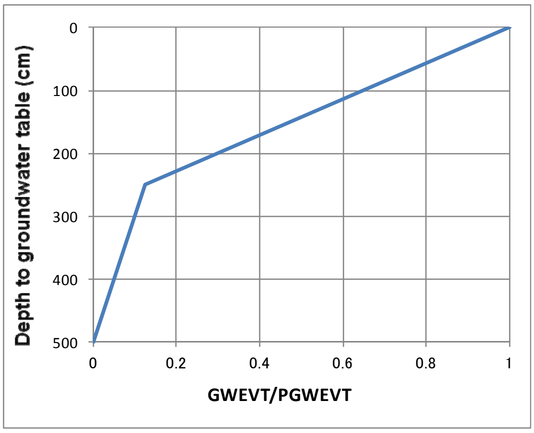
(4) Spatial Distribution of Recharge to Groundwater

Percolation and groundwater discharge estimated from SHER are distributed in 5 km x 5 km size cells encompassing the entire country (Figure 7.6.3). In the SHER model, rainfall, percolation and groundwater recharge area estimated for around 3,000 sub-basins not for six catchments, meaning those values varies from sub-basin to sub-basin.

(5) Groundwater Evapotranspiration

Soil evapotaranpiration estimated by SHER and Groundwater evaporation estimated by MODFLOW are shown in Figure 7.6.4. In addition to soil evapotranspiration from the sub-surface soil (assumed as 2.0 m thick) in SHER, groundwater evapotranspiration (GWEVT), which is once recharged to the aquifer as groundwater and then evapotraspirates through vegetations or trees, is considered.

Groundwater evapotranspiration decreases as a depth to the groundwater table increases and depends on land covers (vegetation) and subsurface soils. Groundwater evapotranspiration was estimated with s piecewise linear function in MODFLOW shown below:



Source: JICA Study Team

Relationship between Groundwater Evapotranspiration and Depth to Groundwater Table

On the ground surface (groundwater depth = 0 m), GWEVT to potential evapotranspiration is 100%. As the depth from the ground surface becomes deeper, GWEVT decreases. At 2.5 m depth below the ground surface, GWEVT is 12.5% of potential evapotranspiration, and at 5 m depth below the ground surface, GWEVT becomes zero.

The spatial distribution of potential groundwater evapotranspiration (PGWEVT) is shown in Figure 7.6.5. PGWEVT is the rest of subtracting EVT estimated by SHER from potential evapotranspiration (PET).

7.6.2 Simulation Results

(1) Spatial Distribution of Groundwater Levels

Simulated groundwater levels of the upper unconfined aquifer and observed ones are shown in Figure 7.6.6. Overall, the simulated and observed contours have similar groundwater flow directions.

(2) Groundwater Evapotranspiration

1) Verification of Groundwater Evapotranspiration Existence using Satellite Images

The spatial distribution of groundwater evapotranspiration was estimated using MODFLOW (Figures 7.6.7). The locations where groundwater evapotranspiration occurs is similar to the locations where groundwater table is shallow (within 5 m depth below the ground surface shown in Figure 7.6.8) since it is assumed that the groundwater evapotrenspiration occurs at the depths from zero to 5 m below the ground surface. Here, it is verified whether trees exist or not at the locations where groundwater evapotranspiraton is predicted and the ground water table is shallow. This verification was made using satellite image derived from Google Earth, and thus, the locations where groundwater evapotranspiration occurs are overlaid on the land use map (Figure 8.3.2) and rivers (Figure 7.6.9) in the whole of Kenya.

Figure 7.6.10 shows the locations with shallow groundwater, categorized into land use: Forest, and Google's satellite images.

Figure 7.6.11 shows the locations with shallow groundwater, categorized into land use: Agriculture, and Google's satellite images.

Figure 7.6.12 shows the locations with shallow groundwater, categorized into land use: Shrub/Woodland, and Google's satellite images.

Figure 7.6.13 shows the locations with shallow groundwater, categorized into land use: Grassland, and Google's satellite images.

Figure 7.6.14 shows the locations with shallow groundwater, categorized into land use: Savannah, and Google's satellite images.

Figure 7.6.15 shows the locations with shallow groundwater, categorized into land use: Bare land, and Google's satellite images.

In conclusion, it is found that trees grow mainly along the rivers on all kinds of land use, even not categorized into Forest. In the locations categorized into Grassland, Savannah and Bare land, the density of the trees are low but evapotranpiration from an individual tree can be large because the trees grow in flat places and under hot and dry conditions.

2) Adopted Equation to Estimate Groundwater Evapotranspiration

Groundwater evapotranspiration decreases as the groundwater table become deeper, and its amount also depends on vegetation and soil type on the ground. Relational equations between the depth of groundwater table and groundwater evapotranspiration have been proposed. Among them, the following exponential decay function, developed by Nirjhar (2012), was adopted here because coefficients for three types of land cover and 11 types of soil texture can be chosen for this equation.

$$\frac{\mathrm{GWEVT}}{\mathrm{PEY}} = \begin{cases} 1 & \text{for } d < d'' \\ y_0 + e^{-b(d-d'')} & \text{for } d > d'' \end{cases} \qquad \text{(Eq. 7.1)}$$

Where GWEVT is Groundwater evapotranspiration, PET is potential evapotranspiration, d is a depth to water table, d” is the decoupling depth, yo is a correction and b is the decay coefficient.

The coefficients for land cover type: forest can be adopted for this equation because trees were identified on the locations for all types of land use. The soil type classification in the entire Kenya is shown in Figure 5.2.34 and loam soils are dominant except for bare land.

Because of these, it is assumed that a representing extinction depth is 500cm and coefficients for Eq. 7.1 are selected by referring soil type: loam and land cover: Forest in the following table. The decay equation is appropriated by a piece-wise linear function can be applied to MODFLOW. In the figure, the decay function is brown and the piece-wise linear function is blue.

Parameters for Equation 7.1

Table 3
Parameters for Equation 17

	Land Cover Type											
	Bare Soil				Grass				Forest			
Soil Type	d'' (cm)	y_0	b (cm^{-1})	r^2 (%)	d'' (cm)	y_0	b (cm^{-1})	r^2 (%)	d'' (cm)	y_0	b (cm^{-1})	r^2 (%)
Sand	16	0	0.171	97	27	−0.012	0.036	99	31	−0.052	0.013	99
Loamy sand	21	0.002	0.13	99	29	−0.018	0.031	98	36	−0.048	0.013	98
Sandy loam	30	0.004	0.065	99	35	−0.013	0.022	97	50	−0.044	0.011	97
Sandy clay loam	30	0.006	0.046	98	31	−0.003	0.020	98	56	−0.014	0.012	98
Sandy clay	20	0.005	0.042	99	35	0.005	0.028	99	87	0	0.017	99
Loam	33	0.004	0.028	98	39	−0.007	0.015	97	66	−0.017	0.010	98
Silty clay	37	0.007	0.046	91	78	0.003	0.020	90	158	0.004	0.035	91
Clay loam	33	0.008	0.027	98	35	0.004	0.014	99	84	0.001	0.011	99
Silt loam	38	0.006	0.019	99	40	−0.003	0.011	98	82	−0.008	0.010	99
Silt	31	0.007	0.021	97	49	0.009	0.021	95	94	0.006	0.010	99
Silty clay loam	40	0.007	0.021	97	49	0.009	0.017	95	94	0.006	0.013	99
Clay	45	0.006	0.019	96	70	0.007	0.017	83	96	0.006	0.012	98

Note: The r^2 shows the goodness of fit of the exponential model to simulated results.

Table 1
Extinction Depths for Different Soil Land Covers

	Land Cover Type (cm)		
Soil Type	Bare Soil	Grass	Forest
Sand	50	145	250
Loamy sand	70	170	270
Sandy loam	130	230	330
Sandy clay loam	200	300	400
Sandy clay	210	310	410
Loam	265	370	470
Silty clay	335	430	530
Clay loam	405	505	610
Silt loam	420	515	615
Silt	430	530	630
Silty clay loam	450	550	655
Clay	620	715	820

Note: Depths are rounded up to nearest 5 cm. Maximum rooting depth (ζ_{RZ}) for grass and forest was assumed to be 100 and 200 cm, respectively.

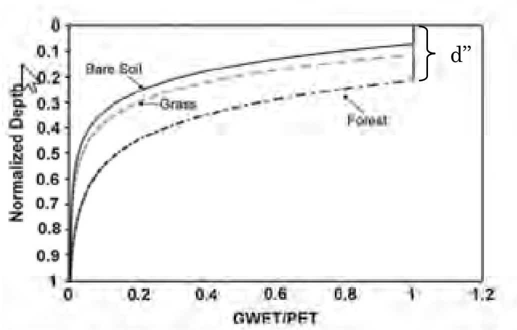
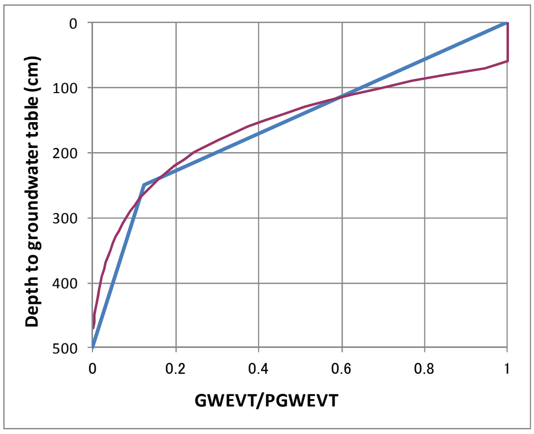


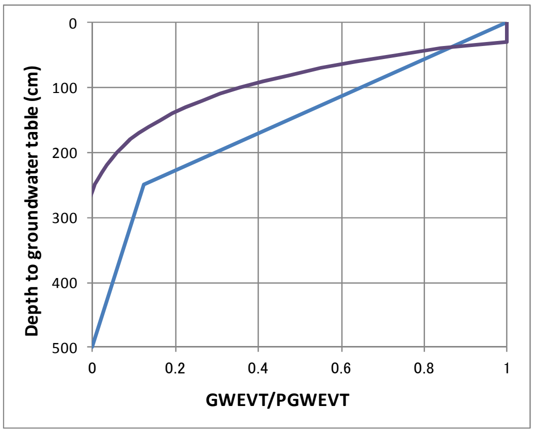
Figure 5. Variation in GWET for different land covers in sandy clay. Normalized depth (DTWT/extinction depth) is used on the vertical axis to facilitate comparison.

Source: Nirjhar Shah, Mahmood Nachabe, and Mark Ross. 2007. Extinction depth and evapotranspiration from ground water under selected land cover. Vol.45 No.3. Groundwater.



Source: JICA Study Team

GWEVT Equations for Forest and Loam



Source: JICA Study Team

GWEVT Equations for Forest and Sand

For bare lands, there is discrepancy between the decay function for sand and forest (a purple line) and the piece-wise linear function (a blue line) as shown below, because the soil type is sand. Thus, it is noted that groundwater evapotranspiration for bare lands can be estimated lager than the actual one.

7.7 Estimation of Sustainable Yield

7.7.1 Sustainable Yield Rate

Evaluation of sustainable yield of groundwater is essential to establish a long-term groundwater development plan. Sustainable yield is defined as the amount of water which can be withdrawn from a groundwater basin annually without producing undesirable results (Todd, 1959). Although a few methods were proposed to quantify the sustainable yield for groundwater basin (Scophocleous, 1998), there were no proper methods to assess the undesirable results caused by the proposed sustainable yield (Zhou, 2009).

A countrywide research for the sustainable yield of groundwater has not yet been implemented in Kenya. It is quite difficult to estimate the sustainable yield of groundwater. According to the study researches of Ponce (2008) and U.S. Geological Survey Circulars 1186 and 1200 (1998, 1999), sustainable groundwater yield may reasonably be around 10% of groundwater recharge taking into consideration the aspects of hydrology, ecology, socio-economy, culture, etc. This study also adopted 10% of groundwater recharge as sustainable yield, since no data on the sustainable yield is available in Kenya.

7.7.2 Renewable Groundwater Recharge

Replying to the note pointing out groundwater recharge of 56.0 BCM/yr for the entire Kenya is too larger than previously reported by other organizations, evapotranspiration is estimated by the FAO Penman-Monteith method instead of the Hamon method and comes out as 21.5 BCM/yr. To avoid too much groundwater pumping, it is considered adequate to apply groundwater recharge of 21.5 BCM/yr for the safe yield estimation.

In general, the rainfall has an increasing trend and also evapotranspiration has an increasing trend in accordance with the temperature rise toward 2055 in the entire Kenya. Affected by such trends, the total groundwater recharge in the entire Kenya shows a declined trend from 21,470 MCM/yearr at present (2010), 19,407 MCM/year in 2030, and 19,287 MCM/year in 2055.

The renewable groundwater recharge amounts by catchment, estimated by hydro-meteorological analysis, are shown in the table below. The difference in trends of renewable groundwater recharge is affected by climate change effects. Climate change effects such as increase/decrease trends of temperature, rainfall and evapotranspiration amount differ by catchment areas.

The evapotranspiration estimated with the FAO-PM method is sensitive to the temperature rise compared with that estimated with the Hamon method, meaning the former is bigger than latter to a similar temperature rise. Because of this, in the present arid catchments such as Ewaso N'giro and Tana, the increases in evapotranspiration clearly prevail over the increases in rainfall in future, and thus their renewal groundwater recharges decrease towards 2055. On the other hand, in the remaining four catchments such as Lake Victoria North, Lake Victoria South, Rift Valley and Athi, the increase in rainfall is almost similar to the increase in evapotranspiration, and thus its groundwater recharges are almost constant or increase over the coming 40 years (present (2010) to 2055).

Annual Groundwater Recharge by Catchment Area under FAO-PM PET Condition

(Unit: MCM/year)

Catchment Area	Present (2010) Climate	2030 Climate	2055 Climate
Lake Victoria North	1,326	1,251	1,612
Lake Victoria South	2,294	2,112	2,126
Rift Valley	1,126	1,126	1,209
Athi	3,345	3,303	3,649
Tana	7,719	6,520	5,840
Ewaso Ng'iro North	5,660	5,095	4,851
Total	21,470	19,407	19,287

Note: The area is measured by the GIS data provided by WRMA.
Source: JICA Study Team

7.7.3 Method to Estimate Sustainable Yield and Sustainable Yield at Present (2010)

By referring to the existing literatures, 10% of groundwater recharge was adopted as a sustainable yield, but the river and riparian areas with 1 km width were excluded from the expected groundwater abstraction areas. The exclusion of the river and riparian areas was decided to avoid potential influence of abstraction on river surface runoff, and therefore the abstraction will need to be restricted. The spatial distribution of the sustainable yield is shown in Figure 7.7.1, and the sustainable yields for six catchment areas are summarized below.

Renewable Groundwater Recharge and Sustainable Yield

Catchment Area	Groundwater Recharge (BCM/year)	Sustainable Yield (BCM/year) （At present(2010)）
Lake Victoria North	1.33	0.12
Lake Victoria South	2.29	0.20
Rift Valley	1.13	0.10
Athi	3.34	0.30
Tana	7.72	0.68
Ewaso Ng'iro North	5.66	0.53
Total	21.47	1.93

Source: JICA Study Team

In addition, a) sustainable yield is estimated as simply 10% of the groundwater recharge in all the locations (Figure 7.7.2), and b) sustainable yield is estimated as 10% of the groundwater recharge in the locations except for discharge areas (Figure 7.7.3). c) Then three estimated sustainable yields are compared as shown in the following table. In case of b), broad areas in the dry regions, where groundwater is actually utilized at present or the need for groundwater is expected to increase in future, are excluded, and thus this is not suitable as sustainable yield Thus, c) 10% of the groundwater recharge excluding rivers is selected as sustainable yield.

Sustainable Yield for Three Trial Cases

Catchment Area	Sustainable Yield (BCM/year)		
	a) 10% of groundwater recharge	b) excluding discharge area from a)	c) excluding rivers from a)
Lake Victoria North	0.13	0.12	0.12
Lake Victoria South	0.23	0.20	0.20
Rift Valley	0.11	0.10	0.10
Athi	0.34	0.29	0.30
Tana	0.77	0.67	0.68
Ewaso Ng'iro North	0.57	0.41	0.53
Total	2.15	1.79	1.93

Source: JICA Study Team

7.7.4 Estimated Sustainable Yield for the Years 2010, 2030 and 2050

The estimated sustainable yield of each catchment for the Years present (2010), 2030, and 2055 are shown in the table below and illustrated in Figure 7.7.4 : the year 2030 and Figure 7.7.5 : for the year 2055.

Sustainable Yield for the Years Present (2010), 2030, and 2055

(Unit: MCM/year)

Catchment Area	Present (2010) Climate	2030 Climate	2055 Climate
Lake Victoria North	116	108	140
Lake Victoria South	203	188	190
Rift Valley	102	102	109
Athi	305	300	332
Tana	675	567	508
Ewaso Ng'iro North	526	475	449
Total	1,927	1,740	1,728

Source: JICA Study Team

7.7.5 Groundwater Balance

(1) Groundwater Abstraction Rate

Since official statistical data of present groundwater use in Kenya are unavailable, the present groundwater use was estimated by utilising the collected borehole information.

Out of 12,444 borehole data obtained from the borehole database of MWI, 6,349 boreholes have exact location data. The rate of present groundwater use was estimated by utilising this 6,349 borehole data, and was then updated at a rate proportional to the total rate of present groundwater use for all 12,444 borehole data. The updated rate of present groundwater use is shown in the table below. The estimated groundwater abstraction rate in 2010 is shown in Figure 7.7.6.

Estimated Groundwater Abstraction Amount in Present (2010)

Catchment Area	Abstraction Amount (MCM/year)
Lake Victoria North	41
Lake Victoria South	36
Rift Valley	115
Athi	230
Tana	68
Ewaso Ng'iro North	35
Total	525

Source: JICA Study Team

(2) Groundwater Balance

Groundwater balance is evaluated comparing the amount of sustainable yield in 2010 and estimated groundwater abstraction rate. Evaluated groundwater balance for each sub-basin is shown in Figure 7.7.7, and the ratio of present groundwater use to sustainable yield for each sub-basin is indicated. The sub-basins having over groundwater abstraction are coloured yellow or red in Figure 7.7.7. The area coincides with the area with the larger amount of groundwater abstraction rate.

7.8 Groundwater Survey in Turkana County

NWMP 2030 was prepared based on the material and data available as of November 2012. On the other hand, "Advanced Survey of Groundwater Resources of Northern and Central Turkana County" was started from June 2012 and the final technical report was completed on August 2013.
The report has been prepared by Radar Technologies International and commissioned by UNESCO under the GRIDMAP Framework for the Government of KENYA, Ministry of Environment, Water and Natural Resources. It is a contribution towards the Kenya Vision 2030 and a pilot of the Kenya Groundwater Mapping Initiative. The project was funded by the Government of Japan, Ministry of Foreign Affairs.

The survey was conducted with the modern advanced technology using the advanced remote-sensing integrated with seismic information.

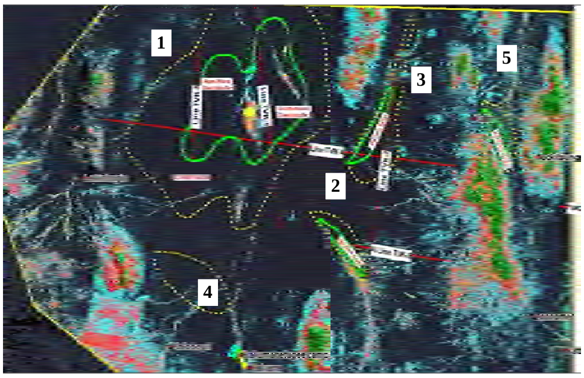
Location of the survey is in the northern and central parts of Turkana County, covering about 36,000 km^2 as shown in Figure 7.8.1.

1) Estimation of annual recharge potential at shallow aquifers

At the shallow aquifers (< 80 m depth) in the area (an area of about 3,240 km^2), an overall annual recharge potential was estimated 2.08 BCM.

2) Estimation of a combined potential at deep aquifers

At the deep aquifers (150 – 600 m depth), the combined potential was estimated 250 BCM/year. Five deep aquifers have been discovered through this survey as shown below. In this figure, the dotted circles show the extent of the deep aquifers.



No	Aquifer Name	Areal extent (km^2)	Estimated total Potential
1	Lotikipi	4,146	200 BCM
2	Lodwar (Lokichar Basin)	140	7 BCM
3	Gatome	345	17 BCM
4	Nakalale	138	7 BCM
5	Kachoda	130	7 BCM

Source: Groundwater Resources survey in the arid regions of kenya

Aquifers in dotted circles and numbered as per the right table

As a result of this survey, the estimated total renewable groundwater resources storage of the northern – central Turkana is about 247 BCM for a total recharge capacity of 3.42 BCM/year, which represents only 1.38% of the total storage quantities.

The findings further indicate that despite the prospects of significant quantities that these aquifers represent, the overall rate of recharge is weak. Therefore, abstraction of water from these aquifers should therefore be done with caution in order to prevent over-abstraction. The safe yields must be ascertained after drilling exercise. The drilling exercise was started on January 2013, and two drilling exercises were completed.

As mentioned in the subsequence Section 7.9, it is recommended the regional groundwater study should be implemented like this survey.

7.9 Recommendations for the Further Study

(1) Sustainable Yield of Groundwater

A sustainable yield of groundwater was assumed to be 10% of groundwater recharge referring study researches of Ponce (2008) and U.S. Geological Survey Cireulares 1186 and 1200 (1998, 1999) due to lack of the relevant data in Kenya. As the sustainable yield of groundwater may affect the water resources development plan in the regional area, it should be carefully determined based on more detailed study taking into account the aspects of hydrology, environment, socio-economy, etc.

(2) Evapotarnspiration

The evapotranspiration should be studied further since it directly affects to groundwater recharge amount. Groundwater evapotranspiration (or riparian evapotranspiration) is an important component of water budget especially in arid and semi-arid regions. In-situ measurements of evapotranspiration should be made for the entire Kenya to provide a better estimate for the water budget for the basins. Also, remote sensing can be useful to estimate the regional evapotranspiration.

(3) Recharge Process

Defining recharge mechanism is essential to estimate renewable recharge to the aquifer. Especially groundwater flow in the mountain ranges of Kenya is complex because precipitation goes down deeply through fractures of volcanic rocks and the movement of groundwater is predicted to be disturbed by the faults. Isotropic tools can be useful for this purpose.

(4) Implementation of Regional Groundwater Study

The groundwater analysis in this study was carried out for the entire country and the groundwater resources were estimated roughly. On the other hand, several regional groundwater development projects have been implemented and the detailed data are available locally. There will be naturally the gap between the country scale study and regional scale studies. A numerical groundwater flow model should be constructed to determine precise sustainable groundwater by simulating recharge and discharge in the regional or local groundwater aquifer. Conducting geophysical investigations and collecting hydrological date is critical for this purpose. The groundwater abstraction data was estimated from the limited borehole data in this study, but those data seem to be not actual abstraction. It is recommended to monitor the groundwater abstraction rate accurately.

(5) Update of Groundwater Potential Map

Based on the more local and detailed information on the aquifer and the above simulation results, the groundwater potential map should be updated to make the map more reliable.

(6) Monitoring of Groundwater in Quality and Quantity

An effective monitoring system of groundwater needs to be established in order to ensure groundwater in quality and quantity. Also, an administrative system which instructs appropriate groundwater use to avoid various problems, induced by uncontrolled groundwater pumping

(7) Conjunctive Use of Surface Water and Groundwater

In arid and semi-arid regions, excessive pumping will result in desertification because its ecosystem is vulnerable and irrigation will cause salinization without an appropriate management of water including the monitoring of groundwater in quantity and quality and instructions to water users. In aquifers along rivers or the irrigation system, conjunctive use of surface water and groundwater can be helpful to maximize the groundwater potential by optimizing the water demand/supply balance.

CHAPTER 8 LAND USE ANALYSIS

8.1 Available Data

Remote sensing techniques were used to create land use/cover maps for the entire Kenya. Specifically, Landsat Thematic Mapper (TM) images were used to analyse the land use/cover change during the period from 1990 to 2010. There are 66 satellite images (33 images for each period) that were needed to cover the entire Kenya. The satellite images were chosen depending on cloud coverage, since it is necessary to have satellite images of low percentage of clouds as much as possible so as to be more useful for effective analysis. Unfortunately, it was difficult to have all satellite images within the same season because of cloud formation. Thus, it was necessary to use Landsat data from different seasons to have the least cloud coverage for better analysis. Therefore, the Landsat TM images for the period of 1984-1988, depending on the cloud coverage, were used to analyse the land use/cover of 1990, while the Landsat TM images for the period of 2008-2011, depending on the cloud coverage, were used to analyse the land use/cover of 2010. Table 8.1.1 and 8.1.2 show a detailed list of Landsat TM data used in this study.

8.2 Methodology

The objective of studying land use/cover change is to monitor the relationship between forest lands and agricultural lands. Also, land use/cover change can provide an idea about the changes of urban areas, which is necessary in water resources studies. ENVI software version 4.8 was used to analyse the satellite images using the following processes:

(1) Layer Stacking

For each Landsat satellite image, all six bands (from Band 1 to Band 7, except Band 6) were combined into one image in order to create a colour composite satellite image. This can help identify the objects captured in each Landsat scene through changing of the band orders displayed through the red (R), green (G), and blue (B) colours.

(2) Geometric Correction

All satellite images obtained during the period of 2008-2011 were geometrically corrected. The geometric correction was conducted based on image to image techniques, which means each satellite image from 2008-2011 was corrected based on its corresponding image existing within the period from 1984-1988. Using this technique, the shift in location will be minimized to less than 1 pixel. In this study, the root mean square (RMS) error value was less than 0.5 pixel between the corrected image and its reference image. In the end, all 33 Landsat TM satellite images covering the period from 2008-2011 were geometrically corrected, and georeferenced according to the Universal Transverse Mercator (UTM) projection, zone 37N, and WGS84 ellepsoid.

(3) Mosaicking of Landsat TM images

Instead of analysing Landsat TM images one by one, it was necessary to merge the satellite images to reduce the number of input data. The merging process of satellite images is called mosaic. In other words, mosaicking involves combining multiple images into a single composite image.

In this study, the images were mosaicked/merged based on the six catchment areas, since combining all 33 satellite images into one scene will produce a file size of more than 10 GB. Analysing the satellite data based on catchment areas is more efficient than analysing one image covering the entire Kenya.

(4) Classification of Satellite Images

Satellite images within each catchment area were classified to produce land use/cover maps. An initial step to perform the classification is to collect training sites for each class. For each training site, the number of collected pixels range from 70 to 100 pixels. To select the training sites, several band combinations were used such as 742 and 453 illustrated through the RGB colours. In the 742 band combination the vegetation show various green shades because Band 4 (high reflectance of vegetation) is presented in the colour green. In the 453 band combination, vegetation appears in shades of red. When a crop has relative lower moisture content, the reflection from Band 5 will be relatively higher, meaning more contribution of green, thus resulting in a more orange colour. The colour green will begin to dominate in this combination when vegetation reflects lower in the visible and near infrared (VNIR) and higher in the short wave infrared (SWIR). In the 453 band, non-vegetated soils and urban areas will appear in blue towards gray colours.

Satellites images were classified into ten land use/cover classes, namely, urban, forest, water, bare land, mangrove, shrub/woodland, grassland, agriculture, savannah, and wetland. These classes were selected based on the available reference land use/cover map prepared by the FAO in 2000 (UNEP, 2009). The description of each land use/cover class is illustrated in the following table.

A supervised classification system using a maximum likelihood classifier was applied. Maximum likelihood classification assumes that the statistics for each class in each band are normally distributed. It also calculates the probability that a given pixel belongs to a specific class. Visual interpretation was employed in order adjust the misclassified results manually, and also to modify the areas covered by clouds. A median convolution filter 7 x 7 was conducted in order to remove the scattered pixels distributed within the classified images.

Description of each land use/cover category

Classes	Definition
Urban	Residential, industrial and commercial complexes, transportation, communication and utilities.
Forest	Deciduous, evergreen and mixed forest (natural and manmade forests).
Water	All areas of open water, including streams, lakes and reservoirs.
Bare land	Area of thin soil, sand, or rock, almost has no vegetation.
Mangrove	Trees and shrubs growing below the high-water level of spring tides. Their root systems are regularly inundated with saline water. They extend throughout tropical and subtropical ecosystems
Shrub/Woodland	A woody perennial plant, smaller than a tree, with several major branches arising from near the base of the main stem. It is mostly covered with woods or dense growths of trees and shrubs
Grassland	An area in which the natural vegetation consists largely of perennial grasses, characteristic of subhumid and semi-arid climates. It is used for grazing or pasture.
Agricultural	Crop fields, vegetable lands and cultivated areas (irrigated and non- irrigated vegetation).
Savannah	A flat, grass covered area of tropical or subtropical regions, nearly treeless in some places but generally having a mix of widely spaced trees and bushes.
Wetland	Areas of marsh, fen, peat land or water. They could be natural or artificial and the water permanent or temporary, static or flowing, fresh, brackish or saline. Wetlands include areas of marine water whose depth during low tide must not exceed 6 m.

Source: Anderson et al., 1976 Modified by JICA Study Team

8.3 Land Use Analysis

Figures 8.3.1 and 8.3.2 show the land use/cover maps of 1990 and 2010, respectively, produced using the methodology mentioned in the previous sub-section.

Statistical analysis shows that about 80% of the total land uses in Kenya in both 1990 and 2010 are classified as savannah, shrub/woodland, bare land, and grassland. This is actually expected since most of Kenya's land area mainly consists of ASALs. The detailed statistical analysis is shown in the table below.

During the period from 1990 and 2010, the area of forest lands was reduced from 3.1% to 2.2%, whereas the agricultural land area was increased from 14.9% to 16.1%. Looking at the land use/cover maps of 1990 and 2010, there are parts of forest lands that were converted to agricultural lands, especially near Mt. Kenya, and Mau forest. Also, forests are being destroyed by large-scale, uncontrolled, irregular, or illegal human activities, such as charcoal production, logging, encroachment and settlements, cultivation of different kinds of crops, and livestock grazing.

Mangrove forests are relatively small in Kenya. They are mainly located at the eastern side of Kenya along the shoreline of the Indian Ocean. However, these mangrove areas were also reduced from 0.06% to 0.04% during the past 20 years. Overexploitation of wood products and conversion to salt pans, agriculture, and other land uses are the main causes of the reduction of mangrove forests (UNEP, 2009).

Comparison Between the Land Use/Cover of 1990 and 2010

Class Name	1990		2010	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)
Urban	57.1	0.01	357.1	0.06
Forest	18,327.7	3.11	12,831.4	2.18
Water	8,358.9	1.42	8,513.9	1.45
Bare land	80,524.0	13.68	43,048.8	7.31
Mangrove	344.8	0.06	260.8	0.04
Shrub/Woodland	117,106.0	19.90	177,191.8	30.11
Grassland	35,419.5	6.02	46,705.2	7.94
Agriculture	87,374.4	14.85	94,973.1	16.14
Savannah	240,967.2	40.94	204,605.0	34.77
Wetland	54.5	0.01	47.1	0.01
Total	**588,534**	**100**	**588,534**	**100**

Source: JICA Study Team

The increase of shrub/woodland and decrease of savannah, especially in the southern part of Kenya, are attributed to different reasons. Some of them are technically related from the satellite images that were used, while others are related to human activity. The majority of Landsat TM images within the southern part of Kenya for the period from 2008 to 2011 were taken in the rainy season (September to November) due to unavailability of cloud-free images within the dry season (December to February). This technical issue has showed an increase of green cover, mainly shrubs, and decrease of savannah within the southern and south eastern parts of Kenya compared to the same location during the period from 1984 to 1988.

Moreover, human activities played an important role in decreasing the area of savannah during the last 20 years due to the increase of urban areas as well as agricultural areas placed in locations very close to national parks, such as the Nairobi National Park (UNEP, 2009), as most national parks are covered by savannah.

The increase of grassland from 6% to 8%, mainly in the northeastern part of Kenya might be attributed to land degradation, which changed the land use from shrub/woodland and savannah to grassland. This change is due to the increase of livestock population and permanent settlements within this area. Consequently, this increase opened an opportunity for more pastoralism activities.

The decrease of bare land from 13.7% to 7.4% is due to the seasonal variations of the satellite images used, which showed an increase of the area of shrub/woodland, and mainly shrubs on behalf of bare land.

Urban areas were expanded during the last 20 years from 0.01% to 0.06%. This is a normal trend all over the world due to the increase of population. Most of urban areas are concentrated in the main cities such as the capital city of Nairobi, Mombasa, Kisumu, and Kakamega, among other urban areas.

Tables

Table 1.2.1 General Features of Synoptic Stations

No.	Name	Station No.	Year Opened	Coordinate		Elevation
				Latitude	Longitude	
1	Makindu	9237000	1904	-2.2833	37.8333	1,000
2	Voi	9338001	1904	-3.4000	38.5667	597
3	Lamu	9240001	1906	-2.2667	40.9000	30
4	Narok	9135001	1913	-1.1333	35.8333	1,890
5	Moyale	8639000	1915	3.5333	39.0333	1,097
6	Wajir	8840000	1917	1.7500	40.0667	244
7	Marsabit	8737000	1918	2.3000	37.9000	1,345
8	Lodwar	8635000	1919	3.1167	35.6167	506
9	Kabete	9036208	1920	-1.2500	36.7333	1,942
10	Garissa	9039000	1932	-0.4833	39.6333	147
11	Moi Air Base	9136087	1933	-1.2773	36.8623	1,626
12	Kisumu	9034025	1938	-0.1000	34.7500	1,146
13	Laikipia Air Base	8937022	1939	0.0328	37.0269	1,873
14	Nyahururu	9036135	1941	-0.0333	36.3500	2,377
15	Thika	9137048	1941	-1.0167	37.1000	1,463
16	Mombasa Airport	9439021	1946	-4.0333	39.6167	55
17	Kitale	8834098	1950	1.0167	35.0000	1,875
18	Wilson Airport	9136130	1951	-1.3167	36.8167	1,679
19	Dagoretti Corner	9136164	1954	-1.3000	36.7500	1,798
20	Jomo Kenyatta International Airport	9136168	1954	-1.3167	36.9167	1,624
21	Machakos Katumani	9137089	1956	-1.5833	37.2333	1,600
22	Msabaha	9334007	1956	-3.2667	40.0500	91
23	Kakamega	8934096	1957	0.2833	34.7833	2,133
24	Mtwapa	9339036	1959	-3.9333	39.7333	21
25	Mandera	8441000	1961	3.9333	41.8667	230
26	Malindi	9340009	1961	-3.2333	40.1000	23
27	Kisii	9034088	1962	-0.6667	34.7833	1,707
28	Kericho	9035279	1963	-0.3667	35.3500	2,184
29	Nakuru	9036261	1964	-0.2667	36.1000	1,901
30	Meru	8937065	1966	0.0833	37.6500	1,554
31	Nyeri	9036288	1968	-0.4333	36.9667	1,759
32	Eldoret Met	8935181	1972	0.5333	35.2833	2,133
33	Embu	9037202	1975	-0.5000	37.4500	1,493
34	Eldoret Airport	8935115	2001	-0.4333	35.2333	2,084
35	Suba	9034103	2006	-0.2500	34.0800	1,481
36	Kangema	N/A	N/A	-0.6833	36.9667	N/A

Source: KMD

Table 1.2.2 Observed Items at Synoptic Stations

Station Name	Observed Items												
	Rainfall	Wind Speed	Direction	Relative Humidity	Temp max	Temp min	Sunshine Hour	Radiation	Soil Temp	Pressure	Cloud Top	Cloud Height	Evap.
Makindu	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Voi	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓
Lamu	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Narok	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Moyale	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Wajir	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓
Marsabit	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
Lodwar	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
Kabete	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
Garissa	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓
Moi Air Base	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Kisumu	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Laikipia Air Base	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Nyahururu	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Thika	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mombasa Airport	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Kitale	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Wilson Airport	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Dagoretti Corner	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Jomo Kenyatta International Airport	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Machakos Katumani	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Msabaha	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Kakamega	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mtwapa	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mandera	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Malindi	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Kisii	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Kericho	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Nakuru	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Meru	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Nyeri	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Eldoret Met	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Embu	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Eldoret Airport	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Suba	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓
Kangema	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓

Source: JICA Study Team

Table 1.3.1 List of River Gauging Stations Used for Analysis in NWMP (1992)

Catchment Area	River Basin	Name			
Lake Victoria North	Sio	1AD02	1AH01		
Lake Victoria South	Nyando	1GB03 1GC06	1GB05 1GD02	1GB08 1GD04	1GB09
Rift Valley	Turkwel	2B09	2B27	2B30	3G02
	Kerio	2C05	2C07	2C08	3G02
	Lake Bogoria	2ED02	2EE07	2EE08	
	Lake Baringo	2ED02	2EE07	2EE08	
	Lake Nakuru	2EE07	2FC05	2GB01	2GC04
	Lake Naivasha	2EE07	2FC05	2GB01	2GC04
	Lake Elementaita	2EE07	2FC05	2GB01	2GC04
	Ewaso Ngiro	2K01	2K03	2K06	3G02
Athi	Athi	3AA04 3CB05 3G03	3BA29 3DA02	3BA32 3F02	3BD05 3G02
	Rare, Pemba and Mwachi	3KG01	3G02		
Tana		4AA01 4AC04 4BC01 4CB04 4DD02 4EB01 4F13	4AA07 4AD01 4BE02 4DA10 4EA03 4EB09 4F17	4AB05 4BB01 4BF01 4DC02 4EB06A 4EB11 3G02	4AC03 4BC02 4CA02 4DD01 4EA06 4F10
Ewaso Ng'iro North		5AC08	5BB02	5D05	5E03

Source : WRMA Catchment Management Strategy

Table 1.3.2 List of River Gauging Stations based on Catchment Management Strategies (1/7)

National Stations (Total 22)

S/N	Catchment Area	Station ID	Station Name	Long/ Eastings	Lat/ Northings	Operation
1	LVNCA	1AA01	Malaba	34.2708	0.6417	Operated
2	LVNCA	1AD02	Malakisi	34.3419	0.6250	Operated
3	LVNCA	1AH01	Sio	34.1417	0.3875	Operated
4	LVNCA	1EF01	Nzoia at Ruambwa	34.0903	0.1236	Operated
5	LVNCA	1FG02	Yala	34.2653	0.0431	Operated
6	LVSCA	1GD03	Nyando	34.9600	-0.1250	Operated
7	LVSCA	1JG04	Sondu Miriu	34.8020	-0.3360	Operated
8	LVSCA	1KB05	Gucha Migori	34.2070	-0.9470	Operated
9	LVSCA	1LA04	Mara	35.0360	-1.2330	Not Operated
10	LVSCA	1HB04	Lake Victoria	34.7400	-0.0880	Operated
11	RVCA	2B13	Lake Turkana	35.9170	3.5520	Operated
12	RVCA	2EB10	Lake Bogoria			Not Operated
13	RVCA	2EH1	Lake Baringo	36.0270	0.6160	Operated
14	RVCA	2FA9	Lake Elementaita	36.2400	-0.4080	Operated
15	RVCA	2FC4	Lake Nakuru	36.0920	-0.3210	Not Operated
16	RVCA	2GD6	Lake Naivasha	36.4170	-0.7690	Operated
17	RVCA	2K04	Ewaso Ng'iro South	35.8450	-1.1010	Not Operated
18	ACA	3HA13	Sabaki (Baricho)	39.7670	-3.1170	Not Operated
19	ACA	3J02	Lake Jipe	37.7580	-3.5420	Operated
20	ACA	3J12	Lake Challa	37.7130	-3.3136	Operated
21	TCA	4G01	Tana at Garrisa	39.7000	-0.4500	Operated
22	ENNCA	5E03 (5ED01)	Ewaso Ng'iro at Archer's Post	37.6780	0.6420	Operated

Source : WRMA Catchment Management Strategy

Table 1.3.2 List of River Gauging Stations based on Catchment Management Strategies (2/7)

Management Unit Stations (Total 47)

S/N	Catchment Area	Station ID	Station Name	Long/ Eastings	Lat/ Northings	Operation
1	LVN	1CE01	Kipkarren	34.9653	0.6083	Operated
2	LVN	1DA02	Nzoia	34.8069	0.5889	Operated
3	LVN	1DD01	Nzoia (Mumias)	34.4875	0.3722	Operated
4	LVN	1ED01	Lusumu	34.4806	0.3092	Operated
5	LVN	1EG02	Wuroya	34.2431	0.1500	Operated
6	LVN	1FG01	Yala	34.5451	0.8080	Operated
7	LVS	1GB03	Ainamutua	35.0560	-0.0720	Not Operated
8	LVS	1GD07	Nyando	35.1640	-0.1640	Operated
9	LVS	1HA11	Nyamasaria	34.9999	-0.0722	Operated
10	LVS	1HB05	Awach Seme	34.4740	-0.0890	Not Operated
11	LVS	1HD09	Awach Kibuon	34.7833	-0.0250	Not Operated
12	LVS	1HE01	Awach Tende	34.5490	-0.4670	Operated
13	LVS	1JC19	Kimugu	34.1754	-0.4767	Not Operated
14	LVS	1JD03	Yurith	35.0790	-0.4760	Not Operated
15	LVS	1JF08	Kipsonoi	35.0780	-0.5100	Operated
16	LVS	1JG05	Sondu	35.0130	-0.3920	Operated
17	LVS	1KB01A	Gucha	34.2750	-0.9540	Not Operated
18	LVS	1KC03	Migori	34.4710	-1.0640	Operated
19	LVS	1LA03	Nyangores	35.3470	-0.7860	Operated
20	LVS	1LB02	Amala	35.4380	-0.8970	Operated
21	RVCA	2B21	Turkwell	35.6000	3.1110	Operated
22	RVCA	2B33	Suam			Operated
23	RVCA	2C7	NDO	35.6470	0.4510	Not Operated
24	RVCA	2D1	Suguta	36.1060	1.1820	Not Operated
25	RVCA	2EB8	Waseges			Not Operated
26	RVCA	2EE7B	Perkera			Operated
27	RVCA	2EG3*	Molo	36.0110	0.4440	Proposed
28	RVCA	2FA8	Mereroni	36.2200	-0.3930	Operated
29	RVCA	2FC16	Njoro			Not Operated
30	RVCA	2GA1	Gilgil	36.3630	-0.5990	Operated
31	RVCA	2GB1	Malewa	36.4030	-0.5560	Operated
32	RVCA	2K01	Ewaso Ngiro South	35.7580	-1.1510	Operated
33	ATHI	3BA32	Nairobi	37.1190	-1.1940	Not Operated
34	ATHI	3BC08	Ruiru	36.8780	-1.0890	Operated
35	ATHI	3CB05	Ndarugu	37.1610	-1.1310	Operated
36	ATHI	3F09	Athi Kibwezi Bridge	38.0577	-2.2015	Operated
37	TANA	4BC02	Tana Sagana	37.2070	-0.6720	Operated
38	TANA	4BE01	Maragua	37.1530	-0.7500	Operated
39	TANA	4CC07	Thika	37.3820	-1.1040	Operated
40	TANA	4DD02	Thiba	37.5060	-0.7320	Operated
41	TANA	4EA07	Mutonga	37.8960	-0.3760	Operated
42	TANA	4F19	Kazita	38.0060	-0.2390	Operated
43	ENNCA	5AC08	Ewaso Narok	36.8630	0.5080	Not Operated
44	ENNCA	5BC04	Ewaso Ngiro	36.9050	0.0900	Operated
45	ENNCA	5BE20	Nanyuki	37.0300	0.1470	Operated
46	ENNCA	5D05 (5DC01)	Ewaso Ngiro	36.8670	0.5290	Not Operated
47	ENNCA	5D08 (5DA07)	Isiolo	37.5670	0.3330	Operated

Source : WRMA Catchment Management Strategy

Table 1.3.2 List of River Gauging Stations based on Catchment Management Strategies (3/7)

IntraManagement Unit Stations (Total 123)

S/N	Catchment Area	Station ID	Station Name	Long/ Eastings	Lat/ Northings	Operation
1	LVNCA	1BB01	Nzoia (Moi's bridge)	35.1333	0.9208	Operated
2	LVNCA	1BB02	Losura	35.2375	0.9542	Operated
3	LVNCA	1BD02	Large Nzoia	35.0611	0.7611	Operated
4	LVNCA	1BE06	Kwoitobus	35.0903	0.9653	Operated
5	LVNCA	1BH01	Kamukuywa	34.8028	0.7847	Operated
6	LVNCA	1DB01	Kuywa	34.7000	0.6236	Operated
7	LVNCA	1EE01	Nzoia	34.2250	0.1778	Operated
8	LVNCA	1FD02	Mokong	35.1244	0.1378	Operated
9	LVNCA	1FF03	Edzawa	34.5583	0.0944	Operated
10	LVNCA	1BG07	Rongai	34.9250	0.7740	Operated
11	LVSCA	1GB06A	Mbogo	35.1440	-0.0580	Operated
12	LVSCA	1GC03	Kipchorian	35.4580	-0.2040	Operated
13	LVSCA	1GC04	Tugunon	35.4140	-0.2530	Operated
14	LVSCA	1GG01	Namuting	35.3470	-0.2030	Not Operated
15	LVSCA	1HA01	Great Oroba	35.0000	-0.0190	Operated
16	LVSCA	1HA02	Little Oroba	34.9710	-0.0280	Operated
17	LVSCA	1HA14	Awach Kajulu	34.8040	-0.0470	Operated
18	LVSCA	1HD03	Awach Kabondo	34.8830	-0.4490	Operated
19	LVSCA	1HD05	Awach Kasipul	34.8400	-0.5010	Operated
20	LVSCA	1HD06	Eaka Kioge	34.9500	-0.5080	Operated
21	LVSCA	1HE02	Mogusii	34.7630	-0.6190	Operated
22	LVSCA	1HE03	Isanda	34.7370	-0.5740	Operated
23	LVSCA	1JA02	Kiptiget	35.2570	-0.5510	Operated
24	LVSCA	1JC19	Old Kimugu Intake	34.1754	-0.4767	Operated
25	LVSCA	1JD04	Ainapkoi	35.5847	-0.4042	Operated
26	LVSCA	1KA09	Riana	34.5170	-0.7140	Operated
27	LVSCA	1KB03	Gucha	34.5710	-0.8080	Operated
28	LVSCA	1KB11	Oyani	34.5333	-0.9033	Operated
29	LVSCA	1KB12	Kenyamware	34.9210	-0.6670	Operated
30	RVCA	2B08	Wei Wei	35.4650	1.3930	Not Operated
31	RVCA	2B24	Morun	35.4290	1.5310	Not Operated
32	RVCA	2C06	Kessup	35.4980	0.6280	Not Operated
33	RVCA	2C14	Kimwarer	35.6330	0.3170	Operated
34	RVCA	2EA01	Maji Matamu	36.1060	0.0000	Not Operated
35	RVCA	2EB03	Waseges	36.2110	0.1860	Operated
36	RVCA	2EC02	Rongai	35.9310	0.1060	Not Operated
37	RVCA	2EE09	Narosura	35.8740	0.2420	Not Operated
38	RVCA	2EG01	Molo	35.9130	0.0860	Not Operated
39	RVCA	2FC05	Njoro	35.9250	-0.3720	Not Operated
40	RVCA	2GA03	Gilgil	36.3440	-0.4920	Operated
41	RVCA	2GB05	Malewa	36.4010	-0.4930	Operated
42	RVCA	2GC04	Turasha	36.4170	-0.4790	Operated
43	RVCA	2GC05	Nandarasi	36.5590	-0.5510	Operated
44	RVCA	2GD02	Karati	36.4190	-0.6940	Not Operated
45	RVCA	2H01	Tongi Tongi	36.5930	-0.9200	Not Operated
46	RVCA	2H03	Little Kendong	36.5890	-1.0610	Operated
47	RVCA	2K03	Narok	35.8450	-1.1010	Operated
48	RVCA	2K10	Ewaso Ng'iro			Not Operated
49	RVCA	2K16	Ewaso Ng'iro			Not Operated
50	ACA	3AA04	Mbagathi	36.6910	-1.3230	Not Operated
51	ACA	3AA06	Mbagathi	36.9820	-1.4400	Not Operated
52	ACA	3BA10	Ruiruaka	36.8230	-1.2270	Operated
53	ACA	3BA29	Nairobi	36.8100	-1.2740	Not Operated
54	ACA	3BB11	Kiu	36.9310	-1.1820	Operated

Source : WRMA Catchment Management Strategy

Table 1.3.2 List of River Gauging Stations based on Catchment Management Strategies (4/7)

IntraManagement Unit Stations (Total 123)

S/N	Catchment Area	Station ID	Station Name	Long/ Eastings	Lat/ Northings	Operation
55	ACA	3BB12	Kamiti	36.9710	-1.1970	Operated
56	ACA	3BD05	Thiririka	37.0410	-1.1540	Operated
57	ACA	3DB01	Athi (Wamunyu)	37.6455	-1.4107	Operated
58	ACA	3DA02	Athi at Munyu	37.1959	-1.0893	Operated
59	ACA	3EA02	Maruba	37.2460	-1.5190	Operated
60	ACA	3F02	Athi [Mavindini].	37.8460	-1.7900	Operated
61	ACA	3F06	Kibwezi Springs	38.0760	-2.3760	Not Operated
62	ACA	3F07	Kiboko	37.0950	-2.2080	Not Operated
63	ACA	3F11	Little Kiboko Hunters	37.7080	-2.2080	Not Operated
64	ACA	3G02	Tsavo	38.4740	-2.9960	Not Operated
65	ACA	3J [NEW]	Lumi Kivarua	37.6961	-3.4353	Operated
66	ACA	3J15C	Lumi	37.7030	-3.3920	Operated
67	ACA	3KB01	Ramisi	39.3730	-4.4500	Not Operated
68	ACA	3KG01	Umba	39.1110	-4.5690	Not Operated
69	ACA	3LA05	Voi	38.5930	-3.3930	Not Operated
70	ACA	3MH26	Marere	39.4080	-4.2000	Operated
71	TCA	4AC03	Sagana	37.0430	-0.4490	Operated
72	TCA	4AC04	Chania	36.9580	-0.4210	Operated
73	TCA	4AD01	Gura	37.0760	-0.5170	Operated
74	TCA	4BB01	Ragati	37.1930	-0.6370	Operated
75	TCA	4BC05	Rwamuthambi	37.2420	-0.5850	Not Operated
76	TCA	4BD New	Mathioya			Proposed
77	TCA	4BE10	Tana Rukanga	37.2580	-0.7250	Operated
78	TCA	4BF01	Saba Saba	37.2640	-0.8640	Operated
79	TCA	4CA02	Chania	37.0630	-1.0260	Operated
80	TCA	4CB04	Thika	37.0660	-1.0210	Operated
81	TCA	4DA10	Thiba	37.3170	-0.6210	Operated
82	TCA	4DB04	Nyamindi	37.3690	-0.6150	Not Operated
83	TCA	4DC03	Rupingazi	37.4380	-0.5330	Not Operated
84	TCA	4EA06	Mutonga	37.8560	-0.2790	Operated
85	TCA	4EB06	Ruguti	37.8580	-0.3510	Operated
86	TCA	4EB07	Thuchi	37.8710	-0.3620	Operated
87	TCA	4EB11	Mara	37.8710	-0.3420	Operated
88	TCA	4EC New	Ena			Proposed
89	TCA	4F09	Ura	37.9790	0.0650	Not Operated
90	TCA	4F10	Kazita	37.9780	-0.0960	Not Operated
91	TCA	4F17	Thingithu	37.9600	-0.1690	Not Operated
92	TCA	4F20	Thanandu			Operated
93	ENNCA	5AA13	Lake Ol Bolossat			Not Operated
94	ENNCA	5AA01A (5AA17)	Ewaso Narok	36.36900	0.04800	Operated
95	ENNCA	5AA05	Equator	36.36300	0.02000	Operated
96	ENNCA	5AA13	Lake Ol Bolossat	36.402790	0.011110	Proposed
97	ENNCA	5AB02	Pesi	36.51700	0.20000	Operated
98	ENNCA	5AB04	Pesi	36.52700	0.06300	Operated
99	ENNCA	5AC10	Ewaso Narok	36.72400	0.43800	Operated
100	ENNCA	5AC15	Ewaso Narok	36.53700	0.25700	Operated
101	ENNCA	5AD01	Mutara	36.55300	0.06700	Operated
102	ENNCA	5AD04	Mutara	36.66300	0.08000	Operated
103	ENNCA	5BA03	Moyok	36.87100	0.26300	Not Operated
104	ENNCA	5BB02	Ewaso Ng’iro	36.86700	0.13300	Operated
105	ENNCA	5BC02	Naro Moru	37.02500	0.16500	Operated
106	ENNCA	5BC05	Rongai	37.06700	0.04200	Operated
107	ENNCA	5BC06	Burguret	37.03800	0.10900	Operated

Source : WRMA Catchment Management Strategy

Table 1.3.2 List of River Gauging Stations based on Catchment Management Strategies (5/7)

IntraManagement Unit Stations (Total 123)

S/N	Catchment Area	Station ID	Station Name	Long/ Eastings	Lat/ Northings	Operation
108	ENNCA	5BC08	Engare Ngobit	36.78300	0.05000	Proposed
109	ENNCA	5BD02	Surugoi	36.60300	0.07600	Operated
110	ENNCA	5BE01	Nanyuki	37.07700	0.02100	Operated
111	ENNCA	5BE02	Ontulili	37.13900	0.04000	Operated
112	ENNCA	5BE04	Sirimon	37.20000	0.06100	Proposed
113	ENNCA	5BE05	Teleswani	37.23000	0.08300	Operated
114	ENNCA	5BE06	Timau	37.24200	0.08800	Operated
115	ENNCA	5BE07	Likii	37.08700	0.02100	Operated
116	ENNCA	5BE19	Ngusishi	37.26100	0.10000	Operated
117	ENNCA	5BE21	Nanyuki	37.02800	0.13200	Operated
118	ENNCA	5D02 (5DA01)	Ngare Nything			Proposed
119	ENNCA	5D04 (5DA02)	Ngare Ndare	37.34400	0.18600	Proposed
120	ENNCA	5D10 (5DA03)	Rugusu (Western Marania)	37.47400	0.19300	Proposed
121	ENNCA	5D11 (5DA04)	Kithima (Marania Ruguthu)	37.49100	0.20100	Proposed
122	ENNCA	5D14 (5DA05)	Likiundu	37.80400	0.23300	Not Operated
123	ENNCA	5D-NEW (5DA06)	Ewaso Ngiro			Not Operated

Source : WRMA Catchment Management Strategy

Table 1.3.2 List of River Gauging Stations based on Catchment Management Strategies (6/7)

Special Stations (Total 29)

S/N	Catchment Area	Station ID	Station Name	Long/ Eastings	Lat/ Northings	Operation
1	LVNCA	1CA02	Sergoit	35.067	0.633	Operated
2	LVNCA	1CB05	Sosiani	35.090	0.626	Operated
3	LVNCA	1EB02	Isiukhu	34.750	0.254	Operated
4	LVNCA	1FC01	Kimondi	35.049	0.200	Operated
5	LVNCA	1FE02	Yala	34.936	0.183	Operated
6	LVNCA	1FG03	Yala	34.143	0.006	Operated
7	LVSCA	1GD02	Nyando	35.157	-0.169	Operated
8	RVCA	2FC13B	Sewage Effluent			Not Operated
9	ACA	3ED01	Thwake	37.828	-1.785	Not Operated
10	ACA	3G03	Mzima springs	38.028	-3.014	Operated
11	ACA	3G06	Nor Turesh	37.568	-2.958	Operated
12	TCA	4AA05	Sagana	37.039	-0.443	Operated
13	TCA	4AB01	Muringato	36.943	-0.400	Operated
14	TCA	4AB06	Amboni	36.992	-0.407	Operated
15	TCA	4BE10	Tana	37.258	-0.725	Operated
16	TCA	4CC03	Yatta Furrow	37.361	-1.094	Operated
17	TCA	4DA New	Thiba			Proposed
18	TCA	4DC06 II	Kapingazi	37.450	-0.483	Operated
19	TCA	4EA03	Kithino	37.681	-0.102	Operated
20	TCA	4EB09	Tungu	37.660	-0.304	Operated
21	TCA	4F08	Thangatha	37.974	0.048	Proposed
22	TCA	4F13	Tana Grand Falls	38.018	-0.285	Operated
23	TCA	4F16	Tana			Proposed
24	TCA	4F28	Rujirweru			Proposed
25	TCA	4G02	Tana Garsen	40.117	-2.275	Not Operated

Source : WRMA Catchment Management Strategy

Table 1.3.2 List of River Gauging Stations based on Catchment Management Strategies (7/7)

Special Stations (Total 29)

26	ENNCA	5D-OLDONYIRO (5DC02)	Ewaso Ngiro	36.870	0.599	Proposed
27	ENNCA	5E06 (5EC01)	Bakuli Springs	37.990	2.333	Proposed
28	ENNCA	5E-NEW (5EC02)	Ngurunit Springs	37.275	1.721	Proposed
29	ENNCA	5H01 (5HA01)	Daua River	41.856	3.962	Proposed

Source : WRMA Catchment Management Strategy

Table 1.3.3 Surface Water Quality in Six Catchment Areas

Catchment Area	Description of Surface Water Quality
LVNCA	The water quality in this catchment has been on the decline over the years due to increase in sources of pollution. In the upper zone, water quality is affected by pollution from agricultural activities, and sewerages from urban centres. In the middle zone, pollution is by municipalities and urban centres, industries, coffee factories, car washing, sediment produced in this zone, fertilizers and agro-chemicals. Pollution in the lowlands zone is from effluent from towns and urban centres, sediments, poor sanitation facilities, watering of animals directly in the dams/ pans, domestic washing, salty conditions, fluorine. The lake zone which is characterised by dependency on both ground and surface water exploitation has pollution coming from sanitation effluent from pit latrines, effluent from beaches and market centres, car washing as well as domestic washing.
LVSCA	The Naydo river is the most affected. Mara and Nyando had the highest annual average EC values due to discharge of industrial effluents from sugar factories into Nyando river and discharge of domestic effluents from hotels and lodges along Mara river.
RVCA	Nairobi is classified as the highest risk to water quality. Only Lake Naivasha has fresh water. Other lakes in the catchment have brackish to saline waters. In the upper parts of the rivers, water is of good quality but in the lower parts have high siltation and agricultural pollutants affecting water quality.
ACA	The high color and turbidity in Athi River at RGS 3AA6 by degradation of riparian area through peasant farming using irrigation immediately upstream of the Mavoko town. Total dissolved solid and conductivity were unusually high due to industrial pollution and use of agro-chemicals within the environs of the river. High level of color and turbidity were also seen at RS 3EA3 (Maruba Dam).
TCA	The rivers had fresh neutral low to moderate mineralized water with turbidity varying from <5N.T.U to 66.9 N.T.U. Turbidity was lowest in upper parts of the river and increase downstream in increase in human activities. Chemically, the rivers have suitable water for domestic use, irrigation and other purposes but the water require coagulation and filtration where turbidity exceed 5N.T.U, and also disinfection/boiling to render the water portable. Water samples from Muringato, Amboni, Nairobi, Thego, and Thika river showed that the rivers were polluted to some degree. Pollution in Thika River was magnified downstream of Thika-Nairobi.
ENNCA	The upper zones displayed low levels of turbidity, fluoride, EC and general mineral content. Water is generally suitable for domestic purposes. The middle and lower zones carried the bulk of human and animal activities that could easily be the source of the bacterial contamination. Inappropriate land use changes, soil erosion in catchments, and deterioration of riparian areas result in increase of turbidity which led to degradation in the quality of water resources.

Source: Water Situation Report 2007/2008, WRMA

Table 2.1.1 List of Temperature Observation Stations and Data Availability for 1979 - 2010

ID	Station ID	Station Name	Latitude	Longitude	Total Validation
1	8635000	LODWAR METEOROLOGICAL STATION	3.1167	35.6167	78.2%
2	8639000	MOYALE MET. STATION	3.5333	39.0500	68.3%
3	8641000	MANDERA MET STATION	3.9333	41.8667	71.0%
4	8737000	MARSABIT MET STATION	2.3167	37.9833	50.5%
5	8834098	KITALE METEOROLOGICAL STATION	1.0000	34.9833	51.5%
6	8840000	WAJIR MET STATION	1.7500	40.0667	81.6%
7	8934096	KAKAMEGA AGROMET STATION	0.2833	34.7667	60.1%
8	8935115	KAPTAGAT ARMS PLATEAU	0.4500	35.4667	30.6%
9	8935181	ELDORET MET.STATION	0.5333	35.2833	36.3%
10	8937022	NANYUKI MET. STATION	0.0500	37.0333	34.0%
11	8937065	MERU MET.STATION	0.0833	37.6500	53.2%
12	9034025	KISUMU METEOROLOGICAL STATION	-0.1000	34.7500	56.0%
13	9034088	KISII MET(NYANZA AG.RES.STATION)	-0.6833	34.7833	51.7%
14	9035279	HAIL RESEARCH STATION KERICHO	-0.3667	35.2667	56.9%
15	9035318	KABARAK AGROMET STATION	-0.1833	35.9833	16.9%
16	9036135	NYANDARUA AGRI. RES. STATION	-0.0333	36.3500	54.6%
17	9036261	NAKURU METEOROLOGICAL STATION	-0.2667	36.1000	45.0%
18	9036288	WAMBUGU F.T.C (NYERI MET STN)	-0.4333	36.9667	52.8%
19	9037202	EMBU MET. STATION	-0.5000	37.4500	96.2%
20	9039000	GARISSA MET STATION	-0.4833	39.6333	50.3%
21	9135001	NAROK METEOROLOGICAL STATION	-1.1000	35.8667	56.9%
22	9136087	NAIROBI EASTLEIGH AERODROME	-1.2667	36.8667	18.5%
23	9136130	NAIROBI WILSON AIRPORT	-1.3167	36.8167	53.3%
24	9136164	DAGORETTI CORNER MET STATION	-1.3000	36.7500	56.3%
25	9136168	J.K.I.A.MET.SATION.	-1.3167	36.9167	40.0%
26	9136208	KABETE UNIVERSITY FIELD	-1.2500	36.7333	56.7%
27	9137048	NATIONAL HORT.RES.STN. THIKA	-1.0167	37.1000	33.4%
28	9137089	KATUMANI EXP. RES. STATION.	-1.5833	37.2333	58.9%
29	9237000	MAKINDU MET. STATION	-2.2833	37.8333	61.6%
30	9240001	LAMU METEOROLOGICAL STATION	-2.2667	40.9000	93.7%
31	9338001	VOI METEOROLOGICAL STATION	-3.4000	38.5667	96.2%
32	9339036	MTWAPA AGROMET STATION	-3.9333	39.7333	57.4%
33	9340007	MSABAHA AGROMET STATION	-3.2667	40.0500	44.8%
34	9340009	MALINDI METEOROLOGICAL STATION	-3.2333	40.1000	52.2%
35	9439021	MOMBASA PORT REITZ AIRPORT	-4.0333	39.6167	46.3%

Source: KMD

Legend
- Annual data availability is more than 90%
- 80% <= data availability < 90%
- 70% <= data availability < 80%
- 60% <= data availability < 70%
- 50% <= data availability < 60%
- 40% <= data availability < 50%
- less than 40%

Table 2.1.2 List of Rainfall Observation Stations and Those Data Availability for 1979 – 2010 (1/3)

ID	Station ID	Station Name	Latitude	Longitude	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total Validation
1	8536001	ILERET POLICE POST	4.3167	36.2333																																	62.2%
2	8635000	LODWAR METEOROLOGICAL STATION	3.1167	35.6167																																	98.7%
3	8635002	KALOKAL FISHERIES DEPARTMENT	3.5333	35.8833																																	65.1%
4	8637002	KALACHA A.I. CHURCH	3.1167	37.4167																																	71.1%
5	8639000	MOYALE MET. STATION	3.5333	39.0500																																	99.2%
6	8641000	MANDERA MET STATION	3.9333	41.8667																																	98.8%
7	8641001	MANDERA RHAMU POLICE POST	3.9333	41.2333																																	69.3%
8	8735004	KEKORONGO IRRIGATION SCHEME	2.8833	35.4167																																	50.5%
9	8735005	KAPUTIR IRRIGATION SCHEME	2.1000	35.4667																																	64.9%
10	8735007	KATILU IRRIGATION SCHEME	2.2500	35.4333																																	63.3%
11	8737000	MARSABIT MET STATION	2.3167	37.9833																																	98.6%
12	8739001	GIRIFTU POLICE POST	2.0167	39.7500																																	67.1%
13	8740000	EL WAK , MANDERA	2.7833	40.9500																																	63.3%
14	8834098	KITALE METEOROLOGICAL STATION	1.0000	34.9833																																	98.7%
15	8835031	KAIBUIBICH KAPENGURIA	1.2000	35.2833																																	87.1%
16	8835039	LEISSA FARM,KITALE	1.1667	35.0333																																	94.1%
17	8835047	KUNYAO CHIEF'S OFFICE	1.8000	35.0500																																	67.8%
18	8836000	MARALAL DISTRICT COMMISSIONER	1.1000	36.7000																																	75.5%
19	8836001	BARAGOI EL BARTA D.O'S OFFICE	1.7833	36.8000																																	62.7%
20	8840000	WAJIR MET STATION	1.7500	40.0667																																	98.4%
21	8934008	KITALE GLOUCESTER VALE ESTATE	0.9000	34.9167																																	93.3%
22	8934016	LUGARI FOREST STATION	0.6667	34.9000																																	94.8%
23	8934059	OHOLO CHIEF'S CAMP.	0.1833	34.3333																																	92.8%
24	8934061	MALAVA AGIRIC. STATION.	0.4500	34.8500																																	91.0%
25	8934096	KAKAMEGA AGROMET STATION	0.2833	34.7667																																	99.7%
26	8934134	BUNGOMA WATER SUPPLY	0.5833	34.5667																																	95.9%
27	8934161	ALUPE COTTON RESEARCH STATION	0.4833	34.1333																																	90.6%
28	8935010	KAPTAGAT FOREST STATION	0.4333	35.5000																																	80.5%
29	8935014	TAMBACH D.O.'S OFFICE	0.6000	35.5333																																	85.8%
30	8935104	TAMBACH CHEBIEMIT AGRIC OFFICE	0.8667	35.5000																																	86.7%
31	8935120	KIBABET ESTATE LTD.	0.1333	35.2833																																	88.9%
32	8935137	TIMBOROA FOREST STATION	0.0667	35.5333																																	93.9%
33	8935177	KATIMOK FOREST STATION	0.6000	35.7833																																	94.6%
34	8935181	ELDORET MET.STATION	0.5333	35.2833																																	99.2%
35	8935188	KAPKEBEN CHEMONI ESTATE	0.1333	35.1333																																	94.2%
36	8935200	KIMOSE AGRIC.HOLDING GROUND	0.2500	35.8833																																	85.6%
37	8936014	MUTARA ESTATE MANAGER'S HOUSE	0.1167	36.6833																																	82.2%
38	8936049	RUMURUTI OL MYSOR	0.4167	36.6667																																	93.7%
39	8936060	COLCHECCIO LTD. LAIKIPIA	0.6333	36.8000																																	83.6%
40	8936067	SNAKE FARM,LAKE BARINGO	0.6333	36.1500																																	82.8%

source: counted by JICA Study Team with original data from Kenya Meteorological Department

Legend
- Annual data availability is more than 90%
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- 70% <= data availability < 80%
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- 50% <= data availability < 60%
- 40% <= data availability < 50%
- less than 40%

Table 2.1.2 List of Rainfall Observation Stations and Those Data Availability for 1979 – 2010 (2/3)

ID	Station ID	Station Name	Latitude	Longitude	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total Validation
41	8937002	TIMAU MARANIA	0.0833	37.4500																																	93.6%
42	8937003	ISIOLO DISTRICT AGRIC.OFFICE	0.3500	37.5833																																	93.7%
43	8937014	MIKINDURI PRIMARY SCHOOL MERU	0.1167	37.8333																																	89.5%
44	8937022	NANYUKI MET. STATION	0.0500	37.0333																																	85.7%
45	8937065	MERU MET.STATION	0.0833	37.6500																																	98.9%
46	8938000	GARBATULLA POLICE STATION	0.5333	38.5167																																	76.0%
47	9034025	KISUMU METEOROLOGICAL STATION	-0.1000	34.7500																																	99.7%
48	9034036	BONDO WATER SUPPLY	-0.0500	34.2833																																	90.9%
49	9034059	MACALDER AGRICULTURAL OFFICE	-0.9667	34.3000																																	73.2%
50	9034087	LAMBWE FOREST STATION	-0.6500	34.3500																																	91.2%
51	9034088	KISII MET(NYANZA AG.RES.STATION)	-0.6833	34.7833																																	97.9%
52	9034124	MASAKA APUNDO'S FARM	-0.2000	34.9833																																	94.2%
53	9035001	JAMJI ESTATE (KERICHO)	-0.4833	35.1833																																	50.3%
54	9035002	LONDIANI FOREST STATION	-0.1500	35.6000																																	50.2%
55	9035013	SOTIK MONIERI TEA ESTATE	-0.6500	35.0667																																	92.5%
56	9035117	MARIASHON FOREST STATION	-0.3667	35.8167																																	91.3%
57	9035220	KORU HOMALINE CO. LTD	-0.1667	35.2833																																	93.7%
58	9035265	BOMET WATER SUPPLY	-0.7833	35.3500																																	90.5%
59	9035267	MENENGAI FARM	-0.2167	35.9667																																	95.4%
60	9035274	CHEMELIL SUGAR SCHEME	-0.0667	35.1333																																	93.7%
61	9035279	HAIL RESEARCH STATION KERICHO	-0.3667	35.2667																																	99.2%
62	9036017	NYERI MINISTRY OF WORKS	-0.4167	36.9500																																	87.6%
63	9036025	N. KINANGOP FOREST STATION	-0.5833	36.6333																																	90.5%
64	9036029	GILGIL KWETU FARM	-0.3500	36.3000																																	94.7%
65	9036081	NAIVASHA VET.EXPT. STATION	-0.6500	36.4167																																	93.2%
66	9036135	NYANDARUA AGRI. RES. STATION	-0.0333	36.3500																																	97.9%
67	9036147	ELEMENTAITA,SOYSAMBU ESTATE	-0.4667	36.2000																																	90.0%
68	9036259	GATARE FOREST STATION	-0.7167	36.7667																																	86.8%
69	9036261	NAKURU METEOROLOGICAL STATION	-0.2667	36.1000																																	97.5%
70	9037096	SAGANA FISH CULTURE FARM	-0.6667	37.2000																																	90.3%
71	9037099	KARATINA KAGOCHI	-0.3833	37.1500																																	93.3%
72	9037123	CHOGORIA FOREST STATION	-0.2833	37.6167																																	93.2%
73	9037177	KALABA CHIEF'S OFFICE	-0.7500	37.3833																																	90.1%
74	9037202	EMBU MET. STATION	-0.5000	37.4500																																	99.2%
75	9037210	KAMBURU POWER STATION	-0.8000	37.6833																																	83.8%
76	9038023	MUMONI FOREST RESERVE	-0.5333	38.0167																																	91.4%
77	9039000	GARISSA MET STATION	-0.4833	39.6333																																	97.9%
78	9134011	SOTIK DIV AGRI OFFICE	-1.0000	34.8833																																	75.4%
79	9134025	MIGORI WATER SUPPLY	-1.0667	34.4667																																	67.7%
80	9135001	NAROK METEOROLOGICAL STATION	-1.1000	35.8667																																	98.6%

source: counted by JICA Study Team with original data from Kenya Meteorological Department

Legend
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- 60% <= data availability < 70%
- 50% <= data availability < 60%
- 40% <= data availability < 50%
- less than 40%

Table 2.1.2 List of Rainfall Observation Stations and Those Data Availability for 1979 – 2010 (3/3)

ID	Station ID	Station Name	Latitude	Longitude	Total Validation
81	9135021	NAROSURA CHIEF'S CAMP	-1.5333	35.8667	65.8%
82	9135026	GOVERNOR'S CAMP	-1.2833	35.0833	50.8%
83	9136084	RUIRU JACARANDA COFFEE RES. STN.	-1.0833	36.9000	94.2%
84	9136164	DAGORETTI CORNER MET STATION	-1.3000	36.7500	98.3%
85	9136185	KAJIADO MASAI RURAL TR. CENTRE	-1.6667	36.8333	92.7%
86	9137048	NATIONAL HORT.RES.STN. THIKA	-1.0167	37.1000	96.2%
87	9137089	KATUMANI EXP. RES. STATION.	-1.5833	37.2333	98.8%
88	9137101	KITONDO FOREST STATION	-1.6833	37.5667	93.4%
89	9137103	THIKA YATTA FURROW	-1.1000	37.3333	92.4%
90	9137131	MANGO SUB-LOCATION	-1.3833	37.4167	90.3%
91	9137177	MITINYANI SECONDARY SCHOOL	-1.3000	37.9833	87.2%
92	9138001	MUTOMO AGRICULTURAL STATION	-1.8500	38.2000	82.2%
93	9138010	MUTHA CHIEF'S CAMP	-1.7833	38.4167	50.5%
94	9140005	GALOLE TANA IRRIGATION SCHEME	-1.5167	40.0000	65.3%
95	9237000	MAKINDU MET. STATION	-2.2833	37.8333	99.4%
96	9237002	KIBWEZI, DWA PLANTATION LTD.	-2.4000	37.9833	93.2%
97	9237040	ILASSIT WATER DEV. CAMP.	-2.9500	37.5833	51.1%
98	9237049	SULTAN HAMUD AGRIC. STATION	-2.0333	37.3833	81.2%
99	9239000	MALINDI ADU LOCATION	-2.8500	39.9667	81.5%
100	9240001	LAMU METEOROLOGICAL STATION	-2.2667	40.9000	99.7%
101	9240003	LAMU D.O.'S OFFICE	-2.3833	40.4333	92.7%
102	9240010	GARSEN WATER DEVELOPMENT DEPT.	-2.2667	40.1167	87.5%
103	9241000	LAMU, FAZA	-2.0500	41.1000	50.5%
104	9337081	TAVETA ZIWANI SISAL ESTATE	-3.2167	37.7667	63.4%
105	9337110	TAVETA WATER DEVELOPMENT STATIO	-3.4000	37.6667	78.4%
106	9337144	NJUKINI FARMER'S CO.OP. SOCIETY	-3.1833	37.7333	65.0%
107	9338001	VOI METEOROLOGICAL STATION	-3.4000	38.5667	99.4%
108	9338018	VOI,RUKANGA-KASIGAU	-3.8333	38.6333	86.1%
109	9338031	MGANGE CHIEF'S OFFICE	-3.4000	38.3167	80.2%
110	9338036	MANYANI GATE	-3.0833	38.5000	72.3%
111	9338059	LIUALENI RANCH HEADQUATERS	-3.7167	38.3000	66.1%
112	9339016	BAMBA RESEARCH SUB-STATION	-3.5333	39.5167	86.4%
113	9339036	MTWAPA AGROMET STATION	-3.9333	39.7333	98.9%
114	9339045	JILORE FOREST STATION	-3.2000	39.9167	88.0%
115	9339068	SOKOKE CHIEF'S OFFICE,KITENGENI	-3.5167	39.7667	80.2%
116	9340009	MALINDI METEOROLOGICAL STATION	-3.2333	40.1000	92.9%
117	9439000	DISTRICT CIVIL ENGINEER'S OFFICE	-4.0500	39.6500	72.1%
118	9439001	KWALE AGRICULTURAL DEPARTMENT	-4.1833	39.4667	83.4%
119	9439015	KINANGO AGRIC. OFFICE KWALE	-4.1333	39.3167	86.0%
120	9439021	MOMBASA PORT REITZ AIRPORT	-4.0333	39.6167	100.0%

source: counted by JICA Study Team with original data from Kenya Meteorological Department

Legend
- Annual data availability is more than 90%
- 80% <= data availability < 90%
- 70% <= data availability < 80%
- 60% <= data availability < 70%
- 50% <= data availability < 60%
- 40% <= data availability < 50%
- less than 40%

Table 3.2.1 List of Synoptic Stations Used for Calculation

ID	Station Name	Established	Selected for Calculation
8635000	Lodwar Meteorological Station	1919	○
8639000	Moyale Met. Station	1915	○
8641000	Mandera Met Station	1936	○
8737000	Marsabit Met Station	1918	○
8834098	Kitale Meteorological Station	1950	
8840000	Wajir Met Station	1917	○
8934096	Kakamega Agromet Station	1957	
8935115	Eldoret International Airport	1997	
8935181	Eldoret Met. Station	1972	
8937022	Laikipia Air Base	1939	○
8937065	Meru Met. Station	1966	
9034025	Kisumu Meteorological Station	1938	○
9034088	Kisii Met Station	1962	
9034103	Suba	2006	
9035279	Hail Research Station, Kericho	1963	
9036135	Nyahururu Agromet Station	1945	
9036261	Nakuru Meteorological Station	1964	
9036288	Nyeri Met Station	1968	
9037202	Embu Met. Station	1975	
9039000	Garissa Met Station	1932	○
9135001	Narok Meteorological Station	1913	○
9136087	Moi Airbase, Nairobi	1954	
9136130	Wilson Airport, Nairobi	1951	
9136164	Dagoretti Corner Met Station	1954	
9136168	Jomo Kenyatta International Airport Met Station 1954		
9136208	Kabete Agromet Station 1915 Selected		
9137048	National Hort. Res. Station, Thika 1941		
9137089	Katumani Exp. Res. Station, Machakos 1956		
9237000	Makindu Met. Station 1904 Selected		
9240001	Lamu Meteorological Station	1906	○
9338001	Voi Meteorological Station	1904	○
9339036	Mtwapa Agromet Station	1959	
9340007	Msabaha Agromet Station	1956	
9340009	Malindi Meteorological Station	1961	
9439021	Mombasa Port Reitz Airport	1890	○
	Kangema		
	Total 36 Stations 14 Stations		

Note: Observation has not officially stated at KANGEMA
Source : KMD

Table 3.2.2 List of Stations used in NWMP 1992 for Calculation

ID	Station Name	Selected for Calculation	Note
8635000	Lodwar Meteorological Station		Synoptic
8639000	Moyale Met. Station Synoptic		Synoptic
8934001	Kakamega D C		
8934008	Kitale Gloucester Vale Estate	Selected	
8935018	Kapsabet D.C.'s Office		
9034001	Kisii D.C.'s Office		
9034004	Kisumu P.C's Office		
9035002	Londiani Forest Station		
9035003	Kericho District Office		
9036002	Naivasha D.O.		
9036017	Nyeri Ministry of Works Selected	Selected	
9036020	Nakuru Railway Station Selected	Selected	
9135001	Narok Meteorological Station Synoptic		Synoptic
9136020	Ihothia Farm, Limuru		
9136028	Kiambu District Office		
9137002	Sassa Coffee, Kenya Canners		
9137010	Machakos District Office		
9237000	Makindu Met. Station Synoptic		Synoptic
9240001	Lamu Meteorological Station Synoptic		Synoptic
9338001	Voi Meteorological Station Synoptic		Synoptic
9340000	Malindi District Office		
9439001	Kwale Agricultural Department		
9439002	Mombasa Old Observatory		
9439045	Mombasa Shimanzi Water Division		
	Total 22 Stations	3 Stations	

Source: NWMP1992

Table 4.3.1 List of GCMs and Developers

No	Model Name	Developers
1	bcc-cm1	Beijing Climate Center, China
2	bccr-bcm2.0	Bjerknes Centre for Climate Research, Norway
3	cccma_cgcm3_1	Canadian Centre for Climate Modelling and Analysis, Victoria, BC, Canada
4	cccma_cgcm3_1_t63	Canadian Centre for Climate Modelling and Analysis, Victoria, BC, Canada
5	cnrm_cm3	Centre National de Researches Meteorologiques, Meteo-France, Toulouse, France
6	csiro_mk3_0	CSIRO Atmospheric Research, Melbourne, Australia
7	csiro_mk3_5	CSIRO Atmospheric Research, Melbourne, Australia
8	gfdl_cm2_0	US Dept of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, Princeton, NJ, USA
9	gfdl_cm2_1	US Dept of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, Princeton, NJ, USA
10	giss_aom	NASA/Goddard Institute for Space Studies, New York, USA
11	giss_model_e_h	NASA/GISS (Goddard Institute for Space Studies)New York, NY
12	giss_model_e_r	NASA/GISS (Goddard Institute for Space Studies)New York, NY
13	iap_fgoals1_0_g	LASG, Institute of Atmospheric Physics, P.O. Box 9804, Beijing 100029, P.R. China
14	ingv_echam4	National Institute of Geophysics and Volcanology, Bologna, Italy
15	inmcm3_0	Institute for Numerical Mathematics, Moscow, Russia
16	ipsl_cm4	Institut Pierre Simon Laplace, Paris, France
17	miroc3_2_hires	Center for Climate System Research, Tokyo, Japan / National Institute for Environmental Studies, Ibaraki, Japan / Frontier Research Center for Global Change, Kanagawa, Japan
18	miroc3_2_medres	Center for Climate System Research, Tokyo, Japan / National Institute for Environmental Studies, Ibaraki, Japan / Frontier Research Center for Global Change, Kanagawa, Japan
19	miub_echo_g	University of Bonn, Bonn, Germany, Meteorological Research Institute, Seoul, Korea
20	mpi_echam5	Max Planck Institute for Meteorology, Hamburg, Germany
21	mri_cgcm2_3_2a	Meteorological Research Institute, Tsukuba, Ibaraki, Japan
22	ncar_ccsm3_0	National Center for Atmospheric Research, Boulder, CO, USA
23	ncar_pcm1	National Center for Atmospheric Research, Boulder, CO, USA
24	ukmo_hadcm3	Hadley Centre for climate Prediction and Research/Met office, UK
25	ukmo_hadgem1	Hadley Centre for climate Prediction and Research/Met office, UK

Source: CMIP3 CMIP3 Climate Model Documentation, References, and Links
(http://www-pcmdi.llnl.gov/ipcc/model_documentation/ipcc_model_documentation.php)

Table 4.4.1 Monthly and Daily Data Availability of GCMs

No	Model Name	Developers	Monthly	Daily
-	bcc-cm1	Beijing Climate Center, China	missing	missing
-	bccr-bcm2.0	Bjerknes Centre for Climate Research, Norway	missing	
1	cccma_cgcm3_1	Canadian Centre for Climate Modelling and Analysis, Victoria, BC, Canada		
2	cccma_cgcm3_1_t63	Canadian Centre for Climate Modelling and Analysis, Victoria, BC, Canada		
3	cnrm_cm3	Centre National de Researches Meteorologiques, Meteo-France, Toulouse, France		
4	csiro_mk3_0	CSIRO Atmospheric Research, Melbourne, Australia		
5	csiro_mk3_5	CSIRO Atmospheric Research, Melbourne, Australia		
6	gfdl_cm2_0	US Dept of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, Princeton, NJ, USA		
7	gfdl_cm2_1	US Dept of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, Princeton, NJ, USA		
8	giss_aom	NASA/Goddard Institute for Space Studies, New York, USA		
-	giss_model_e_h	NASA/GISS (Goddard Institute for Space Studies)New York, NY		missing
9	giss_model_e_r	NASA/GISS (Goddard Institute for Space Studies)New York, NY		
10	iap_fgoals1_0_g	LASG, Institute of Atmospheric Physics, P.O. Box 9804, Beijing 100029, P.R. China		
11	ingv_echam4	National Institute of Geophysics and Volcanology, Bologna, Italy		
	inmcm3_0	Institute for Numerical Mathematics, Moscow, Russia		missing
12	ipsl_cm4	Institut Pierre Simon Laplace, Paris, France		
13	miroc3_2_hires	Center for Climate System Research, Tokyo, Japan / National Institute for Environmental Studies, Ibaraki, Japan / Frontier Research Center for Global Change, Kanagawa, Japan		
14	miroc3_2_medres	Center for Climate System Research, Tokyo, Japan / National Institute for Environmental Studies, Ibaraki, Japan / Frontier Research Center for Global Change, Kanagawa, Japan		
15	miub_echo_g	University of Bonn, Bonn, Germany, Meteorological Research Institute, Seoul, Korea		
16	mpi_echam5	Max Planck Institute for Meteorology, Hamburg, Germany		
17	mri_cgcm2_3_2a	Meteorological Research Institute, Tsukuba, Ibaraki, Japan		
-	ncar_ccsm3_0	National Center for Atmospheric Research, Boulder, CO, USA		missing
-	ncar_pcm1	National Center for Atmospheric Research, Boulder, CO, USA	missing	missing
-	ukmo_hadcm3	Hadley Centre for climate Prediction and Research/Met office, UK		missing
-	ukmo_hadgem1	Hadley Centre for climate Prediction and Research/Met office, UK		missing

Source: CMIP3 Climate Model Documentation, References, and Links
(http://www-pcmdi.llnl.gov/ipcc/model_documentation/ipcc_model_documentation.php)

Table 4.4.2 Precipitation for 20 years Climatology by Spatial Correlation: Observed Present (Reanalysis) and Simulated Present (20C3M)

GCM	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
cccma_cgcm3_1	0.88	0.92	0.88	0.45	0.69	0.88	0.91	0.92	0.91	0.86	0.80	0.64
cccma_cgcm3_1_t63	0.85	0.90	0.85	0.47	0.76	0.93	0.93	0.90	0.95	0.88	0.78	0.74
cnrm_cm3	0.92	0.93	0.88	0.69	0.81	0.71	0.76	0.90	0.88	0.72	0.75	0.85
csiro_mk3_0	0.91	0.91	0.82	0.43	0.76	0.92	0.96	0.96	0.95	0.75	0.76	0.84
csiro_mk3_5	0.89	0.91	0.89	0.57	0.74	0.93	0.95	0.95	0.95	0.84	0.81	0.81
gfdl_cm2_0	0.97	0.95	0.91	0.66	0.80	0.84	0.92	0.93	0.91	0.90	0.83	0.94
gfdl_cm2_1	0.93	0.91	0.86	0.47	0.72	0.73	0.82	0.81	0.82	0.75	0.78	0.85
giss_aom	0.57	0.56	0.71	0.46	0.43	0.14	0.40	0.55	0.42	0.21	0.21	0.45
giss_model_e_r	0.72	0.59	0.70	0.45	0.49	0.29	0.34	0.49	0.46	0.31	0.39	0.65
iap_fgoals1_0_g	0.88	0.89	0.88	0.65	0.77	0.44	0.76	0.88	0.90	0.83	0.82	0.91
ingv_echam4	0.89	0.85	0.94	0.57	0.83	0.92	0.92	0.84	0.93	0.81	0.74	0.84
ipsl_cm4	0.89	0.92	0.88	0.45	0.67	0.74	0.88	0.90	0.88	0.81	0.78	0.86
miroc3_2_hires	0.86	0.91	0.88	0.71	0.70	0.87	0.87	0.93	0.93	0.81	0.77	0.82
miroc3_2_medres	0.96	0.94	0.91	0.49	0.52	0.78	0.78	0.80	0.85	0.90	0.83	0.94
miub_echo_g	0.84	0.88	0.88	0.35	0.56	0.73	0.91	0.91	0.94	0.83	0.60	0.73
mpi_echam5	0.92	0.90	0.86	0.53	0.79	0.91	0.95	0.97	0.95	0.82	0.77	0.77
mri_cgcm2_3_2a	0.82	0.87	0.84	0.58	0.59	0.76	0.76	0.84	0.91	0.77	0.69	0.74

Source: Evaluated by JICA Study Team with the data obtained from Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

Table 4.4.3 Precipitation for 20 years Climatology by RMSE: Observed Present (Reanalysis) and Simulated Present (20C3M)

(Unit: mm/day)

GCM	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
cccma_cgcm3_1	2.54	1.89	1.77	2.33	1.67	1.48	1.39	1.29	1.65	2.15	3.02	4.64
cccma_cgcm3_1_t63	3.12	2.29	1.77	2.50	1.78	1.52	1.34	1.58	1.78	2.48	4.02	4.64
cnrm_cm3	2.77	1.29	1.09	1.88	2.82	2.51	1.97	1.79	1.91	2.84	3.86	3.10
csiro_mk3_0	1.14	1.00	1.38	2.31	1.57	0.88	0.69	0.80	1.23	2.04	2.24	1.66
csiro_mk3_5	1.12	0.98	1.21	2.35	2.05	0.85	0.79	0.94	1.48	2.37	2.93	2.13
gfdl_cm2_0	1.39	1.13	1.40	2.16	1.87	1.29	0.93	0.99	1.20	1.99	2.62	2.05
gfdl_cm2_1	1.31	0.90	1.48	2.35	1.88	1.34	1.56	1.66	1.35	1.84	2.90	2.40
giss_aom	4.22	3.60	2.02	1.91	1.67	2.52	2.08	2.02	2.25	2.79	3.86	4.25
giss_model_e_r	2.69	3.26	2.87	2.40	2.44	2.64	2.32	2.18	2.11	2.83	3.61	3.40
iap_fgoals1_0_g	2.51	2.21	1.80	1.91	1.55	2.58	1.42	1.20	1.47	2.04	2.39	2.01
ingv_echam4	1.13	1.26	1.11	1.75	1.56	0.88	0.89	1.30	1.05	1.62	1.52	1.26
ipsl_cm4	3.01	2.09	1.36	2.30	1.55	1.27	1.50	1.39	1.07	1.49	2.32	3.02
miroc3_2_hires	2.33	1.62	1.90	1.87	2.11	1.97	2.27	2.00	2.18	2.18	3.11	2.38
miroc3_2_medres	1.66	1.72	1.07	1.86	1.74	1.72	2.12	2.71	2.84	1.14	1.14	0.83
miub_echo_g	1.52	1.20	1.04	2.11	2.62	1.60	0.93	1.08	0.81	1.30	2.15	2.35
mpi_echam5	0.94	0.91	1.48	2.14	1.61	1.09	1.03	1.10	0.70	1.40	1.62	1.78
mri_cgcm2_3_2a	2.03	2.01	2.08	2.83	2.56	2.15	2.07	1.78	2.35	3.23	3.19	2.74

Note: RMSE (Root-mean-square error)

Source: Evaluated by JICA Study Team with the data obtained from Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

Table 4.4.4 Outgoing Longwave Radiation for 20 years Climatology by Spatial Correlation: Observed Present (Reanalysis) and Simulated Present (20C3M)

GCM	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
cccma_cgcm3_1	0.76	0.86	0.86	0.74	0.78	0.88	0.86	0.86	0.84	0.77	0.78	0.58
cccma_cgcm3_1_t63	0.75	0.84	0.90	0.70	0.81	0.86	0.86	0.82	0.86	0.84	0.83	0.63
cnrm_cm3	0.74	0.86	0.93	0.80	0.73	0.74	0.77	0.85	0.92	0.78	0.82	0.87
csiro_mk3_0	0.86	0.95	0.94	0.74	0.81	0.92	0.92	0.90	0.90	0.77	0.79	0.85
csiro_mk3_5	0.85	0.92	0.95	0.80	0.75	0.96	0.96	0.93	0.92	0.84	0.84	0.84
gfdl_cm2_0	0.94	0.98	0.95	0.76	0.75	0.85	0.87	0.91	0.91	0.87	0.83	0.92
gfdl_cm2_1	0.91	0.95	0.91	0.56	0.66	0.61	0.71	0.70	0.73	0.72	0.74	0.74
giss_aom	0.82	0.88	0.91	0.76	0.75	0.61	0.73	0.73	0.66	0.75	0.85	0.81
giss_model_e_r	0.85	0.88	0.92	0.84	0.75	0.71	0.80	0.82	0.80	0.79	0.85	0.74
iap_fgoals1_0_g	0.79	0.83	0.90	0.82	0.73	0.40	0.75	0.82	0.84	0.93	0.95	0.91
ingv_echam4	0.89	0.93	0.98	0.92	0.83	0.88	0.86	0.81	0.85	0.86	0.93	0.83
ipsl_cm4	0.97	0.97	0.93	0.70	0.78	0.80	0.89	0.92	0.94	0.94	0.91	0.93
miroc3_2_hires	0.91	0.96	0.96	0.90	0.85	0.85	0.82	0.84	0.83	0.78	0.85	0.87
miroc3_2_medres	0.96	0.97	0.94	0.75	0.58	0.81	0.76	0.77	0.77	0.91	0.94	0.97
miub_echo_g	0.85	0.96	0.94	0.76	0.64	0.79	0.87	0.81	0.88	0.88	0.92	0.77
mpi_echam5	0.93	0.96	0.98	0.86	0.90	0.90	0.92	0.93	0.95	0.94	0.95	0.89
mri_cgcm2_3_2a	0.95	0.95	0.96	0.87	0.82	0.89	0.87	0.86	0.88	0.88	0.93	0.91

Source: Evaluated by JICA Study Team with the data obtained from Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

Table 4.4.5 Outgoing Longwave Radiation for 20 years Climatology by RMSE: Observed Present (Reanalysis) and Simulated Present (20C3M)

(Unit: W/m^2)

GCM	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
cccma_cgcm3_1	19.62	16.48	15.19	19.45	16.93	14.60	17.24	16.87	15.60	16.30	15.98	24.59
cccma_cgcm3_1_t63	20.48	17.47	13.15	19.54	14.23	13.37	16.89	16.46	13.94	13.44	16.71	25.49
cnrm_cm3	28.04	16.53	13.91	12.17	18.78	15.41	18.00	17.55	9.62	16.93	19.14	19.40
csiro_mk3_0	15.53	12.64	16.21	14.03	9.95	11.66	12.99	12.76	12.37	16.54	16.52	14.97
csiro_mk3_5	14.96	12.98	11.50	12.58	12.25	25.34	23.40	20.43	15.82	13.57	16.67	13.71
gfdl_cm2_0	11.02	9.61	16.32	21.48	15.71	15.66	17.25	18.91	15.88	15.02	14.63	10.43
gfdl_cm2_1	14.23	17.81	23.21	31.79	17.95	18.42	23.27	22.84	19.94	19.75	17.11	17.00
giss_aom	21.29	21.69	14.69	13.33	12.09	16.92	14.03	14.80	19.44	19.35	19.92	21.97
giss_model_e_r	16.38	16.65	13.19	15.14	12.46	14.48	16.66	20.06	14.90	15.39	14.89	18.06
iap_fgoals1_0_g	22.94	20.07	14.33	17.37	13.25	24.11	20.56	22.98	16.17	11.47	9.05	13.34
ingv_echam4	13.26	11.37	9.02	8.53	13.89	11.15	16.65	21.19	18.70	19.54	14.46	20.98
ipsl_cm4	8.76	10.15	14.90	24.21	17.39	22.06	31.09	27.90	15.31	14.83	14.27	9.94
miroc3_2_hires	12.29	12.85	10.72	15.30	14.12	15.33	18.90	19.08	18.26	19.62	13.89	12.50
miroc3_2_medres	8.08	7.68	14.75	24.16	19.55	13.32	16.88	19.28	20.83	13.26	16.86	9.21
miub_echo_g	17.00	16.58	14.68	22.30	13.32	13.14	18.11	13.12	11.49	12.06	14.27	23.67
mpi_echam5	10.82	8.83	9.55	13.48	12.17	14.59	13.22	14.80	12.26	14.44	12.88	14.84
mri_cgcm2_3_2a	10.28	10.04	11.87	14.76	12.81	12.01	13.48	13.44	11.67	12.39	9.95	13.21

Note: RMSE (Root-mean-square error)

Source: Evaluated by JICA Study Team with the data obtained from Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

Table 4.4.6 Sea Level Pressure for 20 years Climatology by Spatial Correlation: Observed Present (Reanalysis) and Simulated Present (20C3M)

GCM	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
cccma_cgcm3_1	0.38	0.43	0.49	0.62	0.81	0.87	0.89	0.88	0.83	0.66	0.40	0.38
cccma_cgcm3_1_t63	0.36	0.42	0.48	0.59	0.82	0.90	0.93	0.91	0.85	0.66	0.36	0.25
cnrm_cm3	0.65	0.81	0.85	0.79	0.74	0.83	0.91	0.93	0.92	0.85	0.45	0.51
csiro_mk3_0	0.52	0.49	0.53	0.66	0.84	0.89	0.93	0.93	0.84	0.73	0.72	0.63
csiro_mk3_5	0.54	0.45	0.54	0.66	0.83	0.83	0.89	0.91	0.85	0.76	0.73	0.63
gfdl_cm2_0	0.67	0.59	0.59	0.66	0.79	0.83	0.86	0.86	0.80	0.69	0.70	0.73
gfdl_cm2_1	0.64	0.49	0.48	0.56	0.81	0.88	0.85	0.84	0.81	0.73	0.73	0.75
giss_aom	0.77	0.69	0.75	0.76	0.81	0.90	0.92	0.90	0.84	0.77	0.77	0.80
giss_model_e_r	0.36	0.29	0.40	0.44	0.56	0.71	0.75	0.72	0.67	0.55	0.48	0.45
iap_fgoals1_0_g	0.82	0.75	0.80	0.83	0.84	0.84	0.91	0.91	0.89	0.83	0.81	0.86
ingv_echam4	0.49	0.72	0.92	0.95	0.79	0.87	0.83	0.78	0.77	0.40	0.11	0.20
ipsl_cm4	0.65	0.59	0.59	0.64	0.77	0.84	0.85	0.83	0.75	0.70	0.70	0.70
miroc3_2_hires	0.83	0.81	0.87	0.91	0.94	0.95	0.95	0.94	0.92	0.92	0.95	0.91
miroc3_2_medres	0.74	0.78	0.87	0.90	0.91	0.91	0.89	0.84	0.79	0.77	0.85	0.77
miub_echo_g	0.48	0.70	0.79	0.86	0.79	0.88	0.92	0.89	0.86	0.67	0.07	0.27
mpi_echam5	0.91	0.92	0.93	0.97	0.97	0.97	0.97	0.96	0.94	0.92	0.85	0.88
mri_cgcm2_3_2a	0.86	0.87	0.87	0.89	0.92	0.92	0.92	0.91	0.89	0.78	0.82	0.81

Source: Evaluated by JICA Study Team with the data obtained from Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

Table 4.4.7 Sea Level Pressure for 20 years Climatology by RMSE: Observed Present (Reanalysis) and Simulated Present (20C3M)

(Unit: hPa)

GCM	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
cccma_cgcm3_1	1.73	2.32	1.97	1.75	1.23	1.52	1.84	2.04	1.88	1.65	1.47	1.58
cccma_cgcm3_1_t63	1.56	1.91	1.87	1.78	1.17	1.37	1.47	1.66	1.51	1.69	1.81	1.55
cnrm_cm3	2.21	1.92	1.40	1.04	1.38	1.56	1.50	1.08	1.04	0.69	1.24	1.80
csiro_mk3_0	1.54	1.59	1.68	1.46	1.00	0.94	0.88	1.07	1.09	1.07	1.07	1.23
csiro_mk3_5	1.45	1.91	1.98	2.10	1.16	1.27	1.33	1.32	1.20	0.96	0.76	1.19
gfdl_cm2_0	1.13	1.49	1.58	1.68	1.77	2.02	2.70	2.67	1.93	1.42	0.80	0.76
gfdl_cm2_1	1.80	2.65	2.65	3.05	2.63	2.13	2.40	2.44	2.16	1.99	1.60	1.23
giss_aom	1.03	1.11	1.03	1.21	1.83	2.53	3.04	3.79	3.51	2.42	1.47	1.26
giss_model_e_r	5.08	5.58	5.27	5.24	5.73	6.06	6.00	6.49	6.34	5.73	5.03	4.98
iap_fgoals1_0_g	0.79	0.90	0.85	1.01	1.42	2.07	1.77	2.00	1.77	0.82	0.60	0.59
ingv_echam4	1.86	1.75	2.22	2.58	2.43	2.44	2.36	2.31	2.20	2.52	2.60	2.43
ipsl_cm4	2.12	2.37	2.19	2.08	2.24	2.46	2.64	2.86	2.73	1.95	1.55	1.63
miroc3_2_hires	2.40	2.19	1.72	1.40	1.37	1.29	1.04	1.08	1.23	1.62	1.55	1.71
miroc3_2_medres	0.85	0.82	0.77	0.85	1.16	1.17	1.27	1.47	1.20	0.75	0.63	0.72
miub_echo_g	1.24	1.09	1.03	0.79	1.18	1.05	0.83	0.93	1.19	1.27	1.62	1.47
mpi_echam5	0.54	0.56	0.62	0.61	0.56	0.58	0.52	0.82	0.70	0.65	0.73	0.57
mri_cgcm2_3_2a	0.61	0.81	0.94	0.87	0.85	0.89	1.21	1.46	1.07	0.98	0.83	0.64

Note: RMSE (Root-mean-square error)

Source: Evaluated by JICA Study Team with the data obtained from Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

Table 4.4.8 Surface Air Temperature for 20 years Climatology by Spatial Correlation : Observed Present (Reanalysis) and Simulated Present (20C3M)

GCM	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
cccma_cgcm3_1	0.92	0.90	0.90	0.89	0.88	0.84	0.84	0.82	0.79	0.79	0.88	0.92
cccma_cgcm3_1_t63	0.96	0.95	0.94	0.89	0.90	0.90	0.91	0.90	0.88	0.88	0.93	0.95
cnrm_cm3	0.87	0.93	0.96	0.96	0.92	0.87	0.85	0.85	0.91	0.94	0.92	0.88
csiro_mk3_0	0.89	0.90	0.91	0.92	0.92	0.93	0.92	0.92	0.93	0.91	0.92	0.92
csiro_mk3_5	0.84	0.80	0.86	0.89	0.91	0.88	0.86	0.84	0.83	0.87	0.93	0.92
gfdl_cm2_0	0.93	0.92	0.90	0.88	0.85	0.83	0.85	0.85	0.81	0.84	0.87	0.90
gfdl_cm2_1	0.92	0.89	0.85	0.81	0.85	0.87	0.89	0.87	0.82	0.82	0.86	0.89
giss_aom	0.88	0.89	0.93	0.94	0.91	0.87	0.82	0.74	0.74	0.81	0.86	0.88
giss_model_e_r	0.86	0.84	0.89	0.91	0.87	0.83	0.81	0.69	0.62	0.68	0.79	0.86
iap_fgoals1_0_g	0.68	0.68	0.70	0.66	0.69	0.53	0.41	0.33	0.38	0.48	0.65	0.70
ingv_echam4	0.88	0.85	0.89	0.90	0.89	0.84	0.80	0.81	0.84	0.88	0.91	0.91
ipsl_cm4	0.89	0.89	0.91	0.93	0.91	0.87	0.80	0.72	0.81	0.87	0.91	0.91
miroc3_2_hires	0.91	0.93	0.95	0.97	0.95	0.92	0.90	0.89	0.91	0.93	0.96	0.94
miroc3_2_medres	0.83	0.83	0.89	0.89	0.88	0.85	0.81	0.75	0.79	0.83	0.89	0.87
miub_echo_g	0.90	0.90	0.91	0.92	0.90	0.87	0.88	0.81	0.80	0.85	0.87	0.89
mpi_echam5	0.97	0.97	0.97	0.95	0.93	0.92	0.92	0.91	0.90	0.93	0.94	0.97
mri_cgcm2_3_2a	0.85	0.85	0.88	0.89	0.87	0.83	0.80	0.77	0.80	0.80	0.85	0.88

Source: Evaluated by JICA Study Team with the data obtained from Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

Table 4.4.9 Surface Air Temperature for 20 years Climatology by RMSE: Observed Present (Reanalysis) and Simulated Present (20C3M)

(Unit: °C)

GCM	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
cccma_cgcm3_1	1.91	2.66	2.80	2.92	2.92	3.26	3.18	3.17	3.58	3.30	2.38	1.51
cccma_cgcm3_1_t63	1.14	1.53	2.03	2.54	2.37	2.51	2.29	2.13	2.46	2.35	1.54	1.05
cnrm_cm3	2.24	1.76	1.20	1.05	1.39	1.95	1.85	1.45	1.22	1.05	1.14	1.84
csiro_mk3_0	1.57	1.75	2.26	2.59	1.87	2.07	2.28	2.21	2.27	2.05	1.58	1.51
csiro_mk3_5	4.39	4.86	5.33	5.67	5.08	5.70	5.77	5.57	5.62	5.05	4.21	3.96
gfdl_cm2_0	1.36	1.32	1.79	2.20	2.14	2.20	2.33	2.35	2.50	2.12	1.81	1.91
gfdl_cm2_1	1.33	1.82	2.57	3.17	2.37	1.87	2.35	2.80	2.88	2.43	1.64	1.69
giss_aom	1.63	1.58	1.60	1.94	2.02	2.12	2.71	3.12	2.93	2.39	1.87	1.63
giss_model_e_r	2.04	2.22	1.99	2.25	2.47	2.69	3.21	3.68	3.64	2.93	2.28	1.89
iap_fgoals1_0_g	5.37	6.15	6.40	7.00	5.28	5.35	7.27	8.17	8.22	7.01	5.04	4.44
ingv_echam4	2.73	3.54	4.01	4.04	3.32	3.80	3.86	3.57	3.49	2.91	2.52	2.23
ipsl_cm4	2.69	2.90	3.30	3.67	3.53	3.60	3.89	3.84	3.62	3.43	3.02	2.63
miroc3_2_hires	1.40	1.39	1.60	1.88	1.72	1.59	1.52	1.56	1.61	1.65	1.10	1.16
miroc3_2_medres	2.07	1.88	1.63	1.77	1.78	2.07	2.06	1.90	1.63	1.52	1.28	1.77
miub_echo_g	1.43	1.41	1.52	1.87	1.67	1.73	1.92	1.95	1.97	1.80	1.55	1.51
mpi_echam5	1.75	1.75	2.49	3.45	3.37	3.00	2.91	3.13	3.30	3.00	2.65	2.01
mri_cgcm2_3_2a	2.12	2.13	2.41	2.64	2.60	2.36	2.16	2.09	2.27	2.49	2.35	2.02

Note: RMSE (Root-mean-square error)

Source: Evaluated by JICA Study Team with the data obtained from Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

Table 4.4.10 Selection of GCMs Used for Calculation

GCMs		Correlation				RMSE				Selected for Calculation
No.	Name	P	Olr	SLP	TAS	P	Olr	SLP	TAS	
1	cccma_cgcm3_1									Selected
2	cccma_cgcm3_1_t63									Selected
3	cnrm_cm3									Selected
4	csiro_mk3_0									Selected
5	csiro_mk3_5								1	
6	gfdl_cm2_0									Selected
7	gfdl_cm2_1									Selected
8	giss_aom	1								
9	giss_model_e_r	1						1		
10	iap_fgoals1_0_g		1		1				1	
11	ingv_echam4			1						
12	ipsl_cm4									Selected
13	miroc3_2_hires									Selected
14	miroc3_2_medres									Selected
15	miub_echo_g			1						
16	mpi_echam5									Selected
17	mri_cgcm2_3_2a									Selected

Note: In the RMSE and Correlation, the cells inscribed “1” means the model abandoned through the evaluation.
RMSE (Root-mean-square error)
P : Precipitation
Olr :Outgoing Longwave Radiation
SLP :Sea Level Pressure
TAS :Surface Air Tempreture

Source: Evaluated by JICA Study Team with the data obtained from Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

Table 5.2.1 Selected Stations for Calibration of SHER Model

Catchment	Station Code	Station Name	Latitude	Longitude	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Total Availability	Selected for Calibration
LVN	1AD02	Malakisi	0.6250	34.3419	100%	100%	97%	70%	79%	65%	83%	97%	89%	80%	75%	67%	0%	0%	50%	82%	0%	0%	0%	0%	0%	0%	0%	0%	33%	26%	10%	0%	0%	0%	40.1%	
LVN	1AH01	Sio	0.3875	34.1417	98%	98%	90%	99%	99%	99%	66%	99%	100%	100%	100%	99%	99%	0%	99%	100%	99%	92%	0%	100%	41%	100%	100%	58%	33%	50%	91%	71%	0%	0%	76.0%	✔
LVN	1BD02	Large Zoia	0.7611	35.0611	100%	91%	95%	70%	100%	100%	100%	100%	67%	78%	58%	37%	78%	98%	58%	0%	0%	0%	0%	80%	97%	95%	100%	91%	0%	0%	0%	0%	0%	0%	56.4%	✔
LVN	1BG07	Rongai	0.7740	34.9250	98%	96%	93%	100%	100%	100%	79%	86%	86%	85%	85%	57%	81%	84%	75%	82%	33%	0%	0%	96%	99%	92%	91%	100%	8%	76%	100%	33%	33%	25%	72.4%	✔
LVN	1CE01	Kipkaren	0.6083	34.9653	82%	81%	80%	66%	70%	49%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	98%	33%	17%	100%	92%	50%	25%	10%	0%	0%	31.8%	
LVN	1EE01	Nzoia	0.1780	34.2250	100%	98%	100%	97%	99%	80%	0%	0%	60%	18%	55%	41%	51%	11%	15%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	27.5%	
LVN	1EF01	Nzoia at Ruambwa	0.1236	34.0903	99%	100%	100%	100%	67%	75%	100%	100%	83%	0%	89%	92%	100%	100%	100%	100%	100%	99%	100%	100%	100%	100%	100%	71%	0%	54%	100%	71%	0%	0%	80.0%	✔
LVN	1EG02	Wuoroya	0.1500	34.2431	83%	85%	80%	74%	69%	78%	74%	82%	42%	62%	68%	71%	45%	87%	95%	99%	100%	53%	82%	50%	9%	4%	0%	0%	0%	0%	0%	0%	0%	0%	49.8%	✔
LVN	1FC01	Kimondi	0.2000	35.0486	91%	62%	98%	97%	100%	92%	100%	100%	100%	99%	100%	100%	100%	100%	67%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	50%	99%	67%	25%	0%	54.8%	
LVN	1FE01	Yala	0.1330	34.5750	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	83%	67%	83%	50%	100%	66%	67%	100%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	54.4%	
LVN	1FG01	Yala	0.0861	34.5583	100%	85%	82%	86%	96%	99%	99%	99%	95%	98%	100%	78%	59%	64%	70%	70%	41%	71%	71%	71%	71%	12%	0%	0%	0%	0%	0%	0%	0%	0%	57.2%	✔
LVN	1FG02	Yala	0.0431	34.2653	100%	96%	57%	96%	98%	96%	100%	89%	89%	97%	99%	85%	75%	100%	49%	0%	58%	99%	17%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	50.0%	
LVS	1GB05	Ainamatua	-0.0260	35.1750	83%	70%	17%	79%	67%	93%	97%	91%	100%	85%	81%	83%	98%	98%	100%	75%	50%	84%	100%	25%	0%	0%	0%	0%	0%	67%	99%	99%	16%	0%	61.8%	✔
LVS	1GC04	Tugenon	-0.2530	35.4140	100%	97%	100%	100%	100%	100%	100%	100%	100%	100%	100%	92%	92%	100%	24%	50%	75%	75%	24%	0%	83%	92%	92%	100%	100%	92%	100%	92%	67%	100%	84.8%	
LVS	1GD03	Nyando	-0.1250	34.9600	100%	66%	35%	73%	67%	78%	100%	99%	98%	99%	96%	88%	100%	93%	70%	63%	57%	59%	0%	0%	0%	0%	0%	0%	0%	88%	22%	83%	66%	0%	56.6%	✔
LVS	1GD07	Nyando	-0.1640	35.1640	92%	83%	28%	93%	92%	87%	85%	83%	96%	93%	92%	100%	100%	83%	92%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	43.3%	✔
LVS	1GG01	Namuting	-0.2030	35.3470	92%	100%	100%	100%	100%	100%	100%	100%	100%	100%	94%	100%	100%	100%	100%	100%	92%	67%	92%	75%	82%	91%	100%	33%	58%	16%	0%	0%	0%	0%	76.4%	
LVS	1JG01	Sondu	-0.3930	35.0080	86%	76%	58%	100%	100%	100%	99%	100%	100%	91%	83%	48%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	34.7%	✔
LVS	1KB05	Gucha Migori	-0.9470	34.2070	83%	100%	99%	83%	100%	87%	98%	100%	100%	100%	81%	99%	100%	98%	24%	0%	0%	0%	0%	0%	0%	0%	0%	23%	25%	21%	62%	88%	66%	0%	54.6%	
LVS	1KC03	Migori	-1.0640	34.4710	100%	90%	93%	100%	100%	92%	100%	100%	100%	100%	100%	100%	100%	100%	41%	0%	0%	0%	0%	0%	0%	0%	0%	75%	33%	83%	100%	100%	49%	0%	61.9%	✔
LVS	1LA03	Nyangores	-0.7860	35.3470	100%	98%	96%	42%	58%	100%	100%	90%	95%	99%	93%	82%	81%	39%	0%	0%	100%	96%	93%	75%	91%	98%	87%	88%	71%	97%	91%	92%	82%	0%	77.8%	✔
RV	2B07	Suam	1.4820	35.0080	82%	60%	90%	100%	81%	0%	88%	94%	73%	65%	66%	37%	12%	35%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	29.4%	
RV	2B33	Suam	1.4667	35.0167	0%	0%	0%	0%	0%	0%	0%	9%	96%	96%	57%	100%	100%	83%	84%	100%	83%	100%	83%	100%	75%	100%	100%	16%	0%	6%	0%	6%	0%	0%	46.5%	
RV	2C07	Ndo	0.4510	35.6470	37%	76%	82%	61%	7%	19%	0%	0%	48%	88%	60%	36%	36%	41%	17%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	20.3%	✔
RV	2C16	Kerio	1.2175	35.7094	0%	0%	47%	76%	66%	96%	97%	95%	100%	99%	99%	43%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	27.3%	✔
RV	2EE07	Perkerra	0.4575	35.9658	100%	79%	99%	96%	84%	83%	77%	95%	97%	7%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	27.2%	✔
RV	2K06	Seyabei	-1.0900	35.9520	87%	89%	68%	69%	56%	100%	100%	100%	91%	92%	91%	100%	89%	89%	100%	54%	92%	66%	15%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	51.5%	
AT	3BA32	Nairobi	-1.1940	37.1190	98%	90%	90%	72%	69%	39%	36%	47%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	18.1%	✔
AT	3BC08	Ruiru	-1.0890	36.8780	93%	92%	83%	0%	0%	67%	83%	100%	100%	100%	98%	93%	99%	88%	89%	69%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	41.8%	✔
AT	3DA02	Athi Munyu	-1.0893	37.1959	99%	98%	72%	96%	88%	91%	98%	84%	97%	97%	88%	90%	98%	90%	58%	100%	49%	0%	0%	46%	15%	25%	32%	99%	99%	0%	0%	0%	0%	0%	60.3%	✔
AT	3HA12	Sabaki Cableway	-3.0390	38.6830	10%	52%	78%	41%	87%	30%	52%	64%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	13.8%	✔
TN	4BC02	Tana Sagana	-0.6720	37.2070	98%	98%	95%	99%	96%	98%	99%	97%	98%	96%	82%	88%	95%	90%	84%	0%	0%	0%	0%	0%	66%	82%	99%	83%	47%	47%	77%	77%	57%	0%	68.3%	✔
TN	4BE01	Maragua	-0.7500	37.1530	96%	93%	82%	96%	95%	97%	95%	96%	72%	92%	100%	100%	93%	100%	33%	16%	82%	96%	92%	33%	100%	66%	67%	100%	100%	100%	100%	100%	100%	100%	86.4%	✔
TN	4BE03	Irati	-0.7830	37.0170	100%	55%	100%	55%	90%	75%	100%	100%	100%	100%	100%	100%	100%	85%	71%	100%	83%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	51.0%	✔
TN	4CA02	Chania	-1.0260	37.0630	96%	87%	75%	93%	96%	86%	86%	97%	85%	95%	65%	82%	95%	90%	70%	0%	0%	0%	0%	0%	66%	78%	94%	81%	47%	47%	76%	77%	57%	0%	64.1%	
TN	4CB04	Thika	-1.0210	37.0660	69%	93%	100%	98%	98%	93%	94%	88%	85%	94%	90%	98%	79%	97%	96%	87%	96%	89%	86%	75%	72%	78%	82%	79%	90%	76%	94%	32%	95%	32%	84.5%	
TN	4DA10	Thiba	-0.6210	37.3170	96%	100%	100%	98%	96%	95%	97%	85%	96%	87%	88%	90%	86%	87%	63%	86%	0%	67%	15%	81%	62%	30%	92%	74%	91%	26%	0%	0%	0%	0%	66.3%	
TN	4DC03	Rupingazi	-0.5330	37.4380	99%	98%	99%	96%	95%	96%	90%	85%	88%	92%	95%	94%	92%	90%	83%	69%	65%	0%	0%	47%	21%	0%	0%	0%	0%	68%	97%	7%	0%	0%	58.9%	
TN	4EA07	Mutonga	-0.3760	37.8960	100%	100%	87%	84%	87%	91%	100%	100%	85%	100%	100%	41%	92%	83%	100%	83%	100%	100%	100%	41%	58%	0%	0%	0%	0%	51%	57%	0%	0%	0%	64.7%	
TN	4F13	Grand Falls	-0.2850	38.0180	95%	98%	95%	96%	93%	98%	79%	78%	77%	75%	90%	98%	81%	87%	83%	72%	84%	34%	0%	34%	0%	0%	0%	0%	0%	93%	100%	96%	0%	85%	64.0%	✔
TN	4G01	Garissa	-0.4500	39.7000	52%	98%	99%	99%	100%	97%	99%	92%	100%	100%	99%	99%	87%	100%	98%	92%	41%	75%	92%	92%	100%	58%	96%	72%	92%	64%	95%	100%	99%	90%	89.2%	✔
TN	4G02	Garsen	-2.2750	40.1170	28%	52%	48%	38%	19%	68%	74%	83%	92%	100%	100%	83%	100%	81%	9%	0%	0%	61%	41%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	35.9%	
EN	5AC10	Ewaso Narok	0.4380	36.7240	100%	100%	100%	92%	83%	100%	8%	51%	55%	54%	55%	50%	54%	43%	42%	51%	52%	46%	57%	47%	87%	84%	91%	92%	92%	100%	75%	82%	50%	100%	69.7%	✔
EN	5AC15	Ewaso Narok	0.2570	36.5370	0%	0%	65%	76%	64%	70%	70%	70%	57%	58%	69%	69%	70%	60%	49%	62%	62%	53%	45%	56%	96%	99%	100%	92%	100%	84%	100%	70%	75%	100%	68.1%	✔
EN	5BB02	Ewaso Ngiro	0.1330	36.8670	99%	98%	99%	92%	97%	95%	95%	96%	90%	94%	97%	98%	96%	96%	95%	95%	98%	83%	90%	88%	98%	100%	92%	91%	100%	8%	96%	100%	42%	31%	88.3%	
EN	5BC04	Ewaso Ngiro	0.0900	36.9050	100%	93%	84%	41%	25%	36%	25%	14%	20%	21%	28%	24%	70%	4%	55%	74%	63%	69%	90%	90%	74%	99%	62%	75%	92%	8%	64%	96%	61%	34%	56.5%	
EN	5E03	Nwaso Ngiro at Archer's Post	0.6420	37.6780	96%	100%	100%	100%	100%	100%	99%	100%	100%	81%	75%	81%	83%	83%	37%	83%	0%	0%	0%	25%	92%	100%	91%	0%	0%	0%	32%	67%	87%	100%	67.0%	✔

Source: JICA Study Team

Table 5.3.1 Calibrated Soil Parameter of SHER Model (LVNCA)

Surface Soil Parameters for Lake Victoria North (LVN)

Soil Type	Name	Depth of Depression [mm]	θ0 Saturated Water Contents	θs Residual Water Contents	Mualem's n	K0[cm/sec] Saturated Hydraulic Conductivity of Vertical Direction	iK0[cm/sec] Saturated Hydraulic Conductivity of Slope Direction
1	compacted_loam_Recharging	5	0.361	0.280	4.00	1.00E-05	1.00E-04
2	Igneous_loam1_Recharging	7	0.441	0.280	4.00	1.00E-04	1.00E-03
3	Sedimentary_loam1_Recharging	7	0.441	0.280	4.00	1.00E-05	1.00E-04
4	Metamorphic_loam1_Recharging	7	0.441	0.280	4.00	1.00E-04	1.00E-03
5	Igneous_loam2_Recharging	5	0.441	0.280	4.00	1.00E-04	1.00E-03
6	Sedimentary_loam2_Recharging	5	0.441	0.280	4.00	1.00E-05	1.00E-04
7	Metamorphic_loam2_Recharging	5	0.441	0.280	4.00	1.00E-04	1.00E-03
8	bare_sand_Recharging	5	0.440	0.010	8.00	1.00E-03	1.00E-02
9	paddy_silt_Recharging	50	0.441	0.280	4.00	1.00E-06	1.00E-05
10	wetland_silt_Recharging	5	0.441	0.280	4.00	1.00E-06	1.00E-05
11	water_silt_Recharging	0	0.441	0.280	4.00	1.00E-06	1.00E-05
12	compacted_loam_Discharging	5	0.361	0.280	4.00	1.00E-06	1.00E-05
13	Igneous_loam1_Discharging	7	0.441	0.280	4.00	1.00E-05	1.00E-04
14	Sedimentary_loam1_Discharging	7	0.441	0.280	4.00	1.00E-06	1.00E-05
15	Metamorphic_loam1_Discharging	7	0.441	0.280	4.00	1.00E-05	1.00E-04
16	Igneous_loam2_Discharging	5	0.441	0.280	4.00	1.00E-05	1.00E-04
17	Sedimentary_loam2_Discharging	5	0.441	0.280	4.00	1.00E-06	1.00E-05
18	Metamorphic_loam2_Discharging	5	0.441	0.280	4.00	1.00E-05	1.00E-04
19	bare_sand_Discharging	5	0.440	0.010	8.00	1.00E-04	1.00E-03
20	paddy_silt_Discharging	50	0.441	0.280	4.00	1.00E-07	1.00E-06
21	wetland_silt_Discharging	5	0.441	0.280	4.00	1.00E-07	1.00E-06
22	water_silt_Discharging	0	0.441	0.280	4.00	1.00E-07	1.00E-06

Aquifer Paremeters for Lake Victoria North Catchment Area (LVN)

Block Type	Kg [cm/sec] Hydraulic Conductivity
Volcanic rock and Pre-Cenozoic	1.00E-03
Sedimentary Rock	1.00E-05
Quaternary Sedimentary Rock	5.00E-04

Note: All the parameters were derived through calibration by SHER model.
Source: JICA Study Team

Table 5.3.2 Calibrated Soil Parameter of SHER Model (LVSCA)

Surface Soil Parameters for Lake Victoria South (LVS)

Soil Type	Name	Depth of Depression [mm]	θ0 Saturated Water Contents	θs Residual Water Contents	Mualem's n	K0[cm/sec] Saturated Hydraulic Conductivity of Vertical Direction	iK0[cm/sec] Saturated Hydraulic Conductivity of Slope Direction
1	compacted_loam_Recharging	5	0.361	0.280	4.00	1.00E-05	1.00E-04
2	Igneous_loam1_Recharging	7	0.441	0.280	4.00	1.00E-04	1.00E-03
3	Sedimentary_loam1_Recharging	7	0.441	0.280	4.00	1.00E-05	1.00E-04
4	Metamorphic_loam1_Recharging	7	0.441	0.280	4.00	1.00E-04	1.00E-03
5	Igneous_loam2_Recharging	5	0.441	0.280	4.00	1.00E-04	1.00E-03
6	Sedimentary_loam2_Recharging	5	0.441	0.280	4.00	1.00E-04	1.00E-03
7	Metamorphic_loam2_Recharging	5	0.441	0.280	4.00	1.00E-04	1.00E-03
8	bare_sand_Recharging	5	0.440	0.010	8.00	1.00E-03	1.00E-02
9	paddy_silt_Recharging	50	0.441	0.280	4.00	1.00E-06	1.00E-05
10	wetland_silt_Recharging	5	0.441	0.280	4.00	1.00E-06	1.00E-05
11	water_silt_Recharging	0	0.441	0.280	4.00	1.00E-06	1.00E-05
12	compacted_loam_Discharging	5	0.361	0.280	4.00	1.00E-06	1.00E-05
13	Igneous_loam1_Discharging	7	0.441	0.280	4.00	1.00E-05	1.00E-04
14	Sedimentary_loam1_Discharging	7	0.441	0.280	4.00	1.00E-06	1.00E-05
15	Metamorphic_loam1_Discharging	7	0.441	0.280	4.00	1.00E-05	1.00E-04
16	Igneous_loam2_Discharging	5	0.441	0.280	4.00	1.00E-05	1.00E-04
17	Sedimentary_loam2_Discharging	5	0.441	0.280	4.00	1.00E-05	1.00E-04
18	Metamorphic_loam2_Discharging	5	0.441	0.280	4.00	1.00E-05	1.00E-04
19	bare_sand_Discharging	5	0.440	0.010	8.00	1.00E-04	1.00E-03
20	paddy_silt_Discharging	50	0.441	0.280	4.00	1.00E-07	1.00E-06
21	wetland_silt_Discharging	5	0.441	0.280	4.00	1.00E-07	1.00E-06
22	water_silt_Discharging	0	0.441	0.280	4.00	1.00E-07	1.00E-06

Aquifer Paremeters for Lake Victoria South Catchment Area (LVSCA)

Block Type	Kg [cm/sec] Hydraulic Conductivity
Volcanic rock and Pre-Cenozoic	1.00E-03
Sedimentary Rock	1.00E-05
Quaternary Sedimentary Rock	5.00E-04

Source: JICA Study Team

Table 5.3.3 Calibrated Soil Parameter of SHER Model (RVCA)

Surface Soil Parameters for Rift Valley (RV)

Soil Type	Name	Depth of Depression [mm]	θ0 Saturated Water Contents	θs Residual Water Contents	Mualem's n	K0[cm/sec] Saturated Hydraulic Conductivity of Vertical Direction	iK0[cm/sec] Saturated Hydraulic Conductivity of Slope Direction
1	compacted_loam_Recharging	5	0.361	0.280	4.00	1.00E-05	1.00E-04
2	Igneous_loam1_Recharging	7	0.441	0.280	4.00	1.00E-04	1.00E-03
3	Sedimentary_loam1_Recharging	7	0.441	0.280	4.00	1.00E-05	1.00E-04
4	Metamorphic_loam1_Recharging	7	0.441	0.280	4.00	5.00E-05	5.00E-04
5	Igneous_loam2_Recharging	5	0.441	0.280	4.00	1.00E-04	1.00E-03
6	Sedimentary_loam2_Recharging	5	0.441	0.280	4.00	1.00E-05	1.00E-04
7	Metamorphic_loam2_Recharging	5	0.441	0.280	4.00	5.00E-05	5.00E-04
8	bare_sand_Recharging	5	0.440	0.010	8.00	1.00E-02	1.00E-01
9	paddy_silt_Recharging	50	0.441	0.280	4.00	1.00E-06	1.00E-05
10	wetland_silt_Recharging	5	0.441	0.280	4.00	1.00E-06	1.00E-05
11	water_silt_Recharging	0	0.441	0.280	4.00	1.00E-06	1.00E-05
12	compacted_loam_Discharging	5	0.361	0.280	4.00	1.00E-06	1.00E-05
13	Igneous_loam1_Discharging	7	0.441	0.280	4.00	1.00E-05	1.00E-04
14	Sedimentary_loam1_Discharging	7	0.441	0.280	4.00	1.00E-06	1.00E-05
15	Metamorphic_loam1_Discharging	7	0.441	0.280	4.00	5.00E-06	5.00E-05
16	Igneous_loam2_Discharging	5	0.441	0.280	4.00	1.00E-05	1.00E-04
17	Sedimentary_loam2_Discharging	5	0.441	0.280	4.00	1.00E-06	1.00E-05
18	Metamorphic_loam2_Discharging	5	0.441	0.280	4.00	5.00E-06	5.00E-05
19	bare_sand_Discharging	5	0.440	0.010	8.00	1.00E-03	1.00E-02
20	paddy_silt_Discharging	50	0.441	0.280	4.00	1.00E-07	1.00E-06
21	wetland_silt_Discharging	5	0.441	0.280	4.00	1.00E-07	1.00E-06
22	water_silt_Discharging	0	0.441	0.280	4.00	1.00E-07	1.00E-06

Aquifer Paremeters for Rift Valley Catchment Area (RVCA)

Block Type	Kg [cm/sec] Hydraulic Conductivity
Volcanic rock and Pre-Cenozoic	1.00E-04
Sedimentary Rock	1.00E-05
Quaternary Sedimentary Rock	5.00E-04

Source: JICA Study Team

Table 5.3.4 Calibrated Soil Parameter of SHER Model (ACA)

Surface Soil Parameters for Athi (AT)

Soil Type	Name	Depth of Depression [mm]	θ0 Saturated Water Contents	θs Residual Water Contents	Mualem's n	K0[cm/sec] Saturated Hydraulic Conductivity of Vertical Direction	iK0[cm/sec] Saturated Hydraulic Conductivity of Slope Direction
1	compacted_loam_Recharging	5	0.361	0.280	4.00	1.00E-05	1.00E-04
2	Igneous_loam1_Recharging	7	0.441	0.280	4.00	1.00E-04	1.00E-03
3	Sedimentary_loam1_Recharging	7	0.441	0.280	4.00	1.00E-05	1.00E-04
4	Metamorphic_loam1_Recharging	7	0.441	0.280	4.00	5.00E-05	5.00E-04
5	Igneous_loam2_Recharging	5	0.441	0.280	4.00	1.00E-04	1.00E-03
6	Sedimentary_loam2_Recharging	5	0.441	0.280	4.00	1.00E-05	1.00E-04
7	Metamorphic_loam2_Recharging	5	0.441	0.280	4.00	5.00E-05	5.00E-04
8	bare_sand_Recharging	5	0.440	0.010	8.00	1.00E-03	1.00E-02
9	paddy_silt_Recharging	50	0.441	0.280	4.00	1.00E-06	1.00E-05
10	wetland_silt_Recharging	5	0.441	0.280	4.00	1.00E-06	1.00E-05
11	water_silt_Recharging	0	0.441	0.280	4.00	1.00E-06	1.00E-05
12	compacted_loam_Discharging	5	0.361	0.280	4.00	1.00E-06	1.00E-05
13	Igneous_loam1_Discharging	7	0.441	0.280	4.00	1.00E-05	1.00E-04
14	Sedimentary_loam1_Discharging	7	0.441	0.280	4.00	1.00E-06	1.00E-05
15	Metamorphic_loam1_Discharging	7	0.441	0.280	4.00	5.00E-06	5.00E-05
16	Igneous_loam2_Discharging	5	0.441	0.280	4.00	1.00E-05	1.00E-04
17	Sedimentary_loam2_Discharging	5	0.441	0.280	4.00	1.00E-06	1.00E-05
18	Metamorphic_loam2_Discharging	5	0.441	0.280	4.00	5.00E-06	5.00E-05
19	bare_sand_Discharging	5	0.440	0.010	8.00	1.00E-04	1.00E-03
20	paddy_silt_Discharging	50	0.441	0.280	4.00	1.00E-07	1.00E-06
21	wetland_silt_Discharging	5	0.441	0.280	4.00	1.00E-07	1.00E-06
22	water_silt_Discharging	0	0.441	0.280	4.00	1.00E-07	1.00E-06

Aquifer Paremeters for Athi Catchment Area (ACA)

Block Type	Kg [cm/sec] Hydraulic Conductivity
Volcanic rock and Pre-Cenozoic	1.00E-03
Sedimentary Rock	1.00E-05
Quaternary Sedimentary Rock	5.00E-04

Source: JICA Study Team

Table 5.3.5 Calibrated Soil Parameter of SHER Model (TCA)

Surface Soil Parameters for Tana (TN)

Soil Type	Name	Depth of Depression [mm]	θ0 Saturated Water Contents	θs Residual Water Contents	Mualem's n	K0[cm/sec] Saturated Hydraulic Conductivity of Vertical Direction	iK0[cm/sec] Saturated Hydraulic Conductivity of Slope Direction
1	compacted_loam_Recharging	5	0.361	0.280	4.00	1.00E-05	1.00E-04
2	Igneous_loam1_Recharging	7	0.441	0.280	4.00	1.00E-04	1.00E-03
3	Sedimentary_loam1_Recharging	7	0.441	0.280	4.00	1.00E-05	1.00E-04
4	Metamorphic_loam1_Recharging	7	0.441	0.280	4.00	5.00E-05	5.00E-04
5	Igneous_loam2_Recharging	5	0.441	0.280	4.00	1.00E-04	1.00E-03
6	Sedimentary_loam2_Recharging	5	0.441	0.280	4.00	1.00E-05	1.00E-04
7	Metamorphic_loam2_Recharging	5	0.441	0.280	4.00	5.00E-05	5.00E-04
8	bare_sand_Recharging	5	0.440	0.010	8.00	1.00E-03	1.00E-02
9	paddy_silt_Recharging	50	0.441	0.280	4.00	1.00E-06	1.00E-05
10	wetland_silt_Recharging	5	0.441	0.280	4.00	1.00E-06	1.00E-05
11	water_silt_Recharging	0	0.441	0.280	4.00	1.00E-06	1.00E-05
12	compacted_loam_Discharging	5	0.361	0.280	4.00	1.00E-06	1.00E-05
13	Igneous_loam1_Discharging	7	0.441	0.280	4.00	1.00E-05	1.00E-04
14	Sedimentary_loam1_Discharging	7	0.441	0.280	4.00	1.00E-06	1.00E-05
15	Metamorphic_loam1_Discharging	7	0.441	0.280	4.00	5.00E-06	5.00E-05
16	Igneous_loam2_Discharging	5	0.441	0.280	4.00	1.00E-05	1.00E-04
17	Sedimentary_loam2_Discharging	5	0.441	0.280	4.00	1.00E-06	1.00E-05
18	Metamorphic_loam2_Discharging	5	0.441	0.280	4.00	5.00E-06	5.00E-05
19	bare_sand_Discharging	5	0.440	0.010	8.00	1.00E-04	1.00E-03
20	paddy_silt_Discharging	50	0.441	0.280	4.00	1.00E-07	1.00E-06
21	wetland_silt_Discharging	5	0.441	0.280	4.00	1.00E-07	1.00E-06
22	water_silt_Discharging	0	0.441	0.280	4.00	1.00E-07	1.00E-06

Aquifer Paremeters for Tana Catchment Area (TCA)

Block Type	Kg [cm/sec] Hydraulic Conductivity
Volcanic rock and Pre-Cenozoic	2.00E-02
Sedimentary Rock	1.00E-04
Quaternary Sedimentary Rock	5.00E-03

Source: JICA Study Team

Table 5.3.6 Calibrated Soil Parameter of SHER Model (ENNCA)

Surface Soil Parameters for Ewaso Ngiro (EN)

Soil Type	Name	Depth of Depression [mm]	θ0 Saturated Water Contents	θs Residual Water Contents	Mualem's n	K0[cm/sec] Saturated Hydraulic Conductivity of Vertical Direction	iK0[cm/sec] Saturated Hydraulic Conductivity of Slope Direction
1	compacted_loam_Recharging	5	0.361	0.280	4.00	1.00E-04	1.00E-03
2	Igneous_loam1_Recharging	7	0.441	0.280	4.00	1.00E-03	1.00E-02
3	Sedimentary_loam1_Recharging	7	0.441	0.280	4.00	1.00E-05	1.00E-04
4	Metamorphic_loam1_Recharging	7	0.441	0.280	4.00	5.00E-05	5.00E-04
5	Igneous_loam2_Recharging	5	0.441	0.280	4.00	1.00E-03	1.00E-02
6	Sedimentary_loam2_Recharging	5	0.441	0.280	4.00	1.00E-05	1.00E-04
7	Metamorphic_loam2_Recharging	5	0.441	0.280	4.00	5.00E-05	5.00E-04
8	bare_sand_Recharging	5	0.440	0.010	8.00	1.00E-02	1.00E-01
9	paddy_silt_Recharging	50	0.441	0.280	4.00	1.00E-06	1.00E-05
10	wetland_silt_Recharging	5	0.441	0.280	4.00	1.00E-06	1.00E-05
11	water_silt_Recharging	0	0.441	0.280	4.00	1.00E-06	1.00E-05
12	compacted_loam_Discharging	5	0.361	0.280	4.00	1.00E-05	1.00E-04
13	Igneous_loam1_Discharging	7	0.441	0.280	4.00	1.00E-04	1.00E-03
14	Sedimentary_loam1_Discharging	7	0.441	0.280	4.00	1.00E-06	1.00E-05
15	Metamorphic_loam1_Discharging	7	0.441	0.280	4.00	5.00E-06	5.00E-05
16	Igneous_loam2_Discharging	5	0.441	0.280	4.00	1.00E-04	1.00E-03
17	Sedimentary_loam2_Discharging	5	0.441	0.280	4.00	1.00E-06	1.00E-05
18	Metamorphic_loam2_Discharging	5	0.441	0.280	4.00	5.00E-06	5.00E-05
19	bare_sand_Discharging	5	0.440	0.010	8.00	1.00E-03	1.00E-02
20	paddy_silt_Discharging	50	0.441	0.280	4.00	1.00E-07	1.00E-06
21	wetland_silt_Discharging	5	0.441	0.280	4.00	1.00E-07	1.00E-06
22	water_silt_Discharging	0	0.441	0.280	4.00	1.00E-07	1.00E-06

Aquifer Paremeters for Ewaso Ng'iro Noth Catchment Area (ENNCA)

Block Type	Kg [cm/sec] Hydraulic Conductivity
Volcanic rock and Pre-Cenozoic	1.00E-03
Sedimentary Rock	1.00E-05
Quaternary Sedimentary Rock	5.00E-04

Source: JICA Study Team

Table 5.4.1 Present Monthly Average Rainfall by Sub-basin (1/3)

(Unit: mm/day)

CA	Sub-basin	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
LVNCA	1AA	1.9	2.0	3.7	7.1	6.5	3.8	3.6	4.2	4.9	5.5	4.0	2.2
	1AB	1.6	1.8	3.3	6.6	6.1	3.8	3.8	4.4	4.5	5.0	3.5	1.9
	1AC	1.9	2.0	3.6	7.2	6.5	4.1	3.8	4.4	4.7	5.3	3.7	2.1
	1AD	2.3	2.3	4.3	7.9	7.2	4.1	3.7	4.3	5.4	6.0	4.6	2.6
	1AE	2.5	2.4	4.6	8.0	7.3	3.7	3.3	4.0	5.6	6.6	5.1	3.0
	1AF	2.3	2.3	4.4	7.8	7.1	4.1	3.6	4.2	5.3	5.9	4.5	2.6
	1AG	2.3	2.3	4.6	7.9	7.0	4.1	3.5	4.2	5.4	5.7	4.7	2.7
	1AH	2.4	2.2	4.6	7.9	6.8	3.6	3.1	3.8	5.4	6.1	5.1	3.0
	1BA	1.7	1.2	2.9	5.6	4.6	3.7	4.2	4.2	2.3	3.8	3.7	1.8
	1BB	1.4	1.2	2.7	5.5	4.9	4.1	4.6	4.6	2.9	4.1	3.3	1.5
	1BC	1.2	1.2	2.4	5.5	5.4	4.5	4.9	5.0	3.4	4.2	2.9	1.3
	1BD	1.4	1.3	2.7	5.4	4.8	3.6	4.3	4.7	3.3	3.9	3.0	1.6
	1BE	1.2	1.3	2.5	5.5	5.2	3.9	4.4	4.8	3.7	4.2	2.8	1.4
	1BG	1.2	1.4	2.7	5.7	5.4	3.9	4.3	4.9	4.2	4.3	2.9	1.5
	1BH	1.3	1.5	2.9	6.0	5.6	4.0	4.1	4.9	4.4	4.5	3.0	1.6
	1CA	1.6	1.3	2.9	5.5	4.6	3.7	4.6	4.8	2.8	3.4	3.1	1.8
	1CB	1.7	1.4	2.9	5.6	4.7	3.9	4.9	5.2	3.1	3.4	3.0	2.0
	1CC	2.0	1.5	3.2	5.8	4.9	4.3	5.0	5.5	3.4	3.5	3.4	2.2
	1CD	1.8	1.7	3.2	6.1	5.6	4.6	5.1	5.7	4.2	3.9	3.0	1.9
	1CE	1.5	1.6	3.0	6.1	5.8	4.5	4.5	5.5	4.7	4.3	2.8	1.8
	1DA	1.9	1.9	3.7	7.2	6.7	5.1	4.6	5.6	5.2	4.9	3.4	2.1
	1DB	1.6	1.8	3.3	6.6	6.1	4.1	4.0	4.7	4.6	4.8	3.3	1.8
	1DC	2.0	2.1	4.0	7.5	6.8	4.6	4.0	4.8	5.1	5.1	3.9	2.2
	1DD	2.2	2.2	4.3	7.7	6.9	4.4	3.8	4.5	5.2	5.4	4.3	2.4
	1EA	2.4	2.2	4.4	7.6	7.2	5.8	5.1	6.3	5.5	4.8	3.9	2.5
	1EB	2.5	2.4	4.9	7.9	7.4	5.5	4.4	5.7	5.7	5.1	4.4	2.7
	1EC	2.3	2.2	4.4	7.9	7.3	5.6	4.7	5.8	5.6	5.2	4.0	2.5
	1ED	2.4	2.3	4.8	8.1	7.1	4.7	3.8	4.7	5.7	5.3	4.8	2.8
	1EE	2.5	2.2	4.8	8.1	6.5	3.8	3.1	3.8	5.5	5.5	5.2	3.1
	1EF	2.5	2.1	4.7	7.9	6.3	3.5	2.9	3.6	5.2	5.5	5.1	3.0
	1EG	2.6	2.1	5.0	8.0	6.3	4.0	3.1	4.0	5.4	5.0	5.1	3.2
	1FA	2.1	1.7	3.5	5.8	5.2	4.6	5.3	5.8	3.8	3.7	3.6	2.3
	1FB	2.3	2.0	3.9	6.6	6.1	5.0	5.4	5.9	4.5	4.1	3.7	2.3
	1FC	2.5	2.1	4.2	6.8	6.3	5.2	5.3	5.8	4.7	4.2	4.0	2.5
	1FD	2.5	2.0	4.1	6.4	5.9	4.8	5.1	5.4	4.3	4.1	4.1	2.4
	1FE	2.8	2.3	5.0	7.6	6.8	5.2	4.4	5.4	5.2	4.6	4.4	2.9
	1FF	2.8	2.1	5.1	7.5	6.2	4.2	3.3	4.3	4.8	4.3	4.5	3.2
	1FG	2.6	2.0	4.8	7.5	5.4	3.4	2.5	3.4	4.6	4.7	4.9	3.2
LVSCA	1GA	2.5	1.8	3.9	6.0	5.1	4.3	4.7	5.3	3.7	3.7	3.7	2.4
	1GB	3.0	2.1	4.7	6.7	5.5	4.3	4.3	4.5	4.0	4.0	4.2	2.8
	1GC	2.6	2.0	3.9	5.9	4.9	4.1	4.5	5.2	3.5	3.9	3.7	2.6
	1GD	3.4	2.2	5.0	6.7	5.0	3.6	3.4	3.7	3.5	3.9	4.2	3.0
	1GE	3.5	2.3	4.9	6.9	5.4	3.8	3.5	3.9	3.7	4.4	4.4	3.2
	1GF	3.5	2.3	4.8	6.8	5.2	3.4	3.0	3.6	3.5	4.1	4.3	3.4
	1GG	2.8	2.1	4.3	6.2	5.2	4.2	4.4	4.9	3.7	3.9	3.8	2.6
	1HA1	3.1	2.1	5.0	6.9	5.5	3.7	3.2	3.9	4.0	3.8	4.2	3.2
	1HA2	3.2	2.0	4.9	6.7	4.9	3.3	3.0	3.4	3.5	3.6	4.1	3.2
	1HB1	2.7	1.9	4.8	7.3	5.2	3.3	2.4	3.2	4.2	4.2	4.7	3.2
	1HB2	3.0	1.9	5.1	7.0	5.4	3.3	2.5	3.3	3.9	3.7	4.3	3.4
	1HC	2.5	1.8	4.5	7.1	4.9	2.9	2.1	2.9	4.0	4.3	4.7	3.1
	1HD	3.5	2.7	5.1	7.1	6.0	4.2	2.9	3.9	4.2	4.4	4.7	3.9
	1HE	3.2	2.7	5.1	7.0	6.4	4.2	2.6	3.8	4.4	4.5	4.8	3.9
	1HF	2.3	1.9	4.0	6.2	5.3	2.8	1.8	2.7	3.4	3.9	4.2	3.2
	1HG	2.2	1.9	3.9	6.2	5.1	2.7	1.7	2.5	3.3	3.8	4.2	3.2
	1JA	3.3	2.7	4.6	6.7	5.7	4.3	4.1	4.7	3.8	4.3	4.4	3.1
	1JB	3.9	3.1	5.4	7.6	6.7	4.8	4.3	4.7	4.4	5.1	4.9	3.5
	1JC	3.6	2.7	5.0	7.2	6.4	4.7	4.5	5.0	4.3	5.0	4.7	3.2
	1JD	3.8	2.9	5.3	7.6	6.6	4.8	4.3	4.7	4.4	5.2	4.9	3.5
	1JE	3.9	3.5	5.3	7.1	5.8	4.2	3.1	3.9	4.1	4.0	4.8	4.0
	1JF	3.6	3.2	5.0	7.1	5.9	4.4	3.7	4.4	4.0	4.4	4.7	3.6
	1JG1	3.7	2.9	5.1	7.4	6.1	4.5	3.7	4.4	4.2	4.8	4.7	3.7
	1JG2	3.5	2.6	5.1	7.0	5.7	3.8	2.8	3.7	3.9	4.1	4.5	3.7
	1KA	3.2	2.9	5.0	7.0	6.7	4.3	2.6	3.8	4.4	4.5	4.9	4.0
	1KB	2.9	2.7	4.5	6.6	5.9	3.5	2.2	3.0	3.6	3.9	4.5	3.8
	1KC	3.4	3.2	4.7	6.5	5.6	3.4	2.2	2.9	3.5	3.5	4.4	4.0
	1LA1	3.4	2.9	4.6	6.4	5.3	3.7	3.3	4.0	3.5	3.6	4.4	3.4
	1LA2	3.7	3.4	4.8	6.2	5.2	3.4	2.2	2.9	3.4	3.1	4.2	3.9
	1LA3	3.1	2.8	3.7	5.0	3.8	1.7	1.2	1.4	1.9	2.0	3.5	3.1
	1LB1	3.2	2.9	4.2	5.8	4.6	3.1	2.6	3.3	2.9	3.0	4.0	3.2
	1LB2	3.4	3.1	4.0	5.2	4.0	2.1	1.5	1.8	2.3	2.2	3.6	3.2

Table 5.4.1 Present Monthly Average Rainfall by Sub-basin (2/3)

(Unit: mm/day)

CA	Sub-basin	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RVCA	2AA	0.5	0.3	1.0	1.7	0.9	0.3	0.4	0.3	0.2	0.7	1.3	0.7
	2AB	0.4	0.3	0.9	1.5	0.9	0.4	0.5	0.4	0.3	0.6	1.0	0.6
	2BA	1.2	1.0	2.4	5.1	5.1	4.4	4.7	4.8	3.1	3.9	2.9	1.3
	2BB	0.9	0.7	1.9	4.0	4.0	3.2	3.5	3.6	2.3	3.1	2.5	1.1
	2BC	1.0	0.8	2.0	4.2	4.2	3.4	3.7	3.8	2.6	3.2	2.4	1.2
	2BD	0.5	0.4	1.1	1.9	1.8	1.0	1.1	1.4	0.8	1.1	1.2	0.7
	2CA	0.4	0.3	1.0	1.6	1.4	0.7	0.7	0.8	0.5	0.8	1.0	0.6
	2CB	1.8	1.3	3.1	5.7	4.5	3.9	4.7	4.9	2.4	3.4	3.7	2.2
	2CC	0.8	0.6	1.7	3.0	2.8	2.0	2.2	2.4	1.4	2.0	2.1	1.1
	2D	1.1	0.7	1.9	3.3	2.6	2.0	2.5	2.7	1.3	2.0	2.8	1.5
	2EA	1.3	1.1	2.3	3.7	3.4	2.8	3.6	4.1	2.2	2.5	2.6	1.8
	2EB	1.3	1.1	2.2	3.6	3.3	2.9	3.7	4.1	2.0	2.3	2.6	1.8
	2EC	1.4	1.2	2.4	4.0	3.4	2.6	3.5	4.0	2.3	2.8	2.9	1.9
	2ED	1.7	1.3	2.8	4.8	4.1	3.8	4.9	5.7	2.9	3.1	3.0	2.2
	2EE	1.5	1.1	2.6	4.6	3.8	3.4	4.4	4.6	2.2	2.7	3.1	2.1
	2EF	1.4	1.2	2.5	4.1	3.5	3.1	4.3	4.9	2.4	2.8	2.8	2.0
	2EG1	1.7	1.4	2.6	4.4	3.6	3.0	3.9	4.7	2.6	3.0	3.1	2.2
	2EG2	1.4	1.1	2.4	4.0	3.4	2.9	3.9	4.3	2.1	2.5	2.8	1.9
	2EH	1.6	1.2	2.7	5.0	4.1	3.7	4.7	4.9	2.2	2.8	3.5	2.1
	2EJ	1.2	0.7	1.8	3.4	2.7	2.2	2.9	3.2	1.3	1.8	2.8	1.7
	2EK	1.2	0.9	2.0	3.6	3.1	2.5	3.4	3.7	1.6	1.9	2.7	1.8
	2FA	1.4	1.3	2.2	3.9	3.1	2.8	2.4	3.0	2.2	2.6	2.8	1.7
	2FB	1.3	1.2	2.3	4.0	3.5	2.6	3.2	3.8	2.4	2.8	2.9	1.8
	2FC	1.5	1.3	2.3	3.9	3.2	2.7	2.8	3.4	2.2	2.7	2.8	1.8
	2GA	1.5	1.3	2.2	3.9	3.0	2.7	2.2	2.7	2.1	2.5	2.8	1.6
	2GB	1.4	1.3	2.3	4.1	3.4	2.9	2.5	3.0	2.3	2.8	3.0	1.7
	2GC	1.7	1.7	2.7	5.5	4.7	2.8	1.9	2.5	2.4	3.7	4.0	2.0
	2GD	1.8	1.5	2.5	4.6	3.7	2.4	1.7	2.2	1.8	2.8	3.3	1.8
	2H-1	2.4	1.9	3.0	4.9	3.7	1.1	0.7	0.9	0.7	1.9	4.1	2.4
	2H-2	2.5	1.8	3.1	5.0	3.6	0.7	0.4	0.5	0.4	1.7	4.5	2.5
	2H-3	2.3	1.6	2.9	4.3	2.8	0.5	0.2	0.3	0.3	1.4	4.4	2.7
	2J	0.4	0.3	1.0	1.6	1.2	0.5	0.7	0.8	0.5	0.7	1.1	0.6
	2KA	2.7	2.3	3.2	4.4	3.3	1.7	1.4	1.8	1.5	1.8	3.1	2.3
	2KB	2.6	2.2	2.9	4.3	3.1	0.9	0.6	0.7	0.7	1.3	3.2	2.3
	2KC	2.6	2.1	3.0	4.3	3.1	0.7	0.4	0.5	0.6	1.3	3.5	2.4
ACA	3AA	2.5	1.7	3.2	5.5	4.1	0.8	0.4	0.5	0.5	1.8	5.0	2.6
	3AB	2.4	1.6	3.0	4.3	2.6	0.4	0.2	0.3	0.2	1.5	4.6	2.8
	3AC	2.4	1.6	3.2	5.7	3.1	0.5	0.3	0.3	0.3	1.8	5.8	3.0
	3BA	2.5	1.8	3.4	6.6	4.9	1.0	0.6	0.7	0.6	2.3	5.8	2.7
	3BB	2.5	1.8	3.6	7.4	5.5	1.2	0.8	0.8	0.7	2.8	6.3	2.9
	3BC	2.6	1.9	3.6	7.8	6.0	1.6	1.0	1.1	0.9	3.3	6.5	2.9
	3BD	2.5	1.9	3.6	7.8	5.8	1.5	1.0	1.0	0.9	3.2	6.5	2.9
	3CB	2.4	1.8	3.5	7.7	5.3	1.3	0.8	0.9	0.8	3.1	6.6	3.0
	3DA	2.3	1.4	3.2	5.7	2.4	0.2	0.2	0.2	0.2	1.8	6.2	3.2
	3DB	2.2	1.1	2.7	4.7	1.7	0.2	0.1	0.2	0.2	1.7	7.4	4.0
	3EA	2.4	1.4	2.8	4.5	1.9	0.2	0.1	0.2	0.1	1.4	6.0	3.3
	3EB	2.4	1.3	2.8	4.4	1.8	0.2	0.2	0.2	0.2	1.5	6.7	3.6
	3EC	2.3	1.3	2.8	4.1	1.7	0.2	0.2	0.3	0.2	1.4	6.7	3.6
	3ED	2.3	1.1	2.8	4.3	1.6	0.2	0.2	0.3	0.2	1.6	7.6	4.1
	3FA	2.0	1.3	2.7	3.4	1.5	0.2	0.1	0.2	0.1	1.1	5.7	3.5
	3FB	1.9	1.0	2.5	2.6	0.9	0.1	0.1	0.1	0.2	0.9	5.4	4.2
	3G	1.8	1.2	2.8	3.1	1.4	0.3	0.2	0.2	0.2	1.1	4.3	3.4
	3HA	1.6	0.8	2.4	2.8	1.2	0.3	0.2	0.3	0.4	1.2	4.2	4.0
	3HB	1.3	0.6	1.9	2.9	3.1	1.3	0.9	0.8	0.8	2.3	3.7	3.1
	3HC	0.7	0.3	1.2	3.3	5.5	2.8	2.0	1.4	1.2	3.3	2.9	2.1
	3HD1	0.7	0.3	1.1	3.7	6.5	3.3	2.3	1.5	1.4	3.6	2.9	2.0
	3HD2	0.6	0.2	1.2	3.8	6.4	3.4	2.3	1.5	1.2	3.4	2.9	2.0
	3J	1.7	1.2	3.2	3.7	1.8	0.5	0.3	0.4	0.3	1.3	3.8	3.2
	3K	1.3	0.6	1.8	4.7	7.0	3.3	2.2	1.7	1.5	3.7	3.9	2.2
	3LA	1.3	0.6	1.9	3.3	3.8	1.5	1.1	0.9	0.9	2.7	3.8	2.9
	3LB	0.8	0.3	1.1	4.0	7.1	3.4	2.4	1.6	1.5	3.8	2.9	1.9
	3MA-1	1.5	1.0	3.0	3.6	2.2	0.9	0.5	0.7	0.6	2.0	4.3	3.4
	3MA-2	1.4	0.9	2.4	3.8	4.3	2.0	1.3	1.2	1.0	2.9	4.1	2.7
	3MB	1.1	0.5	1.6	4.5	6.8	3.0	2.0	1.6	1.4	3.7	3.6	2.1
	3MC	1.3	0.6	1.8	4.7	7.0	3.3	2.2	1.8	1.4	3.8	3.8	2.2
	3MD1	0.9	0.3	1.3	5.5	8.7	3.6	2.6	1.8	1.7	4.0	3.8	1.9
	3MD2	1.1	0.4	1.4	5.3	8.1	3.6	2.4	1.9	1.6	4.1	3.9	2.0
	3N	1.9	1.4	2.7	3.3	1.6	0.2	0.1	0.2	0.1	1.1	4.5	3.0

Table 5.4.1 Present Monthly Average Rainfall by Sub-basin (3/3)

(Unit: mm/day)

CA	Sub-basin	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TCA	4AA	2.1	1.2	2.7	6.7	5.4	0.8	0.9	1.0	0.9	4.4	5.9	2.8
	4AB	1.9	1.4	2.5	5.8	5.2	1.4	1.3	1.4	1.3	3.9	4.7	2.5
	4AC	2.0	1.6	2.7	6.5	5.8	1.6	1.3	1.5	1.4	4.2	5.1	2.6
	4AD	2.2	1.8	2.9	7.3	6.4	1.9	1.5	1.7	1.6	4.5	5.6	2.7
	4BA	2.0	1.3	2.8	7.9	6.2	0.9	0.8	0.9	0.8	4.1	6.3	2.5
	4BB	2.1	1.1	2.8	7.4	5.8	0.7	0.8	0.9	0.8	4.3	6.3	2.8
	4BC	1.8	1.1	2.9	8.0	5.7	0.7	0.7	0.8	0.6	4.1	6.5	2.4
	4BD	2.3	1.8	3.1	8.5	6.9	1.8	1.4	1.6	1.3	4.6	6.5	2.8
	4BE	2.3	1.7	3.2	8.8	6.6	1.5	1.1	1.3	1.0	4.3	6.9	2.7
	4BF	2.1	1.4	3.3	8.0	5.0	0.7	0.6	0.6	0.5	3.1	6.6	2.6
	4BG	1.9	1.2	3.2	7.3	3.7	0.4	0.3	0.3	0.3	2.6	6.2	2.6
	4CA	2.6	2.1	3.5	8.4	6.9	2.4	1.6	1.9	1.6	4.5	6.6	3.0
	4CB	2.6	2.1	3.6	9.1	7.1	2.0	1.4	1.5	1.2	4.5	7.3	3.1
	4CC	2.2	1.4	3.3	6.9	3.4	0.4	0.3	0.3	0.3	2.4	6.3	2.9
	4DA	1.9	1.1	3.1	8.0	5.1	0.6	0.6	0.7	0.6	4.0	6.9	2.6
	4DB	2.0	1.1	3.4	8.8	5.5	0.7	0.7	0.9	0.7	5.0	8.2	3.0
	4DC	2.2	1.1	3.6	9.4	5.8	0.7	0.8	1.0	0.7	5.6	9.1	3.3
	4DD	1.8	1.1	3.1	7.6	3.7	0.4	0.5	0.5	0.4	3.7	7.4	2.9
	4DE	1.9	1.2	2.9	6.3	2.4	0.2	0.2	0.2	0.2	2.3	6.3	3.1
	4EA	3.2	1.3	3.9	10.6	5.3	0.6	0.6	0.8	0.6	7.4	12.7	5.3
	4EB	2.9	1.3	4.0	10.7	5.9	0.7	0.8	1.0	0.7	7.1	12.2	4.8
	4EC	2.3	1.2	3.6	9.2	4.8	0.6	0.7	0.8	0.5	5.2	10.0	3.8
	4ED	2.0	1.0	2.8	6.5	2.2	0.2	0.3	0.3	0.2	3.0	8.2	3.9
	4FA	3.1	1.2	3.7	10.1	4.5	0.4	0.5	0.6	0.5	7.0	12.3	5.4
	4FB	2.8	1.1	3.6	9.7	3.8	0.3	0.3	0.4	0.3	5.9	11.9	5.2
	4GA	2.2	0.9	3.1	8.3	2.9	0.2	0.3	0.3	0.2	5.1	10.3	4.4
	4GB	1.8	0.7	2.6	6.8	2.2	0.2	0.2	0.2	0.2	3.5	8.9	3.8
	4GC	1.1	0.3	1.5	3.7	1.0	0.2	0.2	0.2	0.2	1.7	5.4	2.4
	4GD	1.2	0.4	1.7	3.8	1.4	0.5	0.4	0.3	0.3	1.9	5.7	2.8
	4GE	1.6	0.5	2.0	4.4	1.6	0.5	0.4	0.3	0.3	2.0	6.9	3.6
	4GF	1.4	0.4	1.7	3.7	2.4	1.2	0.8	0.5	0.5	2.0	5.6	3.4
	4GG	0.8	0.2	1.1	3.7	5.6	3.3	2.1	1.2	1.0	3.1	3.2	2.5
	4HA	2.0	0.9	2.5	4.0	1.2	0.1	0.1	0.2	0.2	1.4	7.4	4.5
	4HB	1.6	0.6	2.0	3.2	2.1	1.0	0.7	0.5	0.5	1.7	5.5	3.7
	4HC	1.4	0.6	1.9	2.7	2.2	0.9	0.7	0.6	0.6	1.7	4.1	3.4
	4JA	0.8	0.2	1.0	3.0	2.6	1.4	0.7	0.4	0.4	1.7	3.6	2.1
	4JB	0.7	0.4	0.9	3.4	6.4	3.9	1.9	1.0	0.8	2.4	3.0	2.4
	4KA	0.7	0.3	1.0	3.2	5.3	3.2	1.6	0.8	0.7	2.1	3.1	2.3
	4KB	0.8	0.2	1.0	3.3	5.3	3.2	1.7	0.9	0.8	2.3	3.2	2.3
ENNCA	5AA	1.4	1.0	2.0	3.6	3.1	2.7	3.2	3.7	1.9	2.3	2.6	1.8
	5AB	1.4	0.9	1.9	3.7	2.9	2.4	2.8	3.1	1.6	2.3	2.7	1.7
	5AC	1.1	0.6	1.6	3.7	2.5	1.9	2.4	2.3	1.0	1.8	2.7	1.4
	5AD	1.3	0.6	1.6	3.6	2.5	1.8	2.2	2.2	1.1	2.1	2.8	1.5
	5BA	1.7	1.1	2.2	4.8	4.3	1.3	1.3	1.5	1.2	3.5	4.1	2.2
	5BB	1.6	1.1	2.1	4.4	3.9	1.7	1.7	2.0	1.5	3.2	3.5	2.0
	5BC-1	1.6	0.9	1.9	4.3	3.3	1.4	1.7	1.9	1.1	3.0	3.6	2.0
	5BC-2	1.3	0.6	1.6	3.5	2.2	1.5	1.9	1.8	1.0	2.3	3.0	1.5
	5BD	1.4	0.8	1.8	3.6	2.7	2.0	2.3	2.6	1.3	2.3	2.8	1.7
	5BE	2.0	0.9	2.2	4.9	2.9	1.0	1.2	1.4	0.9	4.0	5.2	2.6
	5CA	1.1	0.5	1.6	2.9	2.0	1.7	2.2	2.3	0.9	1.7	2.6	1.3
	5CB	1.2	0.5	1.7	3.0	1.7	1.4	1.8	1.7	0.7	2.0	3.0	1.4
	5CC	1.0	0.5	1.6	3.0	1.9	1.3	1.8	1.8	0.8	1.8	2.8	1.3
	5DA	2.7	1.1	2.9	6.4	2.4	0.5	0.5	0.6	0.5	5.3	7.7	3.9
	5DB	2.0	0.9	2.2	4.3	1.9	0.9	1.2	1.1	0.7	3.6	5.0	2.5
	5DC	1.2	0.5	1.6	3.3	2.0	1.6	1.9	1.7	0.8	2.0	3.1	1.4
	5DD	1.5	0.6	1.9	3.5	1.7	1.2	1.6	1.4	0.7	2.4	3.7	1.7
	5EA	0.5	0.2	0.9	3.2	0.9	0.1	0.1	0.1	0.1	2.2	2.5	1.0
	5EB	0.6	0.3	1.1	3.8	1.4	0.2	0.2	0.2	0.2	2.5	2.8	1.1
	5EC	1.1	0.5	1.5	4.6	1.7	0.4	0.5	0.4	0.2	2.7	3.8	1.8
	5ED	1.7	0.7	2.3	6.5	2.1	0.2	0.2	0.2	0.2	4.2	7.2	3.2
	5FA	1.0	0.4	1.5	4.4	1.2	0.2	0.2	0.2	0.1	2.4	5.2	2.3
	5FB	0.6	0.2	1.0	3.3	0.7	0.2	0.1	0.1	0.1	1.9	3.4	1.5
	5G	0.3	0.2	0.8	3.0	0.9	0.1	0.1	0.1	0.1	2.3	2.1	0.7
	5HA	0.1	0.2	0.6	2.5	0.9	0.1	0.1	0.0	0.1	2.4	1.6	0.5
	5HB	0.2	0.2	0.7	2.7	1.0	0.1	0.1	0.1	0.1	2.4	1.8	0.5
	5J	0.7	0.4	1.2	2.9	1.3	0.3	0.4	0.3	0.2	1.5	1.9	1.0

Source: JICA Study Team

Table 5.4.2 Future Monthly Average Rainfall by Sub-basin (1/3)

(Unit: mm/day)

CA	Sub-basin	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
LVNCA	1AA	1.9	2.3	4.6	8.0	7.3	3.8	3.7	4.6	4.8	5.6	5.0	2.2
	1AB	1.7	2.2	4.2	7.5	6.6	3.8	3.9	4.7	4.4	5.2	4.4	1.9
	1AC	1.9	2.4	4.6	8.1	7.0	4.2	4.0	4.9	4.8	5.6	4.8	2.0
	1AD	2.2	2.7	5.2	8.9	8.2	4.2	3.7	4.8	5.3	6.2	5.7	2.7
	1AE	2.4	2.8	5.6	9.1	8.7	3.9	3.1	4.4	5.4	6.6	6.3	3.2
	1AF	2.2	2.6	5.2	8.8	8.0	4.1	3.7	4.6	5.2	6.1	5.6	2.7
	1AG	2.3	2.6	5.2	8.8	7.9	4.0	3.7	4.6	5.1	6.0	5.7	2.7
	1AH	2.4	2.5	5.3	8.7	8.0	3.6	3.1	4.1	5.1	6.3	6.1	3.1
	1BA	1.4	1.6	3.1	6.4	4.7	3.7	4.4	4.1	2.2	3.8	4.2	1.7
	1BB	1.2	1.6	3.0	6.2	5.2	4.1	4.8	4.6	3.0	4.3	3.9	1.5
	1BC	1.2	1.6	3.0	6.2	5.8	4.5	5.2	5.0	3.6	4.7	3.6	1.3
	1BD	1.3	1.7	3.3	6.4	5.0	3.7	4.5	4.9	3.2	4.0	3.7	1.5
	1BE	1.2	1.7	3.3	6.3	5.6	3.9	4.6	4.8	3.7	4.6	3.6	1.4
	1BG	1.3	1.9	3.4	6.6	5.8	3.9	4.4	5.2	4.0	4.6	3.7	1.4
	1BH	1.4	2.0	3.7	6.9	6.0	4.0	4.3	5.3	4.3	4.8	3.9	1.5
	1CA	1.4	1.7	3.3	6.4	4.5	3.7	4.7	4.6	2.6	3.6	3.8	1.7
	1CB	1.5	1.8	3.4	6.5	4.5	3.9	4.9	4.9	2.8	3.7	3.8	1.7
	1CC	1.6	2.0	3.6	6.5	4.7	4.2	5.0	5.0	3.1	3.9	4.0	1.9
	1CD	1.6	2.2	3.8	7.1	5.6	4.6	5.3	6.1	4.1	4.4	4.1	1.7
	1CE	1.6	2.1	3.8	7.3	6.0	4.6	5.0	6.5	4.5	4.8	4.0	1.6
	1DA	1.9	2.5	4.6	8.4	7.0	5.1	5.0	6.7	5.3	5.6	4.7	2.0
	1DB	1.7	2.2	4.1	7.5	6.4	4.1	4.3	5.2	4.5	5.1	4.3	1.8
	1DC	2.0	2.6	4.8	8.4	7.2	4.5	4.4	5.5	5.0	5.7	4.9	2.2
	1DD	2.2	2.6	5.1	8.6	7.5	4.3	4.1	5.0	5.1	5.8	5.3	2.4
	1EA	2.3	2.9	5.1	8.7	7.4	5.6	5.4	7.2	5.5	5.8	5.1	2.4
	1EB	2.4	3.0	5.5	9.1	7.8	5.2	4.9	6.4	5.5	5.9	5.4	2.6
	1EC	2.2	2.9	5.1	9.1	7.7	5.5	5.1	6.8	5.7	6.1	5.3	2.4
	1ED	2.4	2.7	5.2	9.0	7.8	4.3	4.2	5.3	5.3	6.0	5.6	2.7
	1EE	2.4	2.4	5.1	8.6	7.6	3.5	3.4	4.2	5.0	5.9	5.9	2.9
	1EF	2.3	2.3	5.1	8.3	7.2	3.3	3.0	3.9	4.7	5.9	5.9	3.0
	1EG	2.4	2.4	5.1	8.4	7.1	3.6	3.5	4.3	4.8	5.6	5.8	2.9
	1FA	1.7	2.2	3.7	6.6	5.1	4.5	5.2	5.3	3.5	4.2	4.3	2.0
	1FB	2.0	2.6	4.4	7.3	6.1	5.0	5.4	6.2	4.3	4.7	4.6	2.1
	1FC	2.1	2.7	4.6	7.3	6.3	5.0	5.3	6.1	4.4	4.9	4.9	2.3
	1FD	2.1	2.6	4.4	6.9	5.9	4.8	5.1	5.5	4.0	4.7	4.8	2.3
	1FE	2.5	3.0	5.4	8.3	7.0	4.9	4.6	5.9	4.9	5.4	5.3	2.8
	1FF	2.6	2.8	5.5	7.9	6.5	4.1	3.6	4.5	4.2	5.1	5.2	3.1
	1FG	2.4	2.2	5.1	7.6	6.0	3.0	2.8	3.5	4.1	5.4	5.6	3.0
LVSCA	1GA	2.1	2.4	4.1	6.8	5.1	4.3	4.8	5.0	3.5	4.1	4.3	2.2
	1GB	2.5	2.8	5.0	7.3	5.6	4.3	4.4	4.6	3.8	4.6	4.7	2.7
	1GC	2.2	2.6	3.9	6.7	4.8	3.9	4.7	5.3	3.5	4.0	4.1	2.3
	1GD	2.8	3.0	5.2	7.6	5.3	3.7	3.6	3.8	3.5	4.5	4.7	3.0
	1GE	2.9	3.1	5.3	7.8	5.8	3.9	3.8	4.2	3.8	4.8	4.9	3.1
	1GF	2.8	3.0	5.4	7.5	5.5	3.7	3.2	3.8	3.5	4.6	4.9	3.3
	1GG	2.4	2.8	4.3	7.1	5.1	4.0	4.6	4.9	3.6	4.1	4.3	2.4
	1HA1	2.6	2.9	5.4	7.2	5.6	3.9	3.4	3.9	3.6	4.5	4.8	3.1
	1HA2	2.7	2.8	5.3	7.0	5.1	3.5	3.0	3.5	3.2	4.3	4.6	3.1
	1HB1	2.4	2.3	5.2	7.3	5.6	3.0	2.7	3.2	3.7	4.9	5.3	3.1
	1HB2	2.6	2.7	5.7	7.3	5.6	3.5	2.7	3.3	3.4	4.6	5.0	3.3
	1HC	2.4	2.1	5.0	7.2	5.3	2.6	2.3	2.9	3.6	5.0	5.3	3.0
	1HD	3.0	3.3	5.7	7.8	5.9	4.2	3.1	4.0	3.9	5.0	5.5	3.7
	1HE	3.0	3.2	5.6	8.0	6.2	4.0	2.9	3.8	4.0	5.1	6.0	3.8
	1HF	2.4	2.4	4.7	7.4	5.4	2.5	1.8	2.6	3.3	4.5	5.3	3.3
	1HG	2.3	2.2	4.6	7.0	5.0	2.2	1.7	2.4	3.0	4.3	5.2	3.3
	1JA	2.7	3.2	4.9	7.8	5.7	4.3	4.5	5.0	4.0	4.6	4.9	3.0
	1JB	3.3	3.7	5.8	8.9	6.8	4.7	4.7	5.1	4.6	5.4	5.6	3.5
	1JC	3.0	3.4	5.4	8.4	6.6	4.6	4.9	5.3	4.5	5.2	5.2	3.1
	1JD	3.2	3.5	5.8	8.7	6.8	4.7	4.6	5.1	4.5	5.5	5.5	3.4
	1JE	3.3	3.8	5.8	8.1	5.5	4.2	3.3	4.0	4.0	4.7	5.7	4.1
	1JF	3.0	3.5	5.5	8.0	5.7	4.4	4.0	4.6	4.0	4.8	5.4	3.5
	1JG1	3.1	3.4	5.7	8.1	6.1	4.4	3.9	4.6	4.1	5.1	5.4	3.5
	1JG2	2.9	3.2	5.6	7.6	5.7	4.0	3.1	3.8	3.6	4.8	5.3	3.6
	1KA	3.1	3.4	5.6	8.3	6.4	4.0	2.8	3.8	4.1	5.2	6.3	4.1
	1KB	2.9	3.2	5.2	7.7	5.6	3.1	2.3	3.0	3.4	4.5	5.6	3.9
	1KC	3.3	3.8	5.5	7.7	5.3	3.1	2.3	2.9	3.4	4.2	5.5	4.3
	1LA1	2.8	3.2	4.8	7.7	5.0	3.9	3.6	4.2	3.6	4.2	5.1	3.5
	1LA2	3.5	4.1	5.3	7.4	4.6	3.3	2.3	2.8	3.3	3.6	5.0	4.4
	1LA3	3.0	3.3	4.2	6.3	3.4	2.0	1.4	1.6	2.1	2.4	4.0	3.6
	1LB1	2.8	3.2	4.5	7.1	4.3	3.4	2.8	3.4	3.0	3.6	4.7	3.4
	1LB2	3.2	3.6	4.5	6.4	3.6	2.4	1.7	2.0	2.5	2.6	4.1	3.8

Table 5.4.2 Future Monthly Average Rainfall by Sub-basin (2/3)

(Unit: mm/day)

CA	Sub-basin	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RVCA	2AA	0.5	0.5	1.3	2.2	1.0	0.4	0.3	0.3	0.2	0.8	1.5	0.7
	2AB	0.4	0.4	1.2	1.8	0.9	0.4	0.4	0.4	0.3	0.6	1.1	0.6
	2BA	1.1	1.5	2.8	5.8	5.4	4.4	5.0	4.7	3.2	4.3	3.4	1.2
	2BB	0.8	1.1	2.1	4.6	4.1	3.1	3.6	3.4	2.2	3.3	2.8	1.0
	2BC	0.9	1.2	2.4	4.8	4.4	3.2	3.7	3.6	2.5	3.5	2.8	1.1
	2BD	0.4	0.5	1.1	2.4	1.7	0.9	1.0	1.1	0.6	1.2	1.5	0.7
	2CA	0.4	0.5	1.0	2.1	1.3	0.6	0.6	0.7	0.4	0.8	1.4	0.6
	2CB	1.5	1.8	3.2	6.8	4.6	3.8	4.7	4.4	2.2	3.5	4.3	2.0
	2CC	0.8	0.9	1.8	3.7	2.7	1.8	2.1	2.1	1.2	2.1	2.5	1.0
	2D	1.0	1.0	2.2	4.1	2.6	1.9	2.3	2.3	1.2	2.4	3.0	1.4
	2EA	1.1	1.4	2.2	4.8	3.5	3.1	3.8	3.8	2.3	2.8	3.3	1.9
	2EB	1.2	1.4	2.2	4.8	3.4	3.2	3.9	3.8	2.1	2.6	3.3	1.9
	2EC	1.2	1.6	2.4	5.1	3.4	2.9	3.6	4.0	2.5	3.0	3.5	1.9
	2ED	1.5	1.8	2.8	5.7	3.8	3.7	4.9	5.2	2.8	3.2	3.5	1.8
	2EE	1.3	1.6	2.7	5.9	3.9	3.5	4.6	4.2	2.0	2.9	3.7	2.0
	2EF	1.3	1.7	2.5	5.3	3.5	3.3	4.4	4.7	2.4	2.9	3.3	1.8
	2EG1	1.4	1.9	2.7	5.5	3.5	3.2	4.0	4.9	2.8	3.2	3.6	2.0
	2EG2	1.2	1.5	2.4	5.2	3.6	3.2	4.2	4.1	2.1	2.8	3.4	1.9
	2EH	1.4	1.7	2.9	6.4	4.4	3.8	4.8	4.5	2.0	3.1	4.0	2.0
	2EJ	1.0	1.1	2.0	4.5	2.9	2.4	3.0	3.0	1.3	2.2	2.9	1.6
	2EK	1.1	1.2	2.1	4.7	3.2	2.8	3.6	3.4	1.6	2.3	3.0	1.8
	2FA	1.3	1.4	2.2	4.8	3.0	3.0	2.7	3.0	2.3	2.8	3.3	2.0
	2FB	1.2	1.4	2.3	5.0	3.4	2.8	3.3	3.6	2.6	2.9	3.5	1.9
	2FC	1.3	1.5	2.3	4.9	3.1	2.9	2.9	3.4	2.4	2.8	3.3	2.0
	2GA	1.4	1.5	2.3	4.9	3.0	2.9	2.4	2.8	2.2	2.8	3.4	2.1
	2GB	1.4	1.5	2.4	5.1	3.3	3.1	2.7	3.0	2.4	3.1	3.6	2.2
	2GC	1.8	2.1	3.1	6.8	4.9	3.2	2.3	2.7	2.6	4.1	4.9	2.9
	2GD	1.8	1.9	2.8	5.8	3.8	2.8	1.9	2.3	2.0	3.2	4.0	2.5
	2H-1	2.0	2.2	3.3	6.5	3.6	1.4	0.8	0.9	0.9	2.4	4.5	3.2
	2H-2	1.8	2.1	3.3	6.7	3.2	0.9	0.4	0.5	0.6	2.2	4.8	3.3
	2H-3	1.8	1.9	3.1	5.9	2.5	0.6	0.3	0.4	0.4	1.9	4.7	3.3
	2J	0.4	0.5	1.1	1.9	1.0	0.4	0.6	0.6	0.3	0.7	1.2	0.6
	2KA	2.4	2.6	3.4	5.6	3.1	2.0	1.6	1.9	1.7	2.2	3.5	2.8
	2KB	2.3	2.4	3.2	5.6	2.8	1.2	0.7	0.8	0.9	1.8	3.5	2.8
	2KC	2.2	2.4	3.3	5.8	2.8	1.0	0.5	0.6	0.8	1.8	3.7	3.0
ACA	3AA	1.8	2.1	3.4	7.3	3.7	1.0	0.5	0.5	0.6	2.3	5.3	3.6
	3AB	1.8	1.9	3.2	5.9	2.3	0.6	0.2	0.3	0.4	2.1	5.0	3.6
	3AC	1.9	1.8	3.6	7.1	2.6	0.7	0.4	0.4	0.4	2.5	6.3	4.0
	3BA	1.9	2.1	3.8	8.3	4.4	1.2	0.7	0.7	0.7	2.9	6.2	3.9
	3BB	2.0	2.2	4.0	8.9	5.0	1.5	0.9	0.9	0.8	3.3	6.7	4.1
	3BC	2.1	2.4	4.1	9.3	5.7	1.9	1.2	1.2	1.1	3.9	7.1	4.3
	3BD	2.0	2.3	4.1	9.1	5.3	1.8	1.2	1.1	1.1	3.8	7.0	4.2
	3CB	2.0	2.2	4.1	9.0	4.8	1.6	1.0	1.0	1.0	3.8	7.1	4.2
	3DA	2.1	1.5	3.8	7.2	2.1	0.4	0.3	0.2	0.3	2.6	7.2	4.4
	3DB	2.3	1.3	3.5	6.8	2.1	0.4	0.3	0.3	0.3	2.6	8.5	5.1
	3EA	2.2	1.6	3.4	6.1	1.9	0.3	0.2	0.2	0.3	2.3	6.8	4.4
	3EB	2.3	1.6	3.5	6.5	2.1	0.3	0.2	0.3	0.3	2.4	7.9	4.7
	3EC	2.2	1.6	3.3	6.2	2.2	0.3	0.2	0.3	0.3	2.4	7.9	4.5
	3ED	2.3	1.4	3.3	6.4	2.2	0.3	0.3	0.4	0.4	2.5	8.9	5.0
	3FA	1.8	1.5	2.8	5.0	1.7	0.3	0.1	0.2	0.2	1.8	6.5	4.2
	3FB	1.9	1.2	2.6	3.9	1.3	0.2	0.2	0.2	0.2	1.4	6.5	5.1
	3G	1.8	1.4	3.0	4.2	1.8	0.3	0.3	0.3	0.3	1.5	5.2	4.1
	3HA	1.5	0.9	2.9	4.1	2.0	0.4	0.3	0.4	0.6	1.7	4.9	4.7
	3HB	1.3	0.7	2.3	3.7	3.7	1.3	1.1	0.9	0.8	2.0	4.0	4.1
	3HC	1.1	0.4	1.8	4.1	5.9	2.7	2.1	1.4	1.1	2.3	3.3	3.3
	3HD1	1.2	0.4	1.8	4.4	7.4	3.3	2.5	1.5	1.3	2.6	3.3	3.3
	3HD2	1.1	0.4	1.7	4.6	7.1	3.1	2.4	1.5	1.2	2.3	3.3	3.2
	3J	1.6	1.4	3.4	4.9	2.5	0.5	0.3	0.5	0.4	1.5	4.4	3.9
	3K	1.4	0.8	2.3	5.4	8.2	2.9	2.4	1.9	1.5	2.9	4.1	3.4
	3LA	1.4	0.8	2.5	4.2	4.4	1.5	1.2	1.0	0.9	2.2	4.1	4.0
	3LB	1.2	0.4	1.8	4.7	8.0	3.3	2.6	1.6	1.3	2.7	3.2	3.3
	3MA-1	1.5	1.3	3.4	5.0	3.0	0.7	0.6	0.8	0.9	2.1	5.0	4.4
	3MA-2	1.4	1.0	2.7	4.6	5.2	1.7	1.5	1.4	1.2	2.4	4.5	3.8
	3MB	1.3	0.7	2.2	5.2	7.8	2.7	2.2	1.8	1.4	2.8	3.7	3.4
	3MC	1.4	0.8	2.2	5.4	8.3	3.0	2.5	2.0	1.5	2.9	4.1	3.3
	3MD1	1.3	0.6	2.1	6.6	10.0	3.3	2.7	2.0	1.6	3.3	3.7	3.4
	3MD2	1.4	0.7	2.1	6.3	9.8	3.3	2.7	2.1	1.6	3.3	3.9	3.4
	3N	1.7	1.7	2.8	4.6	1.6	0.3	0.1	0.2	0.2	1.6	5.3	3.7

Table 5.4.2 Future Monthly Average Rainfall by Sub-basin (3/3)

(Unit: mm/day)

CA	Sub-basin	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TCA	4AA	2.1	1.7	3.2	7.7	6.4	1.1	1.1	0.9	1.1	4.3	6.5	3.9
	4AB	1.9	1.9	3.0	6.9	5.9	1.7	1.6	1.4	1.5	3.9	5.4	3.5
	4AC	2.1	2.2	3.3	7.7	6.4	2.0	1.7	1.6	1.6	4.3	5.8	3.8
	4AD	2.2	2.3	3.6	8.6	7.0	2.3	1.9	1.8	1.9	4.8	6.5	4.0
	4BA	1.9	1.7	3.4	9.3	6.9	1.3	1.0	0.9	1.0	4.4	6.9	3.9
	4BB	2.0	1.6	3.3	8.6	6.8	1.1	0.9	0.8	1.0	4.3	6.9	4.0
	4BC	1.8	1.4	3.4	9.4	6.2	1.0	0.8	0.7	0.9	4.4	7.2	3.7
	4BD	2.2	2.3	3.9	10.0	7.4	2.2	1.7	1.7	1.7	5.2	7.4	4.2
	4BE	2.1	2.1	4.1	10.4	6.7	1.9	1.3	1.3	1.3	5.0	7.7	4.2
	4BF	1.7	1.6	3.9	9.4	4.6	1.1	0.7	0.6	0.7	3.9	7.2	3.9
	4BG	1.7	1.3	3.9	8.7	3.3	0.6	0.4	0.4	0.4	3.4	7.1	3.7
	4CA	2.3	2.7	4.2	9.9	7.1	2.9	2.0	2.1	2.0	5.2	7.5	4.4
	4CB	2.3	2.6	4.4	10.5	7.1	2.4	1.7	1.7	1.6	5.2	8.0	4.7
	4CC	1.8	1.5	4.0	8.1	2.9	0.6	0.4	0.4	0.4	3.1	7.1	4.0
	4DA	1.7	1.3	3.6	9.4	5.4	0.9	0.7	0.7	0.8	4.5	7.6	3.8
	4DB	1.9	1.4	4.0	10.2	5.8	1.0	0.8	0.9	0.9	5.4	8.8	4.2
	4DC	2.0	1.4	4.2	10.8	6.1	1.0	0.9	1.0	1.0	6.0	9.6	4.5
	4DD	1.7	1.1	3.8	9.3	3.8	0.6	0.5	0.6	0.5	4.1	8.0	3.8
	4DE	1.8	1.2	3.7	7.8	2.3	0.4	0.2	0.3	0.2	2.9	7.0	4.0
	4EA	2.8	1.6	4.6	12.1	5.7	0.8	0.7	0.7	0.8	7.7	12.9	6.8
	4EB	2.7	1.6	4.6	12.5	6.4	0.9	0.9	0.9	1.0	7.4	12.4	6.2
	4EC	2.2	1.3	4.2	11.0	5.0	0.8	0.7	0.8	0.8	5.7	10.3	4.9
	4ED	2.0	1.1	3.5	8.4	2.4	0.4	0.4	0.4	0.3	3.5	8.5	4.8
	4FA	2.7	1.5	4.3	11.2	4.8	0.6	0.5	0.5	0.6	7.2	12.6	6.9
	4FB	2.5	1.2	4.0	10.5	4.1	0.4	0.4	0.4	0.5	6.4	12.2	6.6
	4GA	1.9	1.0	3.3	8.4	3.0	0.3	0.3	0.3	0.3	5.2	10.3	5.7
	4GB	1.7	0.7	2.8	7.1	2.2	0.2	0.3	0.2	0.3	4.0	8.7	4.9
	4GC	1.1	0.4	1.6	3.6	0.8	0.2	0.2	0.2	0.2	1.9	4.9	3.1
	4GD	1.3	0.5	1.9	4.4	1.4	0.5	0.4	0.4	0.4	2.2	5.5	3.6
	4GE	1.6	0.6	2.3	5.1	1.6	0.5	0.4	0.4	0.4	2.4	6.8	4.4
	4GF	1.5	0.6	2.0	4.2	2.3	1.0	0.7	0.6	0.6	1.9	5.9	4.3
	4GG	1.2	0.4	1.6	4.3	6.2	2.8	2.0	1.3	1.1	2.1	3.7	3.5
	4HA	2.1	1.0	2.9	5.4	1.4	0.3	0.2	0.2	0.3	2.1	8.4	5.5
	4HB	1.6	0.7	2.0	3.9	2.1	0.8	0.7	0.5	0.6	1.7	6.2	4.6
	4HC	1.5	0.7	2.2	3.6	2.7	1.0	0.8	0.6	0.6	1.7	4.7	4.3
	4JA	0.9	0.3	1.3	3.1	2.8	1.2	0.7	0.5	0.5	1.6	3.6	2.6
	4JB	1.1	0.5	1.2	3.9	7.6	3.4	1.7	1.0	0.9	1.8	3.5	3.1
	4KA	1.0	0.4	1.3	3.6	6.0	2.7	1.4	0.9	0.8	1.7	3.4	3.0
	4KB	1.1	0.4	1.3	3.7	5.8	2.6	1.5	1.0	0.9	1.8	3.5	3.1
ENNCA	5AA	1.1	1.2	2.0	4.5	2.9	2.9	3.3	3.3	2.0	2.5	3.2	1.9
	5AB	1.1	1.1	2.0	4.4	2.6	2.6	2.9	2.8	1.7	2.5	3.2	1.9
	5AC	1.0	0.9	1.8	4.3	2.4	2.1	2.4	2.2	1.1	2.2	2.9	1.6
	5AD	1.0	0.9	1.8	4.1	2.2	2.0	2.2	2.0	1.1	2.3	3.0	1.7
	5BA	1.7	1.6	2.6	5.6	4.8	1.5	1.5	1.3	1.4	3.5	4.6	3.0
	5BB	1.5	1.5	2.4	5.2	4.2	1.8	1.9	1.7	1.6	3.3	4.1	2.6
	5BC-1	1.5	1.2	2.2	4.8	3.5	1.6	1.7	1.5	1.2	3.2	4.2	2.5
	5BC-2	1.1	0.8	1.8	4.0	2.1	1.7	1.8	1.5	1.0	2.6	3.3	1.9
	5BD	1.1	1.0	1.9	4.2	2.4	2.1	2.4	2.2	1.4	2.6	3.2	1.9
	5BE	1.8	1.2	2.6	5.5	3.1	1.3	1.2	1.0	1.0	4.1	5.7	3.3
	5CA	0.9	0.9	1.9	3.8	2.0	2.0	2.3	2.3	1.0	2.0	2.7	1.4
	5CB	1.0	0.9	2.1	3.8	1.8	1.6	1.9	1.7	0.9	2.2	3.0	1.6
	5CC	1.0	0.9	2.1	3.8	1.9	1.5	1.7	1.6	0.8	2.2	3.0	1.5
	5DA	2.3	1.4	3.6	7.1	2.6	0.8	0.5	0.5	0.6	5.2	8.3	4.9
	5DB	1.7	1.2	2.7	5.1	2.0	1.3	1.1	0.9	0.8	3.7	5.4	3.2
	5DC	1.0	0.8	2.0	4.0	2.0	1.9	2.0	1.7	0.9	2.3	3.1	1.7
	5DD	1.2	0.9	2.3	4.3	1.8	1.6	1.7	1.5	0.8	2.6	3.8	2.2
	5EA	0.5	0.4	1.2	3.6	1.6	0.3	0.2	0.1	0.3	2.0	2.6	1.4
	5EB	0.7	0.6	1.5	4.6	2.2	0.4	0.3	0.2	0.3	2.3	3.1	1.6
	5EC	1.1	0.8	2.0	5.7	2.2	0.6	0.6	0.5	0.4	2.7	4.2	2.2
	5ED	1.4	0.9	2.7	6.6	2.3	0.3	0.3	0.2	0.3	4.1	7.5	4.2
	5FA	0.9	0.4	1.7	4.2	1.4	0.2	0.2	0.2	0.2	2.5	5.0	3.0
	5FB	0.6	0.3	1.2	3.1	0.9	0.1	0.1	0.1	0.2	1.8	3.2	2.0
	5G	0.4	0.3	1.1	3.5	1.7	0.3	0.2	0.1	0.2	2.2	2.3	1.0
	5HA	0.2	0.1	0.8	3.0	1.4	0.2	0.2	0.1	0.2	2.1	1.9	0.7
	5HB	0.2	0.2	0.9	3.3	1.7	0.3	0.2	0.1	0.2	2.2	1.9	0.7
	5J	0.8	0.7	1.6	4.1	1.9	0.6	0.4	0.4	0.4	1.8	2.6	1.2

Source: JICA Study Team

Table 5.4.3 Present Monthly Average Naturalised River Discharge by Sub-basin (1/3)

(Unit: m^3/s)

CA	Sub-basin	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
LVNCA	1AA	1.9	1.0	1.1	3.5	8.5	4.8	3.7	3.6	4.9	5.8	5.1	2.7
	1AB	4.1	2.5	2.8	6.6	15.6	10.3	8.8	9.2	10.4	11.4	9.9	5.3
	1AC	0.4	0.1	0.1	0.8	2.8	2.0	1.4	1.2	1.7	2.1	1.7	0.7
	1AD	2.4	1.3	1.3	4.1	10.6	6.2	4.2	3.2	5.1	6.6	6.7	3.9
	1AE	1.1	0.7	0.7	1.7	4.1	2.3	1.5	1.2	1.8	2.7	2.9	1.9
	1AF	3.1	1.9	2.1	4.9	10.7	6.8	4.8	4.1	5.7	7.2	7.2	4.5
	1AG	2.0	1.0	1.1	3.7	8.8	5.5	3.5	2.7	4.2	5.4	5.6	3.4
	1AH	1.6	0.7	0.7	4.1	8.4	4.0	2.1	1.6	3.5	5.1	5.6	3.2
	1BA	2.8	1.5	1.6	4.4	10.5	6.5	7.3	9.0	5.7	5.1	7.3	3.7
	1BB	9.6	5.9	6.3	13.6	33.6	22.4	25.6	30.7	20.5	18.1	22.6	11.6
	1BC	3.4	2.2	2.1	2.9	10.5	9.7	10.9	13.1	11.0	9.5	8.8	4.6
	1BD	6.0	4.6	4.7	4.9	10.7	9.7	10.3	12.6	12.2	10.0	9.5	6.8
	1BE	6.0	3.5	3.0	4.0	21.4	21.3	23.4	28.9	25.6	21.8	20.1	9.8
	1BG	8.8	6.0	6.1	8.7	26.1	22.2	22.9	27.7	26.2	24.3	20.0	10.9
	1BH	5.9	3.8	3.9	7.0	19.4	15.7	15.0	17.4	17.7	16.9	14.1	7.5
	1CA	6.5	4.8	5.0	5.9	11.7	9.2	10.5	12.7	10.8	8.4	8.7	7.1
	1CB	6.4	4.3	4.5	6.5	14.0	10.7	12.7	15.8	12.8	9.1	9.0	7.4
	1CC	11.4	8.7	9.1	13.1	20.8	16.8	19.9	22.4	18.5	14.8	14.4	12.6
	1CD	19.1	13.6	14.3	19.8	41.0	32.0	36.9	43.9	37.3	28.5	26.5	21.2
	1CE	4.5	3.4	3.6	4.5	9.5	8.3	8.5	9.7	9.8	8.4	6.4	4.9
	1DA	8.7	6.4	7.1	11.7	22.8	17.6	16.5	17.3	18.6	16.6	13.3	10.1
	1DB	13.4	9.9	10.8	17.7	34.2	26.5	24.3	25.9	26.7	27.2	23.7	15.5
	1DC	6.2	4.4	4.7	7.0	14.5	11.7	9.9	9.2	11.0	11.0	10.1	7.5
	1DD	6.9	5.0	5.5	8.4	15.7	12.2	9.6	8.6	10.6	11.4	11.2	8.5
	1EA	14.5	11.3	12.4	20.0	30.9	24.7	24.0	25.1	24.9	22.2	19.1	16.0
	1EB	11.7	9.4	10.4	15.3	22.4	17.8	16.1	16.3	17.4	16.8	15.3	13.0
	1EC	7.0	5.7	6.2	8.6	13.2	10.7	10.1	10.0	10.6	10.2	9.1	7.7
	1ED	2.9	2.2	2.4	3.8	6.2	4.6	3.8	3.4	4.2	4.5	4.4	3.5
	1EE	3.7	1.8	1.7	4.8	12.4	7.9	3.7	2.2	5.7	6.7	8.4	6.2
	1EF	2.6	0.3	0.0	2.8	12.9	5.5	0.6	0.2	3.6	4.6	8.1	5.6
	1EG	6.0	3.1	3.2	10.1	18.4	12.2	7.1	5.4	8.9	10.5	11.9	9.6
	1FA	2.0	1.2	1.1	3.2	6.0	4.7	5.8	7.0	5.4	3.7	3.6	2.7
	1FB	8.7	6.1	7.0	13.1	21.9	17.4	19.0	20.4	18.3	14.3	13.2	10.0
	1FC	5.3	3.8	4.1	7.3	12.1	9.7	9.9	10.4	10.1	8.1	7.4	6.0
	1FD	8.7	5.8	6.5	13.2	20.8	16.5	17.4	18.5	16.9	13.5	13.4	10.1
	1FE	13.4	8.5	9.5	21.2	35.3	25.7	21.9	22.0	24.1	21.6	19.7	16.5
	1FF	1.9	0.5	0.5	4.3	8.5	5.0	3.0	2.5	3.5	3.7	3.8	3.2
	1FG	5.0	0.7	0.8	11.7	23.3	8.2	0.8	0.8	5.5	7.2	13.4	10.5
LVSCA	1GA	8.2	4.6	5.4	16.2	23.6	15.9	17.8	21.1	17.2	12.0	13.6	10.1
	1GB	8.3	2.9	5.6	18.3	24.1	14.7	12.7	13.5	14.6	10.7	13.6	10.0
	1GC	16.9	11.2	11.6	26.2	39.8	25.7	27.3	33.9	28.1	22.9	24.6	20.2
	1GD	9.7	5.2	7.9	16.1	19.1	10.4	8.2	9.2	8.7	8.3	11.1	9.8
	1GE	3.6	0.7	1.3	5.2	11.4	4.1	1.7	1.1	1.5	1.8	4.2	1.9
	1GF	7.1	3.6	5.9	10.9	12.7	5.4	4.0	4.2	4.0	5.3	7.6	7.5
	1GG	6.7	3.6	4.8	14.4	19.5	12.0	11.6	14.1	12.1	9.4	10.8	8.1
	1HA1	6.1	2.8	4.5	11.1	15.6	8.1	5.7	6.0	6.8	6.2	7.3	8.0
	1HA2	2.0	0.1	0.4	2.3	3.4	0.6	0.1	0.1	0.2	0.4	1.3	2.9
	1HB1	2.8	0.8	0.6	4.5	9.7	5.2	2.2	1.0	1.7	2.6	4.2	5.4
	1HB2	2.2	0.6	1.1	4.5	7.0	3.5	1.6	1.2	1.5	1.8	2.6	3.4
	1HC	1.8	0.3	0.0	1.2	5.5	3.4	1.0	0.1	0.5	1.1	1.5	3.8
	1HD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1HE	8.7	3.5	3.8	15.5	25.8	15.5	8.2	4.7	8.2	9.4	12.2	11.9
	1HF	6.5	2.0	1.6	10.4	23.8	12.9	6.1	2.5	5.0	7.4	10.6	10.3
	1HG	3.1	0.8	0.0	0.1	3.2	5.5	1.8	0.1	0.2	0.6	0.8	2.7
	1JA	2.5	0.5	0.2	5.0	11.1	3.8	1.2	0.5	0.9	1.1	2.9	4.3
	1JB	20.7	14.5	16.5	31.5	42.5	27.8	25.0	26.0	25.9	24.2	27.3	23.7
	1JC	4.5	3.0	3.6	8.0	10.5	6.5	5.5	5.1	5.6	5.7	6.4	5.2
	1JD	9.7	6.9	7.9	15.3	20.3	13.5	12.4	12.5	12.6	12.6	13.3	11.1
	1JE	7.4	5.7	6.8	11.5	13.1	9.7	8.9	8.2	8.7	8.9	9.9	8.4
	1JF	10.5	7.0	9.6	18.7	21.3	13.1	9.1	7.5	9.9	9.8	12.4	12.2
	1JG1	25.9	17.6	21.9	42.2	53.9	36.3	28.6	25.3	28.6	27.5	32.9	29.3
	1JG2	6.2	3.4	3.5	9.2	14.4	8.9	6.0	4.1	5.6	5.7	7.3	6.0
	1KA	3.2	2.2	2.4	4.4	5.9	3.3	2.2	2.1	2.6	2.6	3.2	3.2
	1KB	4.9	2.2	3.1	10.0	16.4	9.6	4.7	3.1	5.6	6.2	7.7	7.5
	1KC	35.9	18.2	23.3	64.9	104.6	54.1	28.4	19.9	29.7	32.5	42.6	48.6
	1LA1	35.0	23.1	25.3	56.6	86.4	46.1	25.7	15.6	19.3	23.7	32.5	45.1
	1LA2	19.8	12.9	15.1	31.5	41.4	23.7	18.0	17.9	18.8	16.9	22.1	22.3
	1LA3	18.5	13.1	13.6	23.5	32.6	20.0	12.3	9.2	11.1	11.4	13.2	18.3
	1LB1	30.0	23.7	20.6	38.2	56.2	23.3	11.8	7.3	7.4	6.6	9.6	23.6
	1LB2	29.1	19.2	21.4	43.2	55.5	30.4	21.0	19.0	20.8	18.1	25.0	29.5

Table 5.4.3 Present Monthly Average Naturalised River Discharge by Sub-basin (2/3)

(Unit: m^3/s)

CA	Sub-basin	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RVCA	2AA	17.2	17.1	13.4	23.0	41.0	17.1	5.1	1.3	1.6	1.4	3.7	11.7
	2AB	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	2BA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2BB	6.3	2.2	0.7	3.5	28.2	25.9	34.3	44.7	30.1	21.4	22.9	8.6
	2BC	10.1	3.5	1.1	5.6	45.3	41.7	55.2	71.9	48.4	34.4	36.8	13.9
	2BD	8.5	2.8	1.4	3.1	32.5	33.3	42.4	55.3	44.0	33.2	31.7	13.0
	2CA	0.1	0.0	0.0	0.0	0.5	0.3	0.4	1.3	3.2	0.7	0.4	0.6
	2CB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2CC	25.6	11.9	10.6	26.2	85.1	55.5	72.6	106.2	69.6	32.2	53.0	35.4
	2D	18.3	6.8	4.0	13.6	77.0	54.0	63.7	97.2	63.8	38.1	59.8	27.3
	2EA	4.3	0.6	0.2	1.5	13.5	7.8	6.6	15.2	18.0	2.3	9.5	6.1
	2EB	1.9	1.2	0.9	1.3	3.9	2.5	3.9	6.9	6.1	2.4	2.4	1.9
	2EC	3.1	1.9	1.4	2.1	6.5	4.0	6.5	11.5	10.1	4.0	4.0	3.2
	2ED	2.8	1.9	1.3	2.0	5.5	3.8	4.3	7.7	8.6	4.7	4.7	3.6
	2EE	4.7	3.0	1.9	2.9	9.5	8.0	10.7	18.6	19.1	8.8	7.8	6.0
	2EF	5.7	2.6	2.4	4.9	17.5	11.5	17.0	28.2	20.3	7.3	8.8	7.5
	2EG1	3.1	1.9	1.3	1.9	6.2	5.2	7.0	12.2	12.5	5.7	5.1	3.9
	2EG2	1.6	1.0	0.7	1.2	3.8	2.4	3.5	6.4	5.7	2.6	2.8	2.2
	2EH	5.3	3.3	2.5	3.9	12.8	8.0	11.5	21.3	19.2	8.7	9.2	7.2
	2EJ	2.2	0.8	1.4	3.2	8.3	4.5	6.7	12.0	7.7	2.2	4.6	3.1
	2EK	0.2	0.0	0.0	0.0	1.5	0.0	0.0	2.4	2.4	0.0	1.0	3.7
	2FA	1.7	0.9	0.6	1.3	5.2	2.3	4.1	7.5	6.1	1.4	2.1	3.3
	2FB	1.3	1.0	0.6	0.8	3.0	2.0	2.1	2.6	3.3	2.3	2.4	1.8
	2FC	0.3	0.2	0.1	0.2	0.8	0.5	0.5	0.7	0.9	0.6	0.6	0.5
	2GA	3.4	2.8	1.8	2.3	7.3	4.6	4.9	7.1	7.8	5.0	5.4	4.0
	2GB	1.7	1.5	0.7	0.9	3.8	2.9	2.5	2.6	2.9	2.0	2.4	1.8
	2GC	6.9	4.4	2.6	5.1	17.1	11.2	9.4	10.9	11.5	8.3	11.4	7.8
	2GD	7.9	4.3	3.3	10.2	26.0	14.1	7.8	5.9	7.1	8.2	15.6	10.4
	2H-1	11.2	6.1	4.7	14.5	36.7	19.9	11.0	8.3	10.1	11.6	22.0	14.6
	2H-2	0.4	0.2	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1
	2H-3	5.3	6.4	2.2	4.1	10.3	3.1	0.8	0.3	0.1	0.0	0.2	3.3
	2J	2.1	2.7	1.1	1.6	2.8	1.3	0.2	0.0	0.0	0.0	0.0	1.2
	2KA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2KB	34.0	26.9	17.4	38.2	76.8	31.0	15.3	9.7	9.7	7.2	12.9	23.2
	2KC	8.0	6.2	3.8	7.3	14.3	5.3	3.2	2.9	3.1	2.3	3.4	6.6
ACA	3AA	8.9	6.6	5.9	8.9	16.2	7.0	4.2	3.7	3.4	3.6	5.5	7.8
	3AB	5.0	3.7	1.8	3.2	6.3	2.2	0.6	0.3	0.2	0.2	0.9	2.6
	3AC	5.1	3.0	1.5	3.8	8.9	3.0	0.7	0.2	0.1	0.1	2.0	4.9
	3BA	4.5	3.0	2.5	5.8	11.1	3.6	1.4	0.9	0.8	1.0	3.7	5.2
	3BB	3.3	2.4	2.3	4.6	7.9	2.8	1.3	1.0	1.0	1.2	3.2	3.8
	3BC	12.0	8.8	8.3	14.6	26.6	12.3	7.9	6.8	6.2	6.4	11.1	13.7
	3BD	4.9	3.3	3.1	6.4	11.1	4.5	2.8	2.3	2.1	2.2	4.3	5.7
	3CB	9.3	7.4	7.1	10.6	16.9	8.6	7.0	6.4	6.0	6.2	8.6	10.3
	3DA	7.9	4.5	3.8	5.5	9.0	2.8	3.1	4.1	4.0	3.9	5.8	9.2
	3DB	7.2	2.2	0.4	1.3	2.8	1.3	0.1	0.0	0.0	0.0	2.7	11.7
	3EA	10.3	4.1	1.7	3.4	6.1	1.5	0.2	0.0	0.0	0.0	3.6	10.3
	3EB	9.2	3.3	1.0	2.2	3.6	0.8	0.0	0.0	0.0	0.0	3.4	12.3
	3EC	8.8	2.9	0.9	2.2	3.1	0.7	0.0	0.0	0.0	0.0	2.9	12.6
	3ED	4.1	1.1	0.2	0.2	0.6	0.1	0.0	0.0	0.0	0.0	0.7	5.6
	3FA	31.1	9.2	3.5	4.2	6.6	4.6	3.2	2.9	2.8	2.7	4.6	19.8
	3FB	22.5	8.3	0.9	1.4	1.5	2.0	0.0	0.0	0.0	0.0	0.4	18.4
	3G	9.8	6.8	0.8	2.7	1.0	0.3	0.1	0.0	0.0	0.0	0.3	2.0
	3HA	1.9	1.3	0.1	0.2	0.1	0.2	0.0	0.0	0.0	0.0	0.3	1.8
	3HB	3.6	1.9	0.0	0.0	0.3	0.6	0.0	0.0	0.0	1.0	1.2	2.3
	3HC	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.4	1.4	0.4
	3HD1	1.3	0.1	0.0	0.0	0.8	1.1	0.4	0.0	0.0	2.4	3.4	0.4
	3HD2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	3J	1.2	1.4	0.0	0.6	0.3	0.0	0.0	0.0	0.0	0.0	0.3	0.3
	3K	2.9	2.3	1.2	2.2	19.2	5.1	2.6	1.1	0.3	13.4	29.9	2.1
	3LA	0.4	0.2	0.0	0.0	1.9	0.5	0.1	0.1	0.0	17.8	17.1	0.5
	3LB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	3MA-1	0.8	0.8	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	2.2	1.5
	3MA-2	0.2	0.3	0.0	0.0	1.9	0.2	0.2	0.1	0.0	1.6	6.1	0.2
	3MB	0.1	0.0	0.0	0.0	4.5	1.0	0.5	0.1	0.0	9.8	10.7	0.1
	3MC	0.0	0.0	0.0	0.0	2.4	0.3	0.3	0.1	0.0	3.9	4.3	0.0
	3MD1	0.3	0.0	0.0	0.2	16.3	4.9	1.2	0.3	0.0	15.3	11.1	0.4
	3MD2	0.1	0.0	0.0	0.0	0.9	0.4	0.2	0.1	0.0	1.5	1.1	0.1
	3N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 5.4.3 Present Monthly Average Naturalised River Discharge by Sub-basin (3/3)

(Unit: m^3/s)

CA	Sub-basin	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TCA	4AA	7.3	4.2	4.2	9.7	21.6	6.5	3.5	3.1	2.9	4.4	13.8	10.2
	4AB	9.7	6.6	6.2	11.1	26.7	11.0	6.7	5.7	5.1	6.4	15.9	11.7
	4AC	11.6	8.4	8.1	13.2	27.6	13.5	8.9	7.9	7.5	8.9	16.9	13.5
	4AD	13.7	9.4	8.9	18.5	37.1	16.0	10.0	8.7	8.1	10.4	22.1	17.1
	4BA	3.4	1.9	1.4	5.0	14.8	4.2	1.6	1.2	1.1	1.1	6.3	4.7
	4BB	7.6	4.9	4.5	14.9	27.2	8.6	4.5	4.1	3.4	5.5	15.6	10.7
	4BC	5.3	3.9	3.9	2.3	6.0	5.1	4.1	3.8	3.7	3.0	2.8	4.5
	4BD	13.6	8.8	8.1	25.3	47.0	15.3	8.3	7.4	6.4	9.6	26.4	18.7
	4BE	15.5	10.2	8.8	24.3	45.6	17.3	9.6	8.2	7.3	9.1	23.1	20.3
	4BF	8.7	6.6	6.6	11.8	17.6	7.6	6.3	6.0	5.7	5.9	9.3	10.1
	4BG	6.2	4.3	3.2	3.3	12.8	6.3	3.8	3.2	3.0	2.0	3.8	6.9
	4CA	22.7	17.4	17.6	29.8	44.8	24.3	18.7	17.2	16.1	18.4	28.9	26.3
	4CB	15.1	11.6	11.6	20.3	29.6	15.3	11.8	10.9	10.2	11.4	18.1	17.5
	4CC	15.3	10.4	9.4	14.5	24.9	11.3	8.3	7.6	7.3	7.1	11.3	16.7
	4DA	17.6	11.7	11.2	21.0	40.4	16.2	11.4	10.3	9.5	10.2	23.3	21.6
	4DB	8.4	4.6	4.2	16.3	24.5	6.8	3.8	3.2	2.8	4.5	19.7	13.6
	4DC	8.1	4.6	4.3	14.8	22.3	6.7	3.9	3.3	2.9	4.6	18.7	12.9
	4DD	2.4	1.4	0.9	1.1	3.6	1.6	1.0	0.8	0.7	0.5	1.8	2.7
	4DE	4.8	2.9	1.4	1.3	7.3	4.4	2.0	1.3	1.3	0.6	1.3	5.3
	4EA	29.4	15.2	15.3	51.6	58.4	15.4	11.6	10.9	10.3	20.9	84.4	54.1
	4EB	36.2	19.8	21.2	70.3	82.8	22.1	15.6	15.1	14.2	30.6	106.0	64.6
	4EC	19.4	13.7	13.3	23.9	31.8	15.5	13.0	12.2	11.5	12.9	29.3	26.7
	4ED	58.4	29.9	21.3	33.5	56.3	25.4	19.0	17.0	16.0	15.7	56.8	79.4
	4FA	58.1	24.0	19.6	71.6	103.2	22.8	14.0	12.6	11.5	28.0	144.0	112.5
	4FB	35.0	13.6	5.8	28.1	62.9	14.2	6.2	4.4	4.0	4.0	91.0	79.1
	4GA	31.2	14.6	9.4	12.2	43.7	15.5	9.7	8.1	7.4	4.8	77.1	71.4
	4GB	16.7	4.3	0.7	0.3	14.4	3.4	0.0	0.0	0.0	0.0	50.7	60.3
	4GC	4.8	1.4	0.0	0.0	6.1	2.0	0.0	0.0	0.0	0.0	0.0	7.5
	4GD	17.1	2.3	0.0	0.0	10.3	3.4	0.0	0.0	0.0	0.0	0.8	25.5
	4GE	21.9	1.9	0.0	0.0	5.9	1.6	0.0	0.0	0.0	0.0	0.0	15.1
	4GF	134.2	21.1	2.7	1.3	22.1	4.9	0.0	0.0	0.0	0.0	2.6	113.4
	4GG	14.9	2.9	0.9	0.0	7.7	2.6	0.5	0.0	0.0	0.0	12.0	15.4
	4HA	80.7	26.9	17.3	18.8	22.0	14.9	13.3	12.5	11.8	12.1	28.9	76.8
	4HB	43.4	11.7	3.3	1.1	0.5	0.0	0.0	0.0	0.0	0.0	1.1	8.3
	4HC	0.8	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.8
	4JA	22.8	5.0	0.0	0.0	21.5	7.1	0.0	0.0	0.0	0.0	0.5	34.6
	4JB	8.9	1.9	0.0	0.0	8.4	2.8	0.0	0.0	0.0	0.0	0.2	13.5
	4KA	14.4	3.1	0.0	0.0	13.6	4.4	0.0	0.0	0.0	0.0	0.3	21.8
	4KB	24.3	5.3	0.0	0.0	23.0	7.5	0.0	0.0	0.0	0.0	0.5	37.0
ENNCA	5AA	5.7	3.2	1.9	4.7	12.6	6.2	7.8	12.7	11.3	4.6	6.0	4.6
	5AB	2.5	1.7	0.6	2.2	5.7	2.3	2.8	5.2	4.1	1.6	2.4	1.9
	5AC	1.7	1.2	0.2	1.0	6.7	1.9	1.5	2.6	3.6	0.8	1.8	1.8
	5AD	1.8	1.2	0.1	0.6	3.9	1.0	0.8	1.6	1.8	0.4	1.2	1.4
	5BA	1.8	1.6	0.7	1.4	6.1	2.0	0.7	1.1	1.0	0.7	3.5	2.2
	5BB	4.2	2.5	1.6	4.5	13.7	4.2	1.8	2.7	2.8	2.7	8.6	4.4
	5BC-1	11.9	4.9	3.3	8.5	32.3	8.9	5.0	7.4	7.6	5.4	18.2	12.2
	5BC-2	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.4	0.3	0.0	0.0	0.0
	5BD	4.1	2.5	1.4	2.8	8.9	3.3	3.1	5.0	4.8	2.4	4.2	3.5
	5BE	12.2	4.8	3.3	13.4	26.5	5.0	1.4	1.9	1.9	6.7	32.2	20.1
	5CA	5.7	2.1	0.7	1.8	10.5	5.1	3.5	5.9	7.0	1.7	5.3	7.1
	5CB	4.0	1.3	0.1	0.4	2.4	1.0	0.7	0.9	1.1	0.1	1.0	5.7
	5CC	3.5	1.2	0.2	0.8	4.3	1.7	0.9	1.7	3.0	0.4	2.8	6.8
	5DA	33.0	10.6	5.0	31.8	38.2	5.3	1.8	1.2	1.4	9.3	69.5	58.5
	5DB	7.4	3.1	0.7	1.3	3.7	0.8	0.4	0.9	0.7	0.3	3.9	7.5
	5DC	2.0	1.2	0.3	0.3	1.9	1.2	0.8	0.9	1.2	0.4	1.3	2.6
	5DD	3.0	1.5	0.1	0.1	1.5	0.9	0.3	1.0	1.3	0.2	0.9	3.6
	5EA	1.7	0.6	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.0	75.1	65.4
	5EB	3.6	0.9	0.0	0.0	0.0	0.0	0.0	0.6	0.5	0.0	77.0	75.7
	5EC	12.6	0.6	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.2	62.4	60.0
	5ED	62.8	17.0	5.1	13.7	63.2	3.6	0.0	0.0	0.0	0.0	147.3	199.7
	5FA	44.3	8.8	4.0	1.6	1.3	0.0	0.0	0.2	0.0	0.0	9.5	115.9
	5FB	5.1	0.9	0.0	0.0	0.0	0.0	0.0	0.6	0.5	0.0	19.1	31.3
	5G	3.6	0.6	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.0	77.0	75.7
	5HA	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.5	0.5	5.5	9.5	0.6
	5HB	0.1	0.7	0.0	0.0	0.0	0.0	0.0	0.5	0.5	3.8	9.6	0.6
	5J	44.0	14.8	7.4	46.7	129.2	36.8	16.7	8.5	4.6	15.0	130.9	87.6

Source: JICA Study Team

Table 5.4.4 Future Monthly Average Naturalised River Discharge by Sub-basin (1/3)

(Unit: m^3/s)

CA	Sub-basin	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
LVNCA	1AA	1.9	1.2	1.8	6.3	9.9	5.0	3.5	4.2	5.1	5.9	6.0	3.1
	1AB	4.4	3.0	4.1	12.0	18.0	10.7	8.7	10.3	11.0	12.1	11.7	6.4
	1AC	0.4	0.1	0.3	2.1	3.7	2.1	1.3	1.6	2.0	2.2	2.3	0.9
	1AD	2.4	1.5	2.0	7.6	12.8	6.6	4.1	3.9	5.5	6.9	7.8	4.7
	1AE	1.2	0.8	1.0	3.2	5.4	2.7	1.5	1.3	1.9	2.7	3.3	2.3
	1AF	3.2	2.2	2.9	8.3	13.1	7.2	4.8	4.8	6.2	7.5	8.4	5.3
	1AG	2.1	1.2	1.7	6.3	10.6	5.5	3.4	3.3	4.4	5.4	6.4	3.9
	1AH	1.5	0.8	1.3	6.4	10.7	4.3	2.0	2.0	3.4	5.2	6.4	3.6
	1BA	2.8	1.6	1.7	7.0	11.0	6.6	7.9	9.3	5.0	6.2	7.1	3.9
	1BB	9.8	6.6	7.0	22.3	36.5	22.9	27.6	31.5	19.0	22.4	23.0	12.8
	1BC	5.1	3.5	3.4	8.6	17.8	14.0	15.5	18.1	14.6	15.0	13.0	7.2
	1BD	6.9	5.4	5.9	8.7	14.1	11.2	11.2	14.7	12.7	11.7	11.1	8.2
	1BE	7.9	4.9	4.9	13.6	30.6	24.2	24.0	31.0	26.9	26.6	23.6	12.8
	1BG	9.9	7.2	8.2	19.4	32.6	24.1	23.1	30.6	27.5	27.2	23.7	13.2
	1BH	6.7	4.8	5.8	14.8	23.8	17.1	15.4	19.8	19.0	18.9	17.0	9.3
	1CA	6.8	5.2	5.6	9.1	13.0	9.8	11.1	13.4	9.9	9.4	9.7	7.7
	1CB	6.5	4.6	4.9	10.7	14.7	10.8	12.9	15.6	11.2	10.4	10.3	7.7
	1CC	10.9	8.7	9.6	16.9	20.9	16.4	19.4	21.7	16.7	16.4	15.6	12.7
	1CD	19.5	14.7	16.5	31.9	44.3	33.5	38.3	46.6	35.3	32.8	31.4	22.9
	1CE	4.8	3.9	4.6	8.1	11.4	9.2	9.4	12.1	10.5	9.8	8.4	5.8
	1DA	9.1	7.3	9.4	18.7	25.4	18.9	17.5	22.5	21.8	21.0	18.9	12.3
	1DB	14.6	11.6	14.1	28.1	39.5	27.9	25.2	29.5	29.1	30.3	28.4	18.3
	1DC	6.6	5.0	5.9	11.0	17.0	12.4	10.1	11.2	12.4	12.4	12.5	8.9
	1DD	7.2	5.6	6.6	12.1	18.5	12.8	9.9	10.2	11.6	12.2	13.1	9.8
	1EA	14.9	12.4	15.4	27.1	32.6	25.8	24.9	29.4	27.0	26.4	24.2	18.2
	1EB	12.2	10.2	12.2	19.9	24.1	18.4	16.9	18.9	18.7	19.1	18.1	14.6
	1EC	7.3	6.2	7.2	11.5	14.3	11.2	10.5	12.4	12.6	12.8	12.0	9.1
	1ED	2.9	2.3	2.7	4.9	6.9	4.6	3.8	4.0	4.4	4.7	4.9	3.8
	1EE	3.2	1.7	2.1	6.7	15.2	8.0	3.4	3.4	5.5	6.9	9.2	6.8
	1EF	1.8	0.2	0.8	6.5	17.3	6.2	0.4	0.9	3.1	5.4	9.4	6.6
	1EG	5.9	3.1	4.2	12.8	21.4	12.1	7.2	7.4	8.8	11.2	13.2	10.7
	1FA	1.8	1.2	1.3	4.6	6.0	4.5	5.5	6.5	4.6	4.3	4.2	2.7
	1FB	8.1	6.3	8.0	17.0	21.7	17.1	18.5	21.0	17.4	16.5	15.8	10.8
	1FC	4.9	3.8	4.8	9.2	12.1	9.6	9.6	10.9	9.9	9.2	8.8	6.7
	1FD	7.8	5.9	7.5	16.5	21.3	16.3	17.2	18.9	16.0	15.6	15.6	11.0
	1FE	12.3	8.9	12.1	28.4	36.6	26.1	22.1	25.0	24.4	24.5	24.1	18.6
	1FF	1.9	0.6	1.5	7.2	9.6	5.6	3.3	3.3	3.5	4.3	4.9	4.1
	1FG	4.5	0.6	3.0	17.5	28.5	8.2	0.7	1.8	4.2	8.8	15.4	12.8
LVSCA	1GA	6.6	4.7	6.5	20.7	24.0	15.7	17.8	20.9	15.2	14.7	15.1	10.1
	1GB	6.3	3.5	6.5	24.3	25.2	14.6	12.8	14.8	13.4	14.7	15.8	10.5
	1GC	14.1	11.3	13.8	31.8	39.2	25.5	27.7	35.7	28.0	25.8	25.3	19.6
	1GD	3.7	1.3	2.9	18.4	16.7	7.0	2.6	4.6	4.3	6.5	8.0	6.3
	1GE	3.6	1.7	2.8	14.8	13.6	6.1	2.2	3.7	3.3	6.2	7.7	5.8
	1GF	2.6	0.8	2.2	12.8	11.5	4.2	0.7	1.3	0.7	3.5	5.6	5.6
	1GG	5.2	3.8	6.0	18.0	19.7	11.6	11.9	14.7	11.4	11.1	11.6	7.8
	1HA1	5.1	2.9	5.7	15.2	15.9	9.1	6.1	6.5	6.0	7.5	9.5	9.2
	1HA2	1.6	0.3	0.9	7.2	3.2	1.2	0.2	0.3	0.2	0.9	2.1	4.5
	1HB1	3.1	0.7	1.6	7.3	10.8	5.4	2.2	1.4	1.5	3.1	5.1	6.8
	1HB2	2.4	0.8	2.1	7.3	8.2	4.5	2.1	1.6	1.4	2.4	3.7	4.6
	1HC	3.2	0.6	1.3	4.7	8.7	4.9	1.3	0.3	0.2	1.3	2.9	6.4
	1HD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1HE	8.5	4.4	8.0	24.6	30.1	18.5	9.6	6.4	7.5	11.7	16.1	17.2
	1HF	6.1	2.7	5.8	18.9	26.6	13.4	6.2	3.0	4.5	9.1	14.4	14.0
	1HG	5.8	1.5	2.8	12.5	20.4	11.2	2.6	0.2	0.2	1.1	3.3	8.2
	1JA	2.8	0.7	1.9	9.0	13.8	3.7	0.8	0.2	0.3	1.4	4.7	6.1
	1JB	18.3	15.2	19.9	39.7	42.7	29.3	26.8	29.3	27.6	27.3	29.8	25.2
	1JC	3.9	3.2	4.7	10.2	10.8	7.0	5.9	5.9	5.9	6.4	7.2	5.6
	1JD	8.9	7.4	9.9	18.8	20.8	14.1	13.2	14.1	13.4	13.8	14.4	11.4
	1JE	7.3	6.1	7.9	14.0	15.2	11.3	9.5	9.2	9.3	10.4	11.2	9.8
	1JF	8.9	7.6	11.6	22.8	20.4	12.9	9.3	7.9	9.6	11.3	15.2	14.4
	1JG1	23.7	18.6	26.5	52.9	54.6	38.4	30.2	27.9	29.5	32.0	38.4	35.7
	1JG2	4.2	2.6	4.0	11.6	14.3	9.0	5.6	4.6	5.3	6.6	8.1	7.8
	1KA	1.5	0.8	1.1	3.5	4.7	2.5	1.2	0.8	1.1	1.5	2.1	3.0
	1KB	5.5	3.5	6.1	15.8	20.1	10.2	5.0	3.5	4.9	7.9	11.0	10.4
	1KC	39.3	24.5	41.1	103.8	131.0	58.8	28.6	19.2	24.4	38.6	58.4	67.7
	1LA1	40.1	31.3	47.0	98.5	102.0	48.2	24.1	14.2	16.4	29.1	45.4	61.3
	1LA2	16.2	13.1	17.4	42.8	40.0	25.0	19.7	19.5	19.6	20.2	26.4	26.6
	1LA3	17.7	15.4	18.3	37.2	38.6	21.3	12.3	8.0	9.6	11.9	15.1	24.3
	1LB1	30.7	29.4	32.9	79.4	72.5	29.3	13.2	6.3	6.6	8.9	15.5	35.1
	1LB2	26.9	21.9	27.6	67.1	62.0	36.0	24.0	21.2	21.9	23.3	33.0	42.9

Table 5.4.4 Future Monthly Average Naturalised River Discharge by Sub-basin (2/3)

(Unit: m^3/s)

CA	Sub-basin	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RVCA	2AA	21.2	21.2	25.5	66.5	62.4	24.2	8.0	1.7	2.8	5.5	8.5	25.5
	2AB	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	2BA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
	2BB	8.5	3.5	2.0	13.0	35.6	29.0	39.0	46.7	28.1	31.6	26.7	10.9
	2BC	13.7	5.6	3.2	20.9	57.2	46.6	62.8	75.0	45.2	50.8	43.0	17.5
	2BD	11.2	4.0	2.7	20.3	50.8	39.4	44.5	58.9	41.9	46.5	40.1	17.2
	2CA	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.2	0.5	0.4	0.8
	2CB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2CC	27.7	13.7	8.3	63.5	92.6	56.0	72.7	89.9	41.6	39.8	52.1	35.4
	2D	24.9	9.0	4.9	35.0	97.6	63.8	73.0	105.4	52.3	58.1	65.2	34.0
	2EA	7.3	1.1	0.7	18.6	17.3	8.6	4.9	21.7	7.7	8.9	15.8	14.3
	2EB	2.2	1.0	0.6	2.9	4.7	3.2	4.5	6.5	4.0	2.8	3.3	3.0
	2EC	3.7	1.6	1.0	4.7	7.9	5.2	7.5	10.8	6.6	4.6	5.4	5.0
	2ED	3.4	2.1	1.5	3.3	8.3	5.4	5.5	9.2	7.7	5.8	5.5	6.4
	2EE	3.1	2.0	1.5	3.6	8.4	6.4	8.7	14.0	11.1	7.1	6.3	5.9
	2EF	6.0	2.9	1.9	12.7	18.9	12.6	18.6	26.0	13.3	9.3	10.9	8.4
	2EG1	2.8	1.9	1.4	3.3	7.7	5.9	8.0	12.9	10.2	6.6	5.8	5.5
	2EG2	2.0	1.1	0.7	2.9	5.1	3.3	4.1	7.0	4.5	3.2	3.4	3.3
	2EH	6.6	3.7	2.5	9.6	17.0	10.9	13.7	23.4	15.0	10.8	11.5	11.1
	2EJ	3.1	1.1	1.0	8.7	9.3	5.6	7.3	10.7	3.9	3.2	5.2	3.6
	2EK	1.5	0.4	0.3	3.3	2.0	0.9	0.9	4.4	1.6	1.8	3.2	3.3
	2FA	2.6	1.0	0.6	4.5	5.6	3.5	5.5	8.4	3.1	2.3	3.9	3.4
	2FB	1.6	0.9	0.7	1.4	3.2	2.1	2.1	2.6	2.6	2.2	2.7	2.7
	2FC	0.4	0.2	0.2	0.3	0.8	0.5	0.5	0.7	0.7	0.6	0.7	0.7
	2GA	4.5	3.0	2.1	4.9	8.9	5.9	5.4	7.1	6.5	5.4	6.5	6.4
	2GB	2.9	1.8	1.3	3.1	5.0	3.3	2.8	2.5	2.3	2.1	3.4	3.1
	2GC	9.5	5.0	3.7	11.6	17.9	11.4	10.6	9.6	9.3	9.1	14.4	11.5
	2GD	10.4	5.4	5.1	18.3	27.6	15.0	9.0	6.0	6.9	10.1	19.1	15.0
	2H-1	14.7	7.6	7.2	25.8	38.9	21.1	12.7	8.5	9.7	14.2	27.0	21.1
	2H-2	6.0	6.4	3.0	7.7	12.3	4.6	1.1	0.3	0.1	0.0	0.8	5.2
	2H-3	7.8	8.7	3.6	11.7	17.5	4.3	1.1	0.3	0.1	0.0	1.1	6.6
	2J	3.1	3.0	1.2	3.5	5.1	1.4	0.2	0.0	0.0	0.0	0.1	2.5
	2KA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2KB	33.4	27.9	25.6	73.5	79.5	36.9	17.3	9.1	8.5	9.2	22.3	40.2
	2KC	8.5	6.7	5.0	13.3	17.0	5.5	3.3	2.9	2.6	2.4	4.7	10.0
ACA	3AA	6.2	6.2	2.2	5.2	12.3	3.1	0.8	0.2	0.0	0.0	0.0	6.8
	3AB	10.3	8.7	6.6	14.3	19.9	7.7	4.1	3.5	3.3	3.6	6.8	11.5
	3AC	7.3	6.0	3.0	7.8	10.0	3.0	0.6	0.3	0.2	0.2	1.9	5.7
	3BA	5.5	3.4	1.9	7.3	10.3	2.7	0.5	0.2	0.1	0.1	3.2	7.6
	3BB	3.9	2.9	2.4	6.3	9.3	2.9	1.2	0.8	0.7	1.0	3.5	5.6
	3BC	3.4	2.7	2.5	6.4	8.2	2.7	1.3	1.0	0.9	1.3	3.6	4.9
	3BD	12.7	9.6	9.3	19.4	27.2	11.8	7.6	6.3	5.7	6.4	12.8	16.5
	3CB	5.2	4.0	3.7	8.9	11.7	4.6	2.7	2.2	2.0	2.2	5.4	7.1
	3DA	9.7	7.8	7.6	13.1	16.7	8.7	6.8	6.1	5.7	6.1	9.5	11.6
	3DB	8.4	4.7	3.8	12.0	10.6	2.7	3.6	4.1	4.0	3.8	9.2	13.8
	3EA	8.3	2.4	1.0	8.4	7.7	1.7	0.3	0.0	0.0	0.0	7.8	16.3
	3EB	10.7	4.5	2.1	12.9	9.3	1.5	0.2	0.0	0.0	0.0	8.3	16.2
	3EC	10.8	3.9	2.2	14.0	9.3	1.1	0.0	0.0	0.0	0.0	9.4	18.8
	3ED	10.2	3.4	2.2	13.8	9.3	1.1	0.0	0.0	0.0	0.0	8.7	18.4
	3FA	4.6	1.2	0.5	4.5	3.6	0.5	0.0	0.0	0.0	0.0	2.5	8.5
	3FB	38.3	12.2	4.6	19.4	16.4	5.7	3.2	3.0	2.8	2.6	9.0	39.6
	3G	24.8	8.3	1.0	6.4	6.4	2.2	0.1	0.0	0.0	0.0	0.9	36.1
	3HA	14.3	8.5	2.4	16.2	5.1	1.1	0.1	0.0	0.0	0.0	0.3	7.8
	3HB	1.7	1.3	0.1	0.4	0.7	0.1	0.0	0.0	0.0	0.0	0.0	2.8
	3HC	2.5	2.5	0.0	0.0	1.4	0.4	0.0	0.0	0.0	0.0	0.2	5.0
	3HD1	1.1	0.1	0.0	0.0	1.0	1.1	0.1	0.0	0.0	0.0	1.7	2.6
	3HD2	0.5	0.6	0.0	0.0	2.2	1.9	0.4	0.0	0.0	0.0	3.5	2.6
	3J	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	3K	2.7	2.2	0.0	1.1	0.3	0.0	0.0	0.0	0.0	0.0	0.2	0.4
	3LA	4.8	2.9	1.5	3.9	22.5	3.6	1.7	0.4	0.2	4.0	16.2	3.9
	3LB	2.1	0.6	0.0	0.1	4.0	0.4	0.1	0.0	0.0	5.0	11.8	1.2
	3MA-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	3MA-2	2.4	1.2	0.1	0.8	0.5	0.1	0.1	0.1	0.1	0.1	1.8	2.2
	3MB	0.9	0.4	0.0	0.0	1.9	0.2	0.1	0.0	0.0	0.3	3.1	0.3
	3MC	0.9	0.1	0.0	0.0	5.8	0.4	0.3	0.1	0.0	3.4	6.1	0.4
	3MD1	0.0	0.0	0.0	0.0	2.2	0.3	0.1	0.0	0.0	1.5	2.0	0.0
	3MD2	1.7	0.1	0.0	0.2	22.4	3.0	1.0	0.1	0.0	6.8	6.6	0.6
	3N	0.1	0.0	0.0	0.0	1.4	0.2	0.1	0.0	0.0	0.6	0.6	0.1

Table 5.4.4 Future Monthly Average Naturalised River Discharge by Sub-basin (3/3)

(Unit: m^3/s)

CA	Sub-basin	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TCA	4AA	0.0	0.7	0.2	0.9	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.4
	4AB	8.5	4.9	5.2	14.4	26.3	6.9	3.8	3.3	3.0	5.1	12.6	13.8
	4AC	10.5	6.4	6.4	16.2	29.7	10.0	5.5	4.2	3.6	6.2	14.0	13.9
	4AD	6.2	2.8	2.6	12.1	23.6	6.7	2.2	0.8	0.7	3.0	10.1	9.4
	4BA	10.1	5.3	5.6	20.8	35.3	10.8	5.1	3.2	2.9	7.1	17.9	16.4
	4BB	4.9	2.7	2.8	9.5	17.6	4.7	2.3	1.8	1.6	2.3	7.1	7.4
	4BC	11.3	8.0	9.0	23.2	32.0	11.3	7.5	6.5	6.0	10.2	19.8	17.3
	4BD	0.0	0.0	0.0	0.5	1.1	0.0	0.0	0.0	0.0	0.0	0.3	0.1
	4BE	18.1	12.5	13.8	37.9	53.4	18.0	11.5	9.8	9.0	15.7	31.8	28.2
	4BF	15.1	9.0	9.1	32.6	46.5	15.1	7.8	5.8	5.0	9.4	24.7	24.0
	4BG	3.4	1.5	1.3	10.3	11.6	1.4	0.0	0.0	0.0	0.2	4.7	5.5
	4CA	4.8	1.5	0.8	6.0	11.3	2.3	0.1	0.0	0.0	0.0	2.7	6.2
	4CB	10.5	6.6	6.8	24.9	33.9	11.9	6.0	3.7	3.2	7.6	19.5	17.8
	4CC	5.6	3.3	3.1	15.8	21.2	5.6	1.6	0.5	0.3	2.6	10.4	10.3
	4DA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	4DB	2.6	0.3	0.4	4.8	9.8	0.0	0.0	0.0	0.0	0.0	1.3	2.4
	4DC	22.0	12.8	13.6	47.8	58.7	15.8	10.7	9.8	9.3	13.6	39.2	35.3
	4DD	9.4	5.5	5.7	21.1	25.4	7.0	4.3	3.8	3.6	6.6	19.8	16.3
	4DE	3.5	1.6	0.5	3.3	5.7	1.3	0.4	0.3	0.2	0.1	1.9	4.7
	4EA	6.7	2.3	0.6	4.2	10.2	3.0	0.3	0.0	0.0	0.0	1.7	7.8
	4EB	42.6	22.0	21.2	64.8	69.8	22.9	16.5	15.1	14.3	25.3	83.7	75.9
	4EC	45.4	22.2	22.7	88.8	96.2	21.3	14.3	13.5	12.7	30.2	98.7	79.3
	4ED	9.7	3.3	1.3	21.3	24.2	2.1	0.0	0.0	0.0	1.9	19.6	20.2
	4FA	66.9	22.7	6.5	59.5	65.8	4.9	0.0	0.0	0.0	0.0	51.2	116.9
	4FB	85.7	41.0	36.2	104.2	131.5	36.1	27.7	26.1	24.7	40.6	155.6	162.9
	4GA	33.2	9.2	3.0	35.6	60.9	9.7	1.7	0.2	0.0	3.9	82.4	92.2
	4GB	42.9	16.2	11.2	19.5	45.7	15.2	10.6	9.7	9.1	7.2	76.4	91.5
	4GC	31.7	6.3	1.3	1.9	18.3	6.0	1.2	0.4	0.2	0.0	47.4	68.8
	4GD	9.9	2.8	0.4	0.0	10.3	4.6	0.7	0.1	0.0	0.0	0.1	10.6
	4GE	30.6	6.7	1.3	0.4	19.8	9.2	1.9	0.7	0.3	0.1	0.7	32.4
	4GF	31.6	4.3	0.7	0.0	11.0	6.0	1.1	0.2	0.0	0.0	0.1	21.3
	4GG	152.5	28.2	5.2	12.1	32.4	18.1	4.2	1.3	0.5	0.3	7.3	137.4
	4HA	33.9	11.1	2.8	0.1	23.1	27.3	5.4	0.6	0.0	0.0	2.2	32.2
	4HB	69.9	16.6	6.7	21.5	18.0	5.4	2.8	1.5	1.0	1.1	24.3	76.3
	4HC	59.2	16.1	4.6	2.1	1.8	0.8	0.4	0.3	0.3	0.2	0.7	18.3
	4JA	4.0	3.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.5
	4JB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	4KA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	4KB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ENNCA	5AA	5.2	2.5	2.0	8.7	11.6	6.1	8.1	10.7	7.2	5.4	7.4	6.9
	5AB	2.0	0.8	0.6	3.9	4.7	2.1	2.9	3.4	2.2	2.0	3.2	2.6
	5AC	2.9	0.7	0.2	3.5	5.9	1.8	1.6	2.1	1.0	0.7	2.8	3.2
	5AD	1.7	0.5	0.2	1.6	3.1	0.8	0.8	1.1	0.7	0.5	1.6	2.1
	5BA	2.1	1.0	0.8	2.8	7.3	2.0	0.7	0.5	0.4	0.9	3.1	3.1
	5BB	4.3	1.9	1.7	7.8	14.4	4.1	1.8	1.4	1.3	3.2	7.9	6.7
	5BC-1	11.2	4.4	3.3	15.4	31.1	8.5	5.1	5.0	4.1	6.0	17.4	17.3
	5BC-2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	5BD	3.7	1.8	1.5	4.9	7.3	3.1	3.2	3.6	2.8	2.7	4.7	4.7
	5BE	12.2	3.8	4.3	19.7	26.9	5.8	1.4	0.9	0.7	6.6	30.3	26.3
	5CA	4.8	2.0	1.9	13.1	11.0	5.3	3.7	5.8	2.9	1.7	6.2	7.9
	5CB	2.3	0.5	0.1	9.2	3.8	1.0	0.5	0.4	0.3	0.1	1.4	4.6
	5CC	2.6	0.6	0.3	11.8	7.3	1.8	0.6	0.5	0.5	0.2	3.0	6.4
	5DA	30.0	9.3	7.9	40.6	34.8	4.8	1.6	0.9	0.6	10.9	67.6	68.7
	5DB	7.0	2.2	0.8	3.6	3.5	0.8	0.3	0.1	0.0	0.1	4.3	8.7
	5DC	2.4	0.7	0.3	1.7	2.7	1.4	0.9	0.7	0.6	0.4	1.5	3.4
	5DD	2.7	0.7	0.3	3.2	2.3	0.9	0.4	0.5	0.5	0.2	0.9	3.9
	5EA	27.9	0.2	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.8	92.4	67.2
	5EB	33.1	0.7	0.0	6.6	15.5	0.9	0.0	0.0	0.0	3.1	149.6	98.5
	5EC	33.1	0.7	0.5	12.6	38.7	5.3	3.1	2.1	1.4	2.7	101.6	80.0
	5ED	67.0	17.8	5.6	16.7	52.8	2.8	0.0	0.0	0.0	0.0	151.8	211.6
	5FA	48.4	10.4	4.6	1.6	0.0	0.0	0.0	0.0	0.0	0.0	5.0	103.1
	5FB	10.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.5	26.7
	5G	33.1	0.7	0.0	6.6	15.5	0.9	0.0	0.0	0.0	3.1	149.6	98.5
	5HA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.1	5.7	1.0
	5HB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.3	7.2	0.7
	5J	44.0	13.9	7.4	46.7	129.2	36.8	16.7	7.9	4.0	15.0	130.9	87.6

Source: JICA Study Team

Table 6.2.1 Selection of Stations for Frequency Analysis Based on Data Availability (1/2)

Numbers of valid years of which data availability is more than the criteria.

Annual Data Available	1AD02 Malakisi	1AH01 Sio	1BD02 Large Zoia	1BG07 Rongai	1CE01 Kipkaren	1EE01 Nzoia at Ruambwa	1EF01	1EG02 Wuoroya	1FC01 Kimondi	1FE01 Yala
10%	17	26	20	27	15	13	26	20	19	19
20%	16	26	20	27	13	10	26	20	19	18
30%	15	26	20	26	12	10	26	20	18	18
40%	14	25	19	23	11	10	26	20	18	18
50%	14	24	19	23	10	9	26	17	18	18
60%	13	22	17	22	9	7	25	16	17	17
70%	11	21	16	22	8	6	24	13	14	14
80%	8	20	12	19	7	6	21	9	14	14
90%	4	20	12	12	4	5	19	3	14	12
100%	2	7	6	5	2	2	17	2	9	12

Annual Data Available	1FG01 Yala	1FG02 Yala	1GB05 Ainamatua	1GC04 Tugenon	1GD03 Nyando	1GD07 Nyando	1GG01 Namuting	1JG01 Sondu	1KB05 Gucha Migori	1KC03 Migori
10%	22	18	24	29	22	15	26	12	21	21
20%	21	17	22	29	22	15	25	12	21	21
30%	21	17	21	27	21	14	25	12	17	21
40%	21	17	21	27	20	14	24	12	17	20
50%	20	17	21	27	20	14	24	11	17	19
60%	19	14	20	26	18	14	23	10	17	18
70%	18	14	18	25	14	14	22	10	15	18
80%	11	13	15	23	11	14	21	9	15*	17*
90%	8	10	10	22	8	9	20	7	10	16
100%	3	4	2	15	3	2	15	6	8	13

Annual Data Available	1LA03 Nyangores	2B07 Suam	2B33 Suam	2C07 Ndo	2C16 Kerio	2EE07 Perkerra	2K06 Seyabei	3BA32 Nairobi	3BC08 Ruiru	3DA02 Athi Munyu
10%	27	13	16	12	10	9	19	8	14	23
20%	27	12	15	10	10	9	18	8	14	22
30%	27	12	15	10	10	9	18	8	14	21
40%	26	10	15	7	10	9	18	6	14	20
50%	25	10	15	5	8	9	18	5	14	19
60%	24	10	14	5	8	9	16	5	14	17
70%	24	7	14	3	7	9	13	4	12	17
80%	22	6	13	2	6	7	13	3	12	16
90%	17	3	9	0	6	5	9	3	8	13
100%	4	1	7	0	3	2	5	0	3	2

Annual Data Available	3HA12 Sabaki Cableway	4BC02 Tana Sagana	4BE01 Maragua	4BE03 Irati	4CA02 Chania	4CB04 Thika	4DA10 Thiba	4DC03 Rupingazi	4EA07 Mutonga	4F13 Grand Falls
10%	8	24	30	18	24	30	25	21	23	23
20%	7	24	29	17	24	30	24	21	23	23
30%	7	24	29	17	24	30	22	20	23	23
40%	6	24	27	17	24	28	22	20	23	21
50%	5	22	27	17	22	28	22	19	21	21
60%	3	21	27	15	21	28	22	19	18	21
70%	2	20	25	15	19	28	19	16	18	21
80%	1	18	24	13	14	21	18	16	18	16
90%	0	13	22	11	8	15	11	13	12	11
100%	0	1	11	10	0	1	2	0	9	1

Note1: The stations which has more than 15 years valid were selected for the subject of the frequency analysis. The valid year was defined which has more than 80% of data availability. The cells of selected stations are filled with light blue.

Note2: 1KB05 Gucha Migori and 1KC03 Migori are satisfied the standard selection mentioned in Note1. However, those are excluded for the seletion for the frequency analysis because there are strange discharge data of spike-like and difficult to find appropriate annual maximum discharge.

Source: JICA Study Team with original observed data by WRMA and MWI

Table 6.2.1 Selection of Stations for Frequency Analysis Based on Data Availability (2/2)

Numbers of valid years of which data availability is more than the criteria.

Annual Data Available	4G01	4G02	5AC10	5AC15	5BB02	5BC04	5E03
	Garissa	Garsen	Ewaso Narok	Ewaso Narok	Ewaso Ng'iro	Ewaso Ng'iro	Ewaso Ng'iro at Archers' Post
10%	30	16	29	28	29	28	24
20%	30	15	29	28	29	27	24
30%	30	14	29	28	29	21	23
40%	30	13	29	28	28	19	21
50%	29	11	25	26	27	18	21
60%	27	10	15	22	27	17	21
70%	26	8	15	15	27	12	20
80%	24	7	14	8	27	8	19
90%	23	4	10	7	25	6	13
100%	6	3	6	4	3	1	10

Note1: The stations which has more than 15 years valid were selected for the subject of the frequency analysis. The valid year was defined which has more than 80% of data availability. The cells of selected stations are filled with light blue.

Note2: 1KB05 Gucha Migori and 1KC03 Migori are satisfied the standard selection mentioned in Note1. However, those are excluded for the seletion for the frequency analysis because there are strange discharge data of spike-like and difficult to find appropriate annual maximum discharge.

Source: JICA Study Team with original observed data by WRMA and MWI

Table 6.2.2 Annual Maximum Flood Discharge Record (1/2)

(m^3/s)

	1AH01	1BG07	1EF01	1GB05	1GC04	1GG01	1LA03	3DA02	4BC02
Year	Sio	Rongai	Nzoia at Ruambwa	Ainamatua	Tugenon	Namuting	Nyangores	Athi Munyu	Tana Sagana
1980	46.71	6.88	292.94	10.63	4.47	9.61	19.62	217.59	106.86
1981	58.65	31.66	687.05	-	3.69	16.91	28.84	639.71	178.3
1982	60.75	25.91	774.91	-	3.1	18.96	28.35	-	303.89
1983	59.79	-	753.54	-	3.06	15.26	-	116.54	140.69
1984	51.64	8.94	-	-	0.42	5.18	-	116.24	63.02
1985	65.09	9.15	-	19.86	3.1	21.98	-	186.08	198.46
1986	-	-	288.82	14.75	3.85	9.12	11.7	548.59	194.18
1987	58.75	17.34	375.85	4.88	2.9	13.36	28.84	118.56	77.99
1988	62.41	31.66	920.45	21.14	3.2	24.14	28.76	721.79	359.73
1989	68.17	12.55	-	10.73	1.78	24.14	28.19	316.95	80.97
1990	65.06	11.73	538.40	10.63	5.62	24.13	28.76	316.77	112.35
1991	66.77	-	553.21	6.37	2.84	24.14	22.93	48.16	168.21
1992	46.04	17.04	774.10	21.15	4.68	24.14	28.43	175.98	49.33
1993	-	16.72	478.68	6.51	0.85	15.96	-	168.15	65.65
1994	63.79	-	611.66	13.34	-	24.14	-	-	211.2
1995	66.55	23.58	619.31	-	-	13.49	-	71.06	-
1996	65.06	-	389.90	-	-	21.93	28.35	-	-
1997	67.44	-	726.51	10.54	-	-	28.84	-	-
1998	-	-	693.59	12.76	-	19.85	28.84	-	-
1999	68.71	17.34	492.18	-	-	-	-	-	-
2000	-	21.11	415.52	-	0.71	10.93	11.7	-	-
2001	60.32	28.95	854.54	-	2.57	19.84	28.84	-	173.79
2002	68.82	6.31	862.72	-	1.05	12.5	28.76	-	238.44
2003	-	35.19	-	-	2.38	-	27.81	730.69	151.9
2004	-	-	-	-	0.96	-	-	382.56	-
2005	-	-	-	-	1.05	-	25	-	-
2006	71.98	20.36	976.48	11.96	3.45	-	28.15	-	-
2007	-	-	-	21.62	1.96	-	28.14	-	-
2008	-	-	-	-	-	-	18.96	-	-
2009	-	-	-	-	0.5	-	-	-	-
2010	-	-	-	-	-	-	-	-	-

Source: JICA Study Team with original observed data from WRMA and MWI

Table 6.2.2 Annual Maximum Flood Discharge Record (2/2)

(m³/s)

	4BE01	4CB04	4DA10	4DC03	4EA07	4F13	4G01	5BB02	5E03
Year	Maragua	Thika	Thiba	Rupingazi	Mutonga	Grand Falls	Garissa	Ewaso Ngiro	Ewaso Ng'iro at Archers' Post
1980	41.61	-	20.18	11.65	50.15	712.22	-	6.54	80.47
1981	158.88	64.95	44.89	21.13	76.57	809.95	596.17	11.03	371.84
1982	88.18	40.52	62.83	23.71	75.4	742.87	790.22	8.25	548.94
1983	82.44	24.86	56.74	17.21	69.29	592.95	487.59	4.88	86.81
1984	50.42	19.15	19.93	9.99	40.8	-	988.43	3.44	192.76
1985	103.87	44.04	38.63	23.65	57.52	621.79	656.97	4.45	169.67
1986	89.55	49.35	70.06	32.42	68.8	-	650.21	14.89	389.05
1987	31.08	15.77	41.56	17.9	40.89	-	203.83	8.6	169.02
1988	-	47.48	23.36	26.26	76.09	-	909.99	12.76	407.73
1989	86.01	49.77	26.97	16.68	91.51	-	832.26	7.39	480.4
1990	132.48	50.09	30.69	15.05	74.02	884.48	774.31	14.95	-
1991	-	36.01	117.29	24.77	-	346.03	401.09	3.48	50
1992	120.91	-	30	11.44	65.42	453.31	456.95	15	213.71
1993	34.88	15.64	52.41	22.88	64.7	250.39	388.1	11.83	291.6
1994	-	52.16	-	30.13	91.12	486.11	849.07	11.96	-
1995	-	41.21	87.34	-	82.82	-	540.19	3.06	185.87
1996	27.98	17.36	-	-	-	274.52	-	14.36	-
1997	205.75	60.4	-	-	92.7	-	-	15.38	-
1998	183.41	63.93	-	-	91.65	-	1,024.10	13.87	-
1999	-	-	17.65	-	-	-	613.76	2.78	-
2000	17.93	-	-	-	-	-	340.07	2.64	227.12
2001	-	-	-	-	-	-	-	9.49	95.13
2002	-	61.27	47.47	-	-	-	882.54	8.7	340.07
2003	479.22	-	-	-	-	-	-	15.75	-
2004	110.8	26.13	35.35	-	-	-	636.68	13.72	-
2005	71.79	-	-	-	-	219.86	-	-	-
2006	-	33.25	-	13.64	-	328.17	1,395.83	10.61	-
2007	84.7	-	-	-	-	237.13	729.63	2.34	-
2008	60.79	18.82	-	-	-	-	633.78	-	352.79
2009	64.44	-	-	-	-	311.46	511.78	-	133.55
2010	-	-	-	-	-	-	-	-	-

Source: JICA Study Team with original observed data from WRMA and MWI

Table 6.2.3 Probable Flood Discharge based on Observed Record

Station Code	Station Name	Evaluation of Fittness by SLSC						Validity *	Probable Flood Discharge			
		LP3	Gumbel	GEV	LN3	SQRT - ET	Best PDF		10 year RP	25 year RP	50 year RP	100 year RP
1AH01	Sio	0.14	0.10	0.04	0.08	0.10	GEV	invalid	70	71	71	71
1BG07	Rongai	0.06	0.04	0.03	0.04	0.05	GEV	valid	32	37	41	44
1EF01	Nzoia at Ruambwa	0.07	0.05	0.03	0.03	0.06	GEV	valid	899	986	1,036	1,075
1GB05	Ainamatua	0.07	0.06	0.06	0.05	0.06	LN3	invalid	20	24	26	28
1GC04	Tugenon	0.10	0.04	0.04	0.04	0.06	GEV	valid	5	5	6	6
1GG01	Namuting	0.14	0.09	0.04	0.08	0.09	GEV	invalid	25	26	27	27
1LA03	Nyangores	0.22	0.18	0.06	0.14	0.14	GEV	invalid	29	29	29	29
3DA02	Athi Munyu	0.04	0.05	0.05	0.04	0.05	LP3	valid	664	1,012	1,337	1,724
4BC02	Tana Sagana	0.04	0.03	0.03	0.03	0.03	Gumbel	valid	276	342	390	439
4BE01	Maragua	0.03	0.11	0.06	0.03	0.06	LP3	valid	211	310	399	504
4CB04	Thika	0.08	0.06	0.05	0.07	0.07	GEV	invalid	62	69	73	76
4DA10	Thiba	0.02	0.04	0.02	0.02	0.03	GEV	valid	79	105	128	154
4DC03	Rupingazi	0.05	0.04	0.03	0.04	0.05	GEV	valid	29	33	36	38
4EA07	Mutonga	0.11	0.07	0.04	0.07	0.08	GEV	valid	92	96	98	100
4F13	Grand Falls	0.05	0.05	0.05	0.05	0.05	GEV	invalid	804	980	1,109	1,235
4G01	Garissa	0.07	0.03	0.03	0.03	0.05	LN3	valid	1,018	1,183	1,299	1,411
5BB02	Ewaso Ng'iro	0.10	0.08	0.05	0.07	0.08	GEV	invalid	16	17	18	19
5 E03	Ewaso Ng'iro at Archers' Post	0.07	0.03	0.03	0.04	0.04	GEV	valid	454	556	627	694

Note; * SLSC > 0.04
Source: JICA Study Team

Table 6.3.1 Basin Codes and River Names

Catchment Area	Basin Code	River Name	Catchment Area	Basin Code	River Name
LVNCA	1	Ndate	ACA	1	Athi
LVNCA	2	Yala	ACA	2	Rare
LVNCA	3	Nzoia	ACA	3	Mwachi
LVNCA	4	Sio	ACA	4	Pemba
LVNCA	5	Alupe	ACA	5	Lake Jipe
LVNCA	6	Malikisi	ACA	6	Lake Amboseli
LVNCA	7	Malaba	ACA	7	Ramisi
LVSCA	1		ACA	8	
LVSCA	2	Asure	ACA	9	
LVSCA	3	Bololedi	ACA	10	
LVSCA	4	Meareu	ACA	11	Kombeni
LVSCA	5	Mara	ACA	12	
LVSCA	6	Migori	ACA	13	
LVSCA	7		ACA	14	
LVSCA	8	Lambwe	ACA	15	
LVSCA	9	Kitare	ACA	16	
LVSCA	10	Kabondo Awach	TCA	1	Tana
LVSCA	11	Sondu	TCA	2	Duldule
LVSCA	12	Nyando	TCA	3	Lac Garebey
LVSCA	13		TCA	4	Jelulu Fat
LVSCA	14	Kibos	ENNCA	1	Ewaso Ngiro
LVSCA	15		ENNCA	2	L.Ghorgani
LVSCA	16	Awach Seme	ENNCA	3	L.Sartumai
RVCA	1	Lake Natron	ENNCA	4	L.Bor
RVCA	2	Ewaso Ngiro South	ENNCA	5	
RVCA	3		ENCA	6	
RVCA	4	Lake Magadi	ENNCA	7	L.Haro
RVCA	5		ENNCA	8	
RVCA	6	Turoka	ENNCA	9	
RVCA	7		ENNCA	10	
RVCA	8		ENNCA	11	
RVCA	9		ENNCA	12	L.Shangila
RVCA	10		ENNCA	13	
RVCA	11				
RVCA	12	Kedong			
RVCA	13				
RVCA	14	Lake Naivasha			
RVCA	15	Lake Elmenteita			
RVCA	16	Lake Nakuru			
RVCA	17				
RVCA	18				
RVCA	19	Lake Bogoria			
RVCA	20	Lake Baringo			
RVCA	21	Suguta			
RVCA	22	Lake Turkana/Turkwel River			
RVCA	23				
RVCA	24				
RVCA	25				
RVCA	26	Tarach			

Souce: JICA Study Team

Table 6.3.2 Regional Area-Flood Curve (1/5)

LVN-2 Yala

Return Priod \ Date	Present (1981-2000)	Future (2021-2040)	Future (2046-2065)
10-year	$\log_{10} Q = -1.257 + 0.939 \log_{10} A$	$\log_{10} Q = -1.205 + 0.949 \log_{10} A$	$\log_{10} Q = -1.130 + 0.948 \log_{10} A$
25 year	$\log_{10} Q = -1.227 + 0.945 \log_{10} A$	$\log_{10} Q = -1.147 + 0.950 \log_{10} A$	$\log_{10} Q = -1.052 + 0.948 \log_{10} A$
50 year	$\log_{10} Q = -1.212 + 0.951 \log_{10} A$	$\log_{10} Q = -1.111 + 0.950 \log_{10} A$	$\log_{10} Q = -1.005 + 0.948 \log_{10} A$
100-year	$\log_{10} Q = -1.202 + 0.957 \log_{10} A$	$\log_{10} Q = -1.079 + 0.951 \log_{10} A$	$\log_{10} Q = -0.963 + 0.948 \log_{10} A$

LVN-3 Nzoia

Return Priod \ Date	Present (1981-2000)	Future (2021-2040)	Future (2046-2065)
10-year	$\log_{10} Q = -0.866 + 0.776 \log_{10} A$	$\log_{10} Q = -0.845 + 0.798 \log_{10} A$	$\log_{10} Q = -0.482 + 0.686 \log_{10} A$
25 year	$\log_{10} Q = -0.780 + 0.767 \log_{10} A$	$\log_{10} Q = -0.777 + 0.795 \log_{10} A$	$\log_{10} Q = -0.417 + 0.686 \log_{10} A$
50 year	$\log_{10} Q = -0.722 + 0.760 \log_{10} A$	$\log_{10} Q = -0.732 + 0.793 \log_{10} A$	$\log_{10} Q = -0.375 + 0.685 \log_{10} A$
100-year	$\log_{10} Q = -0.669 + 0.752 \log_{10} A$	$\log_{10} Q = -0.692 + 0.790 \log_{10} A$	$\log_{10} Q = -0.337 + 0.685 \log_{10} A$

LVN-6 Malikisi

Return Priod \ Date	Present (1981-2000)	Future (2021-2040)	Future (2046-2065)
10-year	$\log_{10} Q = -1.054 + 0.887 \log_{10} A$	$\log_{10} Q = -1.032 + 0.889 \log_{10} A$	$\log_{10} Q = -0.953 + 0.896 \log_{10} A$
25 year	$\log_{10} Q = -0.974 + 0.883 \log_{10} A$	$\log_{10} Q = -0.952 + 0.882 \log_{10} A$	$\log_{10} Q = -0.869 + 0.890 \log_{10} A$
50 year	$\log_{10} Q = -0.915 + 0.876 \log_{10} A$	$\log_{10} Q = -0.894 + 0.874 \log_{10} A$	$\log_{10} Q = -0.810 + 0.884 \log_{10} A$
100-year	$\log_{10} Q = -0.859 + 0.868 \log_{10} A$	$\log_{10} Q = -0.837 + 0.864 \log_{10} A$	$\log_{10} Q = -0.755 + 0.877 \log_{10} A$

LVN-7 Malaba

Return Priod \ Date	Present (1981-2000)	Future (2021-2040)	Future (2046-2065)
10-year	$\log_{10} Q = -1.233 + 0.998 \log_{10} A$	$\log_{10} Q = -1.185 + 0.991 \log_{10} A$	$\log_{10} Q = -1.143 + 0.999 \log_{10} A$
25 year	$\log_{10} Q = -1.178 + 0.997 \log_{10} A$	$\log_{10} Q = -1.128 + 0.990 \log_{10} A$	$\log_{10} Q = -1.079 + 0.998 \log_{10} A$
50 year	$\log_{10} Q = -1.146 + 0.997 \log_{10} A$	$\log_{10} Q = -1.095 + 0.990 \log_{10} A$	$\log_{10} Q = -1.040 + 0.998 \log_{10} A$
100-year	$\log_{10} Q = -1.120 + 0.997 \log_{10} A$	$\log_{10} Q = -1.068 + 0.990 \log_{10} A$	$\log_{10} Q = -1.005 + 0.999 \log_{10} A$

LVS-2 Asure

Return Priod \ Date	Present (1981-2000)	Future (2021-2040)	Future (2046-2065)
10-year	$\log_{10} Q = -1.492 + 1.125 \log_{10} A$	$\log_{10} Q = -1.566 + 1.221 \log_{10} A$	No valid function available
25 year	$\log_{10} Q = -1.397 + 1.135 \log_{10} A$	$\log_{10} Q = -1.333 + 1.182 \log_{10} A$	No valid function available
50 year	$\log_{10} Q = -1.341 + 1.142 \log_{10} A$	$\log_{10} Q = -1.182 + 1.157 \log_{10} A$	No valid function available
100-year	$\log_{10} Q = -1.295 + 1.149 \log_{10} A$	$\log_{10} Q = -1.048 + 1.134 \log_{10} A$	No valid function available

Souce: JICA Study Team

Table 6.3.2 Regional Area-Flood Curve (2/5)

LVS-5 Mara

Date / Return Priod	Present (1981-2000)	Future (2021-2040)	Future (2046-2065)
10-year	$\log_{10} Q = -1.083 + 0.934\log_{10} A$	$\log_{10} Q = -0.997 + 0.965\log_{10} A$	$\log_{10} Q = -1.042 + 1.011\log_{10} A$
25 year	$\log_{10} Q = -0.959 + 0.915\log_{10} A$	$\log_{10} Q = -0.940 + 0.974\log_{10} A$	$\log_{10} Q = -1.010 + 1.026\log_{10} A$
50 year	$\log_{10} Q = -0.874 + 0.899\log_{10} A$	$\log_{10} Q = -0.901 + 0.980\log_{10} A$	$\log_{10} Q = -0.991 + 1.035\log_{10} A$
100-year	$\log_{10} Q = -0.794 + 0.883\log_{10} A$	$\log_{10} Q = -0.865 + 0.984\log_{10} A$	$\log_{10} Q = -0.972 + 1.042\log_{10} A$

LVS-6 Migori

Date / Return Priod	Present (1981-2000)	Future (2021-2040)	Future (2046-2065)
10-year	$\log_{10} Q = -0.954 + 0.879\log_{10} A$	$\log_{10} Q = -0.872 + 0.877\log_{10} A$	$\log_{10} Q = -0.223 + 0.792\log_{10} A$
25 year	$\log_{10} Q = -0.905 + 0.890\log_{10} A$	$\log_{10} Q = -0.777 + 0.874\log_{10} A$	$\log_{10} Q = -0.131 + 0.793\log_{10} A$
50 year	$\log_{10} Q = -0.875 + 0.898\log_{10} A$	$\log_{10} Q = -0.709 + 0.871\log_{10} A$	$\log_{10} Q = -0.066 + 0.793\log_{10} A$
100-year	$\log_{10} Q = -0.850 + 0.906\log_{10} A$	$\log_{10} Q = -0.644 + 0.867\log_{10} A$	$\log_{10} Q = -0.001 + 0.792\log_{10} A$

LVS-10 Kabondo Awach

Date / Return Priod	Present (1981-2000)	Future (2021-2040)	Future (2046-2065)
10-year	$\log_{10} Q = -1.243 + 0.982\log_{10} A$	$\log_{10} Q = -1.093 + 0.993\log_{10} A$	$\log_{10} Q = -0.890 + 0.998\log_{10} A$
25 year	$\log_{10} Q = -1.184 + 0.982\log_{10} A$	$\log_{10} Q = -1.002 + 0.995\log_{10} A$	$\log_{10} Q = -0.804 + 0.999\log_{10} A$
50 year	$\log_{10} Q = -1.147 + 0.982\log_{10} A$	$\log_{10} Q = -0.940 + 0.995\log_{10} A$	$\log_{10} Q = -0.748 + 0.999\log_{10} A$
100-year	$\log_{10} Q = -1.114 + 0.982\log_{10} A$	$\log_{10} Q = -0.881 + 0.996\log_{10} A$	$\log_{10} Q = -0.698 + 1.000\log_{10} A$

LVS-11 Sondu

Date / Return Priod	Present (1981-2000)	Future (2021-2040)	Future (2046-2065)
10-year	$\log_{10} Q = -1.153 + 0.967\log_{10} A$	$\log_{10} Q = -1.019 + 0.950\log_{10} A$	$\log_{10} Q = -0.973 + 0.983\log_{10} A$
25 year	$\log_{10} Q = -1.108 + 0.967\log_{10} A$	$\log_{10} Q = -0.970 + 0.953\log_{10} A$	$\log_{10} Q = -0.919 + 0.988\log_{10} A$
50 year	$\log_{10} Q = -1.083 + 0.967\log_{10} A$	$\log_{10} Q = -0.940 + 0.955\log_{10} A$	$\log_{10} Q = -0.888 + 0.992\log_{10} A$
100-year	$\log_{10} Q = -1.064 + 0.968\log_{10} A$	$\log_{10} Q = -0.915 + 0.958\log_{10} A$	$\log_{10} Q = -0.862 + 0.997\log_{10} A$

LVS-12 Nyando

Date / Return Priod	Present (1981-2000)	Future (2021-2040)	Future (2046-2065)
10-year	$\log_{10} Q = -0.842 + 0.874\log_{10} A$	$\log_{10} Q = -0.841 + 0.906\log_{10} A$	$\log_{10} Q = -0.723 + 0.934\log_{10} A$
25 year	$\log_{10} Q = -0.782 + 0.872\log_{10} A$	$\log_{10} Q = -0.777 + 0.908\log_{10} A$	$\log_{10} Q = -0.650 + 0.936\log_{10} A$
50 year	$\log_{10} Q = -0.744 + 0.871\log_{10} A$	$\log_{10} Q = -0.736 + 0.909\log_{10} A$	$\log_{10} Q = -0.604 + 0.937\log_{10} A$
100-year	$\log_{10} Q = -0.710 + 0.869\log_{10} A$	$\log_{10} Q = -0.700 + 0.910\log_{10} A$	$\log_{10} Q = -0.562 + 0.938\log_{10} A$

Souce: JICA Study Team

Table 6.3.2 Regional Area-Flood Curve (3/5)

LVS-13

Date / Return Priod	Present (1981-2000)	Future (2021-2040)	Future (2046-2065)
10-year	$\log_{10} Q = -1.100 + 0.998 \log_{10} A$	$\log_{10} Q = -0.999 + 1.015 \log_{10} A$	No valid function available
25 year	$\log_{10} Q = -0.975 + 1.021 \log_{10} A$	$\log_{10} Q = -0.849 + 1.015 \log_{10} A$	No valid function available
50 year	$\log_{10} Q = -0.878 + 1.030 \log_{10} A$	$\log_{10} Q = -0.738 + 1.010 \log_{10} A$	No valid function available
100-year	$\log_{10} Q = -0.779 + 1.035 \log_{10} A$	$\log_{10} Q = -0.629 + 1.003 \log_{10} A$	No valid function available

LVS-14 Kibos

Date / Return Priod	Present (1981-2000)	Future (2021-2040)	Future (2046-2065)
10-year	$\log_{10} Q = -0.012 + 0.551 \log_{10} A$	$\log_{10} Q = -0.079 + 0.591 \log_{10} A$	No valid function available
25 year	$\log_{10} Q = -0.061 + 0.555 \log_{10} A$	$\log_{10} Q = -0.004 + 0.596 \log_{10} A$	No valid function available
50 year	$\log_{10} Q = -0.115 + 0.555 \log_{10} A$	$\log_{10} Q = -0.050 + 0.598 \log_{10} A$	No valid function available
100-year	$\log_{10} Q = -0.168 + 0.553 \log_{10} A$	$\log_{10} Q = -0.102 + 0.599 \log_{10} A$	No valid function available

LVS-16 Awach Seme

Date / Return Priod	Present (1981-2000)	Future (2021-2040)	Future (2046-2065)
10-year	$\log_{10} Q = -1.374 + 0.996 \log_{10} A$	$\log_{10} Q = -1.320 + 0.997 \log_{10} A$	No valid function available
25 year	$\log_{10} Q = -1.276 + 0.996 \log_{10} A$	$\log_{10} Q = -1.218 + 0.997 \log_{10} A$	No valid function available
50 year	$\log_{10} Q = -1.215 + 0.996 \log_{10} A$	$\log_{10} Q = -1.155 + 0.996 \log_{10} A$	No valid function available
100-year	$\log_{10} Q = -1.162 + 0.996 \log_{10} A$	$\log_{10} Q = -1.100 + 0.996 \log_{10} A$	No valid function available

RV-2 Ewaso Ngiro(South)

Date / Return Priod	Present (1981-2000)	Future (2021-2040)	Future (2046-2065)
10-year	$\log_{10} Q = -1.619 + 1.016 \log_{10} A$	$\log_{10} Q = -1.892 + 1.134 \log_{10} A$	No valid function available
25 year	$\log_{10} Q = -1.469 + 0.996 \log_{10} A$	$\log_{10} Q = -1.601 + 1.077 \log_{10} A$	No valid function available
50 year	$\log_{10} Q = -1.374 + 0.983 \log_{10} A$	$\log_{10} Q = -1.403 + 1.037 \log_{10} A$	No valid function available
100-year	$\log_{10} Q = -1.290 + 0.969 \log_{10} A$	$\log_{10} Q = -1.219 + 0.998 \log_{10} A$	No valid function available

RV-12 Kedong

Date / Return Priod	Present (1981-2000)	Future (2021-2040)	Future (2046-2065)
10-year	$\log_{10} Q = -0.206 + 0.593 \log_{10} A$	$\log_{10} Q = -0.287 + 0.648 \log_{10} A$	No valid function available
25 year	$\log_{10} Q = -0.234 + 0.636 \log_{10} A$	$\log_{10} Q = -0.291 + 0.688 \log_{10} A$	No valid function available
50 year	$\log_{10} Q = -0.257 + 0.666 \log_{10} A$	$\log_{10} Q = -0.297 + 0.714 \log_{10} A$	No valid function available
100-year	$\log_{10} Q = -0.282 + 0.693 \log_{10} A$	$\log_{10} Q = -0.305 + 0.738 \log_{10} A$	No valid function available

Souce: JICA Study Team

Table 6.3.2 Regional Area-Flood Curve (4/5)

RV-14 Lake Naivasha

Date / Return Priod	Present (1981-2000)	Future (2021-2040)	Future (2046-2065)
10-year	$\log_{10} Q = -0.647 + 0.773 \log_{10} A$	$\log_{10} Q = -0.325 + 0.704 \log_{10} A$	$\log_{10} Q = -0.230 + 0.714 \log_{10} A$
25 year	$\log_{10} Q = -0.585 + 0.781 \log_{10} A$	$\log_{10} Q = -0.253 + 0.710 \log_{10} A$	$\log_{10} Q = -0.173 + 0.723 \log_{10} A$
50 year	$\log_{10} Q = -0.551 + 0.787 \log_{10} A$	$\log_{10} Q = -0.211 + 0.715 \log_{10} A$	$\log_{10} Q = -0.140 + 0.728 \log_{10} A$
100-year	$\log_{10} Q = -0.524 + 0.794 \log_{10} A$	$\log_{10} Q = -0.177 + 0.720 \log_{10} A$	$\log_{10} Q = -0.112 + 0.733 \log_{10} A$

RV-19 Lake Bogoria

Date / Return Priod	Present (1981-2000)	Future (2021-2040)	Future (2046-2065)
10-year	$\log_{10} Q = -1.134 + 0.923 \log_{10} A$	$\log_{10} Q = -1.092 + 0.960 \log_{10} A$	$\log_{10} Q = -0.857 + 0.945 \log_{10} A$
25 year	$\log_{10} Q = -0.937 + 0.873 \log_{10} A$	$\log_{10} Q = -0.945 + 0.941 \log_{10} A$	$\log_{10} Q = -0.761 + 0.947 \log_{10} A$
50 year	$\log_{10} Q = -0.802 + 0.835 \log_{10} A$	$\log_{10} Q = -0.846 + 0.925 \log_{10} A$	$\log_{10} Q = -0.699 + 0.947 \log_{10} A$
100-year	$\log_{10} Q = -0.676 + 0.798 \log_{10} A$	$\log_{10} Q = -0.753 + 0.909 \log_{10} A$	$\log_{10} Q = -0.643 + 0.947 \log_{10} A$

RV-20 Lake Baringo

Date / Return Priod	Present (1981-2000)	Future (2021-2040)	Future (2046-2065)
10-year	$\log_{10} Q = -0.832 + 0.783 \log_{10} A$	$\log_{10} Q = -1.098 + 0.914 \log_{10} A$	$\log_{10} Q = -0.904 + 0.921 \log_{10} A$
25 year	$\log_{10} Q = -0.801 + 0.792 \log_{10} A$	$\log_{10} Q = -0.933 + 0.883 \log_{10} A$	$\log_{10} Q = -0.824 + 0.930 \log_{10} A$
50 year	$\log_{10} Q = -0.787 + 0.798 \log_{10} A$	$\log_{10} Q = -0.823 + 0.861 \log_{10} A$	$\log_{10} Q = -0.777 + 0.937 \log_{10} A$
100-year	$\log_{10} Q = -0.776 + 0.803 \log_{10} A$	$\log_{10} Q = -0.719 + 0.839 \log_{10} A$	$\log_{10} Q = -0.736 + 0.944 \log_{10} A$

AT-1 Athi

Date / Return Priod	Present (1981-2000)	Future (2021-2040)	Future (2046-2065)
10-year	$\log_{10} Q = -0.928 + 0.826 \log_{10} A$	$\log_{10} Q = -0.681 + 0.830 \log_{10} A$	$\log_{10} Q = -0.757 + 0.930 \log_{10} A$
25 year	$\log_{10} Q = -0.902 + 0.895 \log_{10} A$	$\log_{10} Q = -0.664 + 0.885 \log_{10} A$	$\log_{10} Q = -0.673 + 0.937 \log_{10} A$
50 year	$\log_{10} Q = -0.891 + 0.941 \log_{10} A$	$\log_{10} Q = -0.660 + 0.924 \log_{10} A$	$\log_{10} Q = -0.622 + 0.942 \log_{10} A$
100-year	$\log_{10} Q = -0.885 + 0.983 \log_{10} A$	$\log_{10} Q = -0.661 + 0.960 \log_{10} A$	$\log_{10} Q = -0.578 + 0.946 \log_{10} A$

TN-1 Tana

Date / Return Priod	Present (1981-2000)	Future (2021-2040)	Future (2046-2065)
10-year	$\log_{10} Q = -0.589 + 0.854 \log_{10} A$	$\log_{10} Q = -0.562 + 0.878 \log_{10} A$	$\log_{10} Q = -0.714 + 0.965 \log_{10} A$
25 year	$\log_{10} Q = -0.539 + 0.873 \log_{10} A$	$\log_{10} Q = -0.498 + 0.893 \log_{10} A$	$\log_{10} Q = -0.661 + 0.978 \log_{10} A$
50 year	$\log_{10} Q = -0.513 + 0.887 \log_{10} A$	$\log_{10} Q = -0.462 + 0.905 \log_{10} A$	$\log_{10} Q = -0.630 + 0.986 \log_{10} A$
100-year	$\log_{10} Q = -0.493 + 0.901 \log_{10} A$	$\log_{10} Q = -0.433 + 0.916 \log_{10} A$	$\log_{10} Q = -0.603 + 0.994 \log_{10} A$

Souce: JICA Study Team

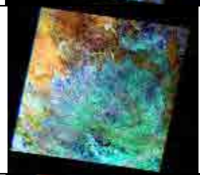
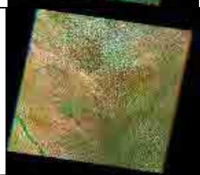
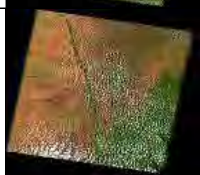
Table 6.3.2 Regional Area-Flood Curve (5/5)

EN-1 Ewaso Ngiro

Return Priod \ Date	Present (1981-2000)	Future (2021-2040)	Future (2046-2065)
10-year	$\log_{10} Q = -1.150 + 0.891 \log_{10} A$	$\log_{10} Q = -0.980 + 0.868 \log_{10} A$	$\log_{10} Q = -0.703 + 0.840 \log_{10} A$
25 year	$\log_{10} Q = -0.957 + 0.889 \log_{10} A$	$\log_{10} Q = -0.868 + 0.877 \log_{10} A$	$\log_{10} Q = -0.766 + 0.901 \log_{10} A$
50 year	$\log_{10} Q = -0.835 + 0.888 \log_{10} A$	$\log_{10} Q = -0.801 + 0.884 \log_{10} A$	$\log_{10} Q = -0.813 + 0.942 \log_{10} A$
100-year	$\log_{10} Q = -0.728 + 0.888 \log_{10} A$	$\log_{10} Q = -0.743 + 0.891 \log_{10} A$	$\log_{10} Q = -0.859 + 0.980 \log_{10} A$

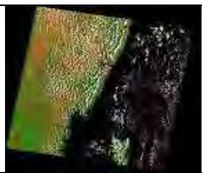
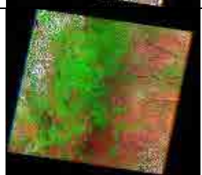
Souce: JICA Study Team

Table 8.1.1 List of Landsat TM data (2008 – 2010) Used in This Study (1/5)

Path/Row	Date	Average Cloud Cover (%)	Preview	Remark
166/057	2010-01-25	0		The image is clear
166/058	2010-02-10	0		The image is clear
166/059	2003-03-03	0		The image is clear
	2010-01-25	2		The clouds are concentrated at the lower left corner of the image, which is about 8%. Therefore, a Landsat image of 2003 is used for checking the areas covered by clouds.
166/060	2002-12-29	1		The image is clear
	2010-02-10	3		The clouds are scattered at the whole image. Therefore, a Landsat image of 2002 is used for checking the areas covered by clouds.
166/061	2010-02-10	8		The cloud cover percentage of 8% is the lowest among the available Landsat images for the period from 2008 to 2010
166/062	2000-01-22	8		Most of clouds are located above the ocean, and some parts near the coastal area.
	2009-12-08	17		Despite of being the cloud cover percentage is high, it is the lowest among the available Landsat images for the period from 2008 to 2010

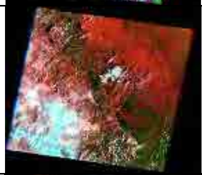
Source : JICA Study Team obtained from GLCF homepage

Table 8.1.1 List of Landsat TM data (2008 – 2010) Used in This Study (2/5)

Path/Row	Date	Average Cloud Cover (%)	Preview	Remark
166/063	2010-02-10	9		Despite of being the cloud cover percentage is high, it is the lowest among the available Landsat images for the period from 2008 to 2010
167/057	2010-02-01	0		The image is clear
167/058	2010-02-01	0		The image is clear
167/059	2010-02-01	0		Generally, the image is clear, however, there are some clouds concentrated in the lower right side of the image.
167/060	2003-04-11	0		The image is clear
	2009-06-06	1		Most of the clouds are concentrated at the lower part of the image representing a total of 5% of this part of the image.
167/061	2009-11-13	3		The clouds are concentrated at the upper left quadrant of the image representing a total of 8.5% of this part. However, it is the lowest among the available Landsat images during the period from 2008 to 2010
167/062	2003-02-06	4		Most of the clouds exist at the lower left quadrant of the image representing a total of 11% of this part of the image.
	2008-09-07	8		Most of the clouds are concentrated at the left part of the image representing a total of 9% of this part of the image.

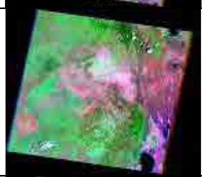
Source : JICA Study Team obtained from GLCF homepage

Table 8.1.1 List of Landsat TM data (2008 – 2010) Used in This Study (3/5)

Path/Row	Date	Average Cloud Cover (%)	Preview	Remark
167/063	2003-02-06	2		The image is clear
	2009-11-13	37		The majority of the clouds exist at the lower left quadrant of the image representing a total of 94% of this part of the image. However, it is located outside the national boundary of Kenya.
168/057	2010-02-08	18		The majority of the clouds exist outside the national boundary of Kenya.
168/058	2010-08-19	0		The image is clear
168/059	2010-08-19	2		The image is clear
168/060	2010-02-08	10		Most of the clouds are concentrated in the lower right quadrant of the image.
	2010-08-19	15		Most of the clouds are concentrated in the central and upper left parts of the image.
168/061	2010-08-19	0		The image is clear
168/062	2010-08-19	13		The clouds exist at the lower right quadrant, however, it is located outside the national boundary of Kenya

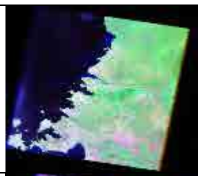
Source : JICA Study Team obtained from GLCF homepage

Table 8.1.1 List of Landsat TM data (2008 – 2010) Used in This Study (4/5)

Path/Row	Date	Average Cloud Cover (%)	Preview	Remark
169/057	2010-01-30	0		The image is clear
169/058	2010-01-30	0		The image is clear
169/059	2010-01-30	0		The image is clear
169/060	2010-01-30	0		The image is clear
169/061	2010-01-30	0		The image is clear
170/057	2010-12-23	0		The image is clear
170/058	2009-06-11	0		The image is clear
170/059	2009-06-11	0		The image is clear
170/060	2009-06-11	0		The image is clear

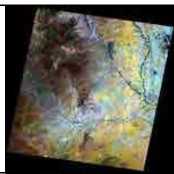
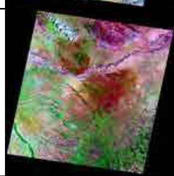
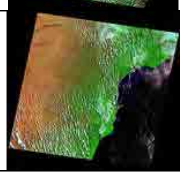
Source : JICA Study Team obtained from GLCF homepage

Table 8.1.1 List of Landsat TM data (2008 – 2010) Used in This Study (5/5)

Path/Row	Date	Average Cloud Cover (%)	Preview	Remark
170/061	2009-06-11	0		The image is clear
171/057	2010-01-12	0		The image is clear

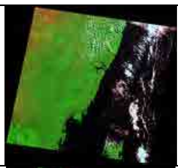
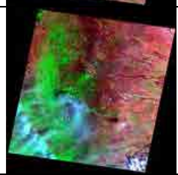
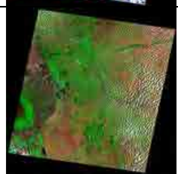
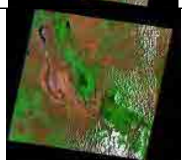
Source : JICA Study Team obtained from GLCF homepage

Table 8.1.2 List of Landsat TM data (1986 – 1988) Used in This Study (1/4)

Path/Row	Date	Average Cloud Cover (%)	Preview	Remark
166/057	1986-01-23	0		The image is clear
166/058	1986-01-23	0		The image is clear
166/059	1986-01-23	0		The image is clear
166/060	1987-01-26	0		The image is clear
166/061	1987-01-26	10		The clouds are mainly located at the lower part of the image.
166/062	1987-09-07	10		The clouds are located at the right part of the image.

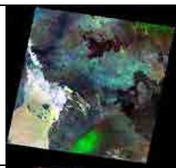
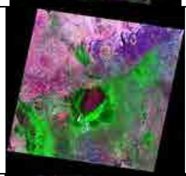
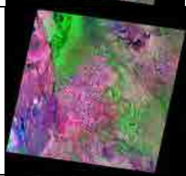
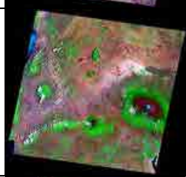
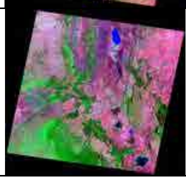
Source : JICA Study Team obtained from GLCF homepage

Table 8.1.2 List of Landsat TM data (1986 – 1988) Used in This Study (2/4)

Path/Row	Date	Average Cloud Cover (%)	Preview	Remark
166/063	1986-06-16	30		The clouds are mainly located at the right part of the image, mainly above the ocean.
167/057	1986-01-14	0		The image is clear
167/058	1986-01-14	0		The image is clear
167/059	1986-01-14	0		The image is clear
167/060	1986-08-26	0		The image is clear
167/061	1986-01-14	10		The clouds exist at the lower left quadrant of the image.
167/062	1987-02-18	10		The clouds are located at the right part of the image.
167/063	1987-02-02	20		The clouds are located at the right part of the image. However, only the upper right quadrant is located with the National boundary of Kenya.
168/057	1986-01-05	0		The image is clear

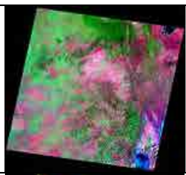
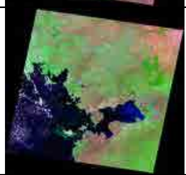
Source : JICA Study Team obtained from GLCF homepage

Table 8.1.2 List of Landsat TM data (1986 – 1988) Used in This Study (3/4)

Path/Row	Date	Average Cloud Cover (%)	Preview	Remark
168/058	1986-01-05	0		The image is clear
168/059	1986-01-05	0		The image is clear
168/060	1987-02-25	0		The image is clear
168/061	1987-02-25	0		The image is clear
168/062	1987-02-25	0		The image is clear
169/057	1986-01-28	20		The clouds exist at the lower right quadrant of the image.
169/058	1986-08-28	0		The image is clear
169/059	1986-01-28	0		The image is clear
169/060	1986-01-28	0		The image is clear

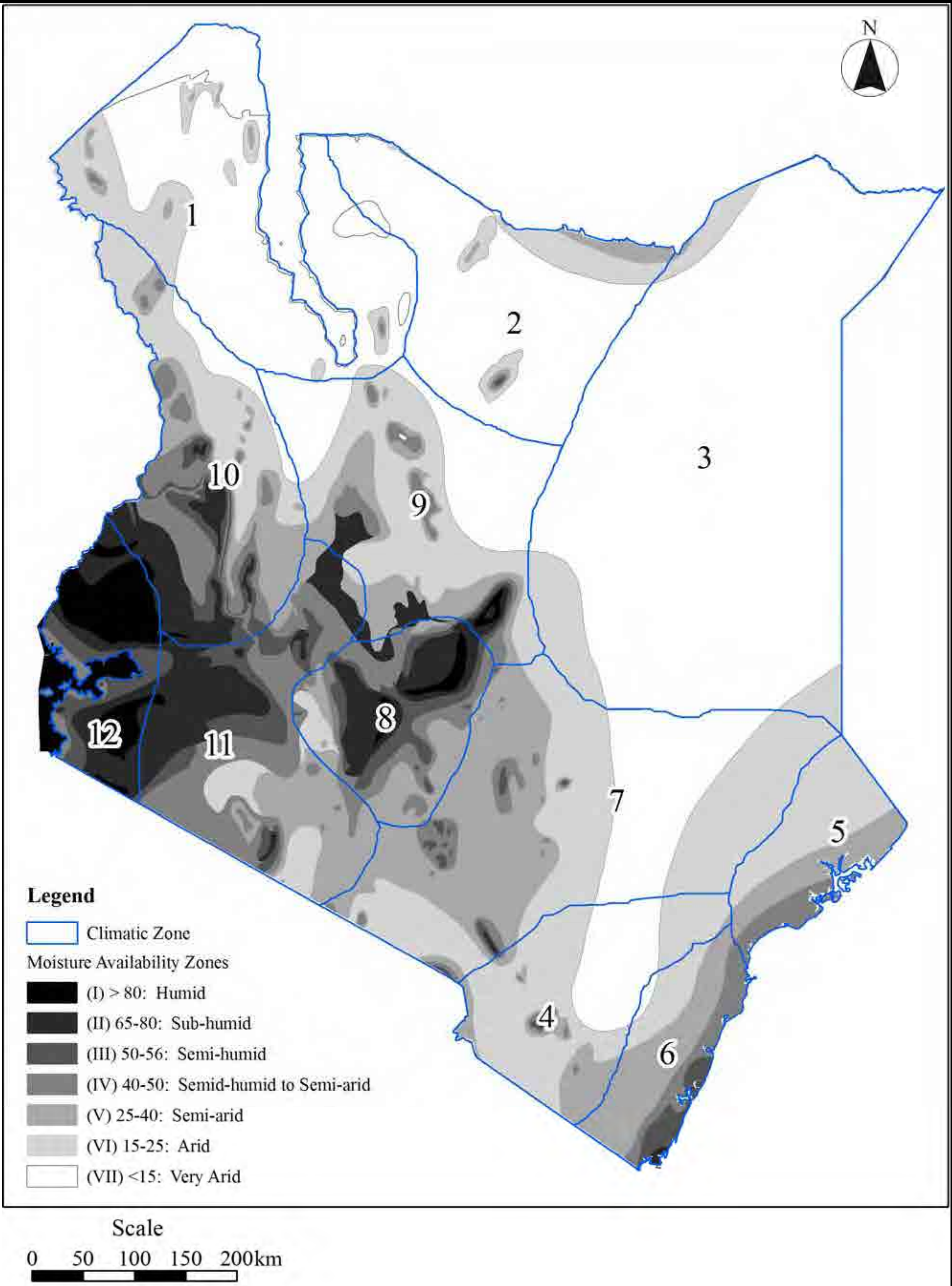
Source : JICA Study Team obtained from GLCF homepage

Table 8.1.2 List of Landsat TM data (1986 – 1988) Used in This Study (4/4)

Path/Row	Date	Average Cloud Cover (%)	Preview	Remark
169/061	1986-01-28	0		The image is clear
170/057	1986-01-03	0		The image is clear
170/058	1986-01-03	0		The image is clear
170/059	1988-02-18	0		The image is clear
170/060	1986-03-08	0		The image is clear
170/061	1986-10-18	0		The image is clear
171/057	1987-01-13	0		The image is clear

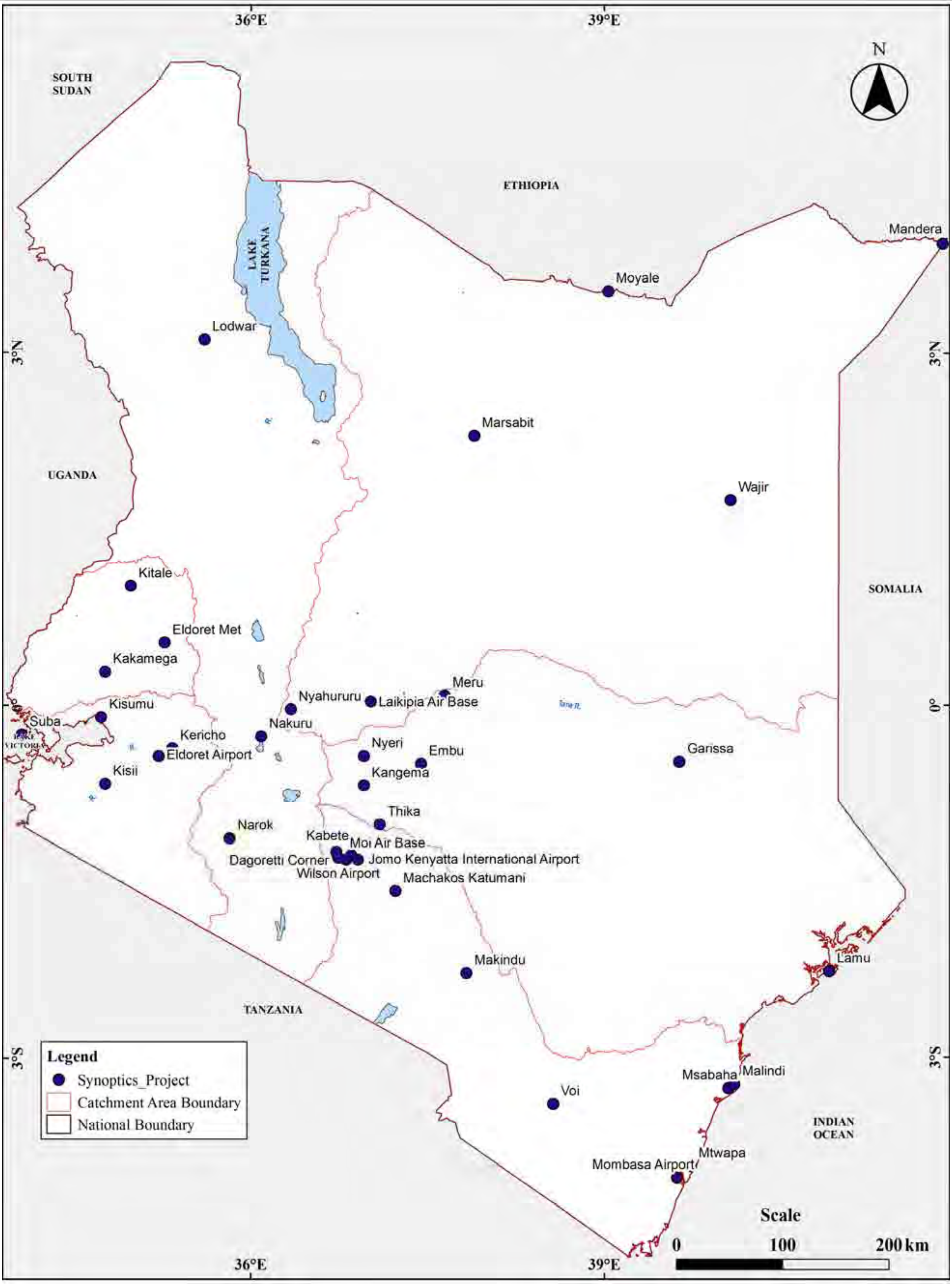
Source : JICA Study Team obtained from GLCF homepage

Figures



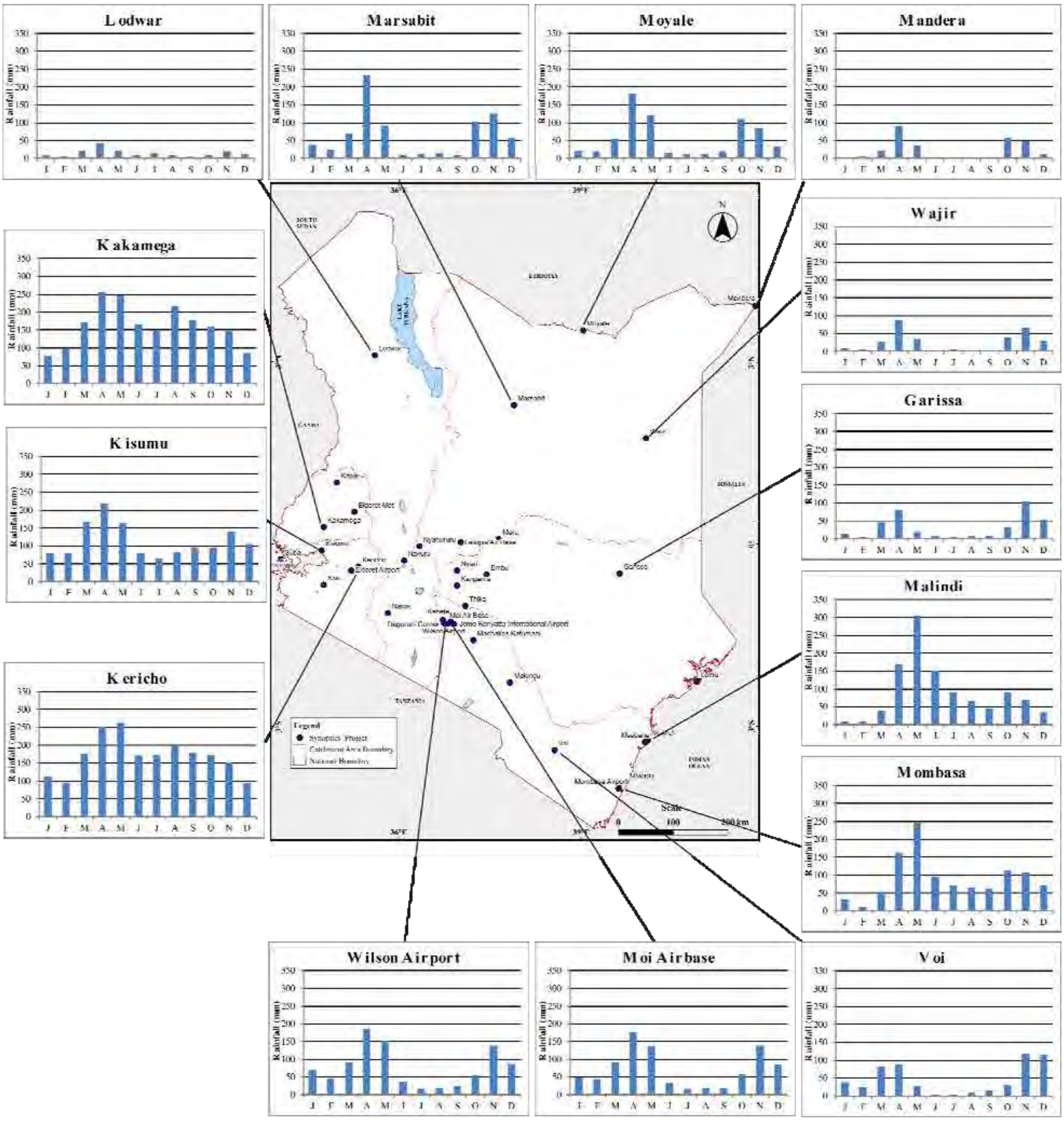
ource: UNEP/GRID database derived from the Exploratory Soil Survey Report number E1, Kenya Soil survey, Nairobi 1982

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 1.1.1** **Climatic Zones of Kenya**
JAPAN INTERNATIONAL COOPERATION AGENCY	



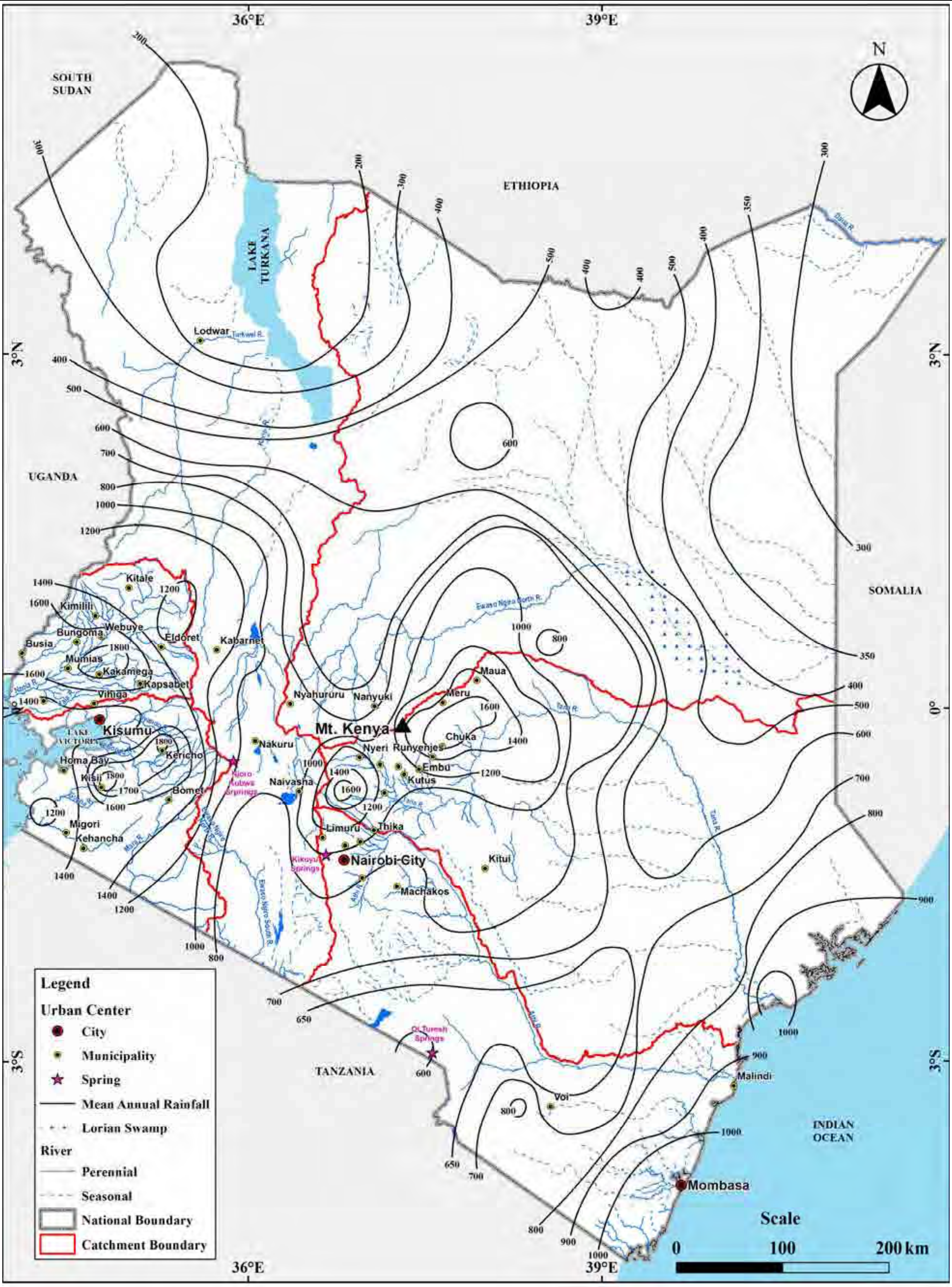
Source: JICA Study Team

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 1.2.1 Location Map of Synoptic**
JAPAN INTERNATIONAL COOPERATION AGENCY	



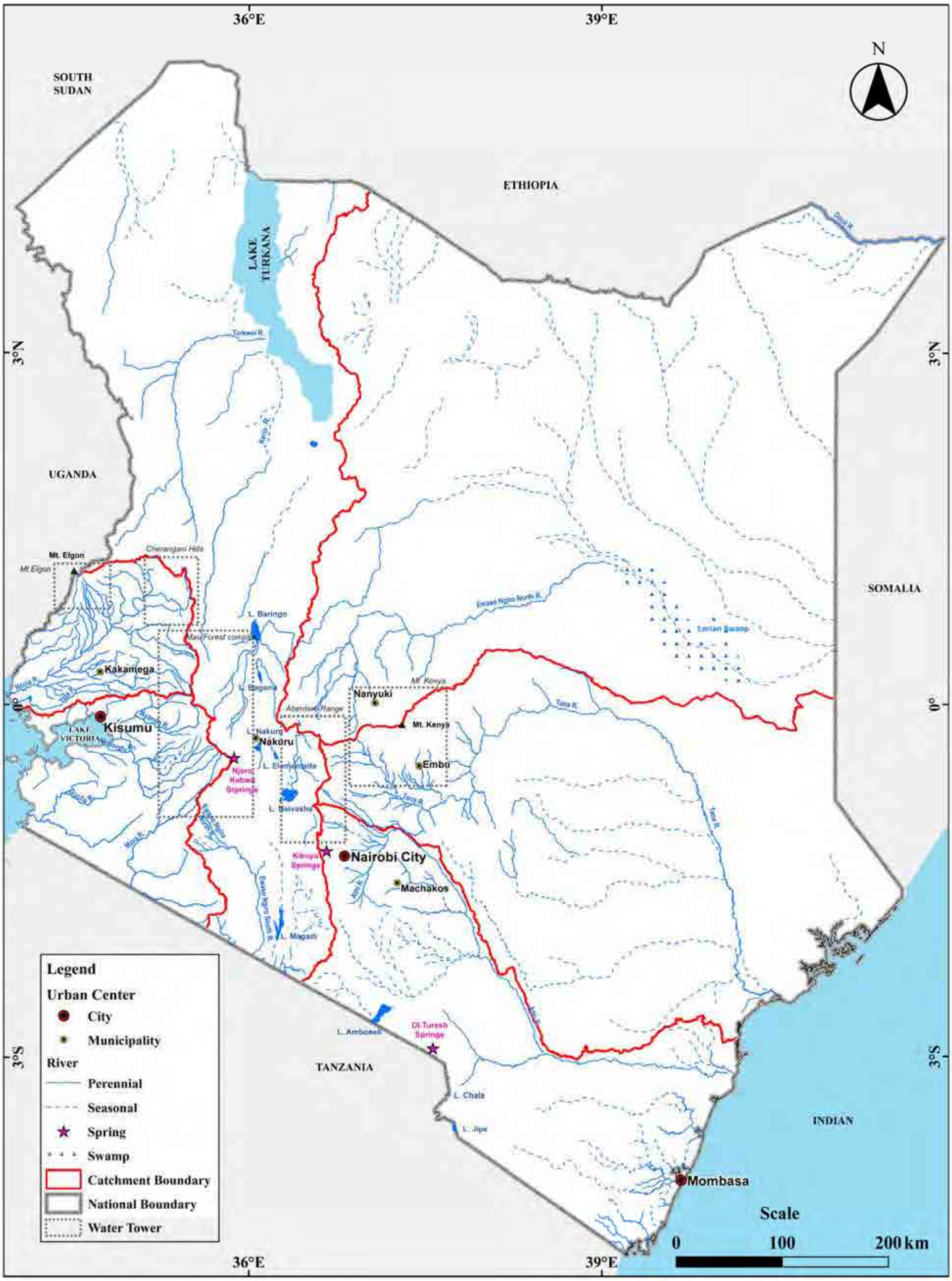
Source: JICA Study Team based on data from WRMA

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 1.2.2 Mean Monthly Rainfall Depth at Representative Rainfall Gauging Stations from 1979 to 2010**
JAPAN INTERNATIONAL COOPERATION AGENCY	



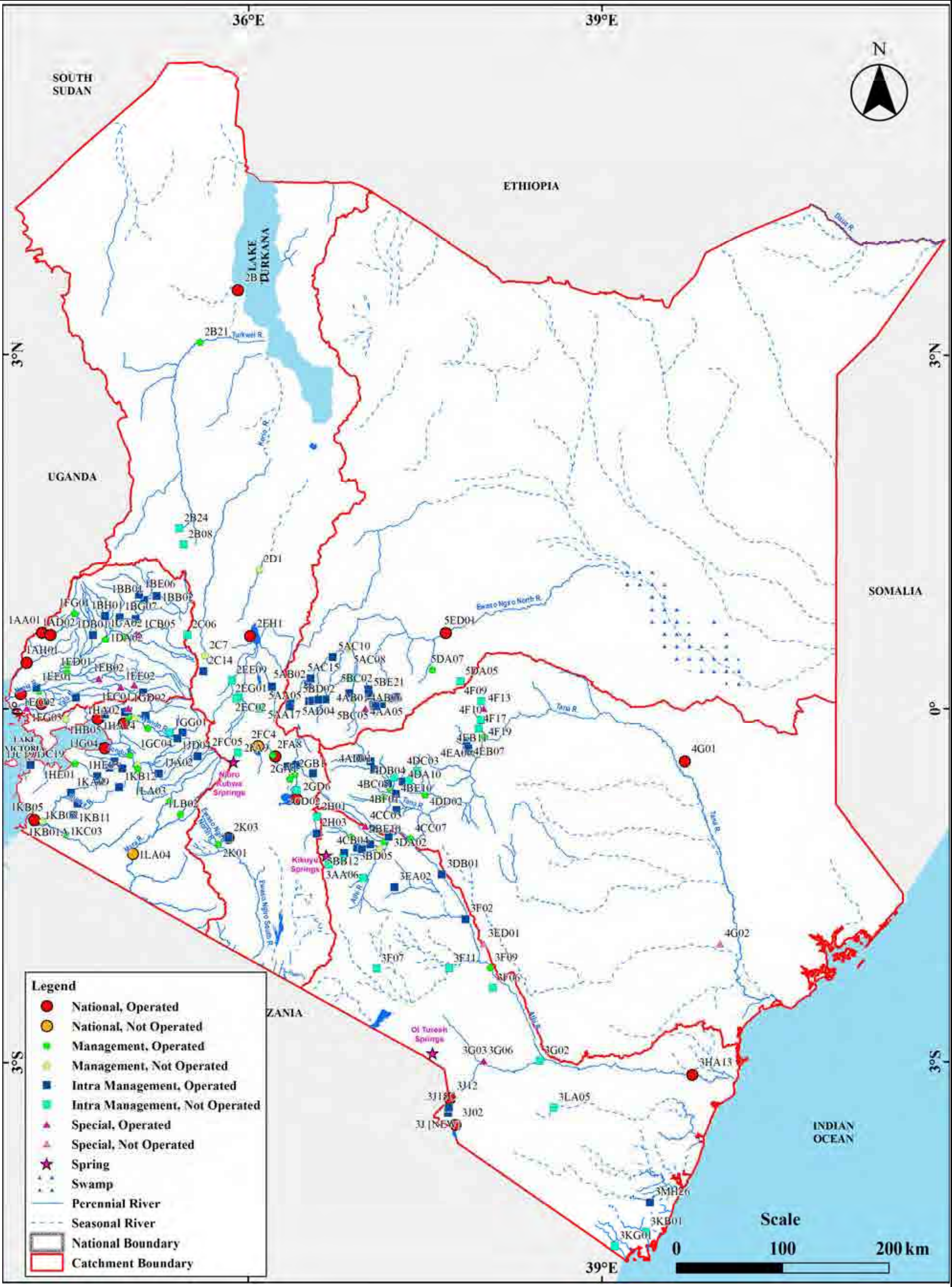
Source: JICA Study Team based on data from WRMA

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 1.2.3 Isohyetal Map of Mean Annual Rainfall for 1981 to 2010**
JAPAN INTERNATIONAL COOPERATION AGENCY	



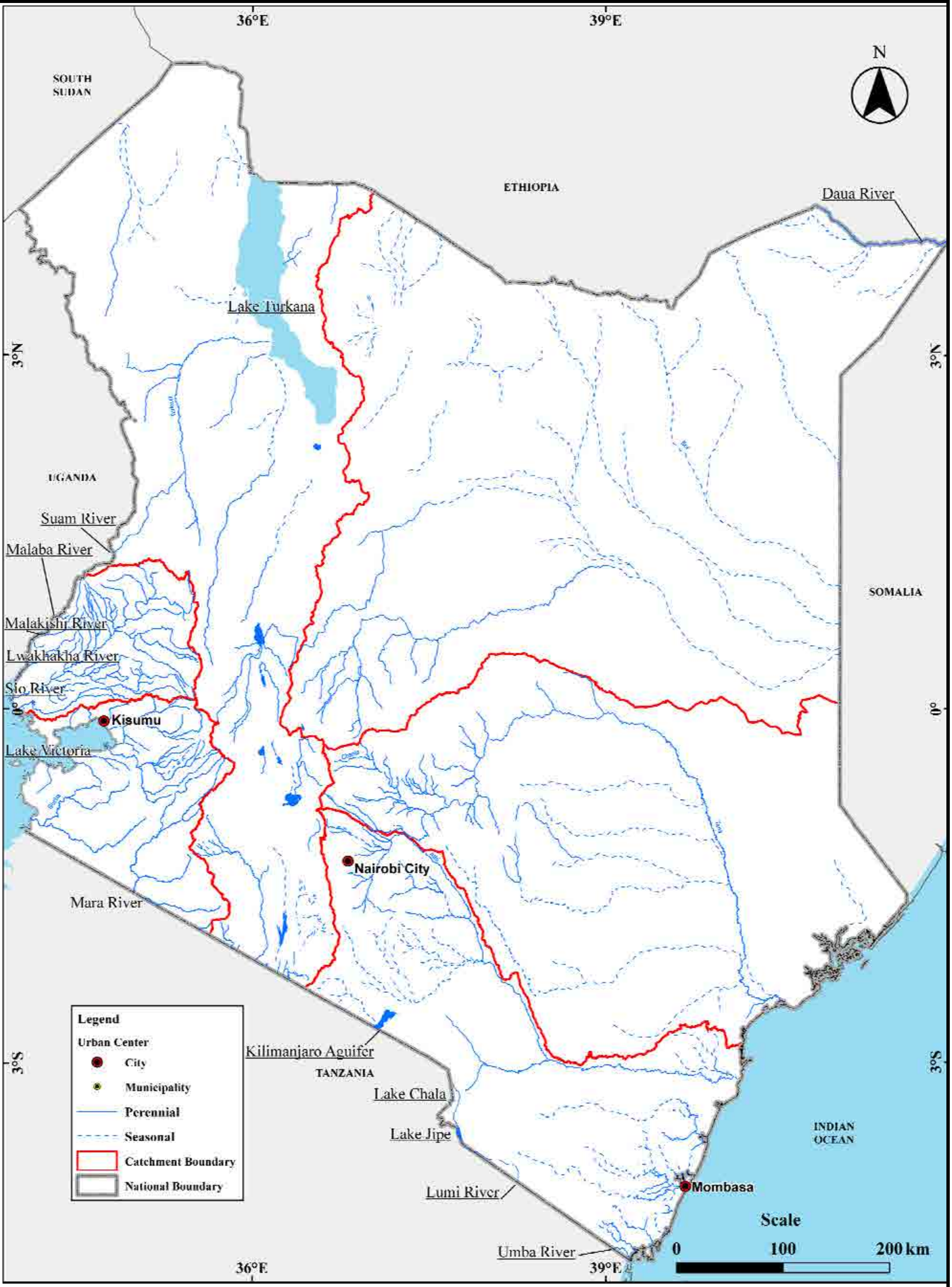
Source: JICA Study Team

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 1.3.1** **Major River and Lakes**
JAPAN INTERNATIONAL COOPERATION AGENCY	



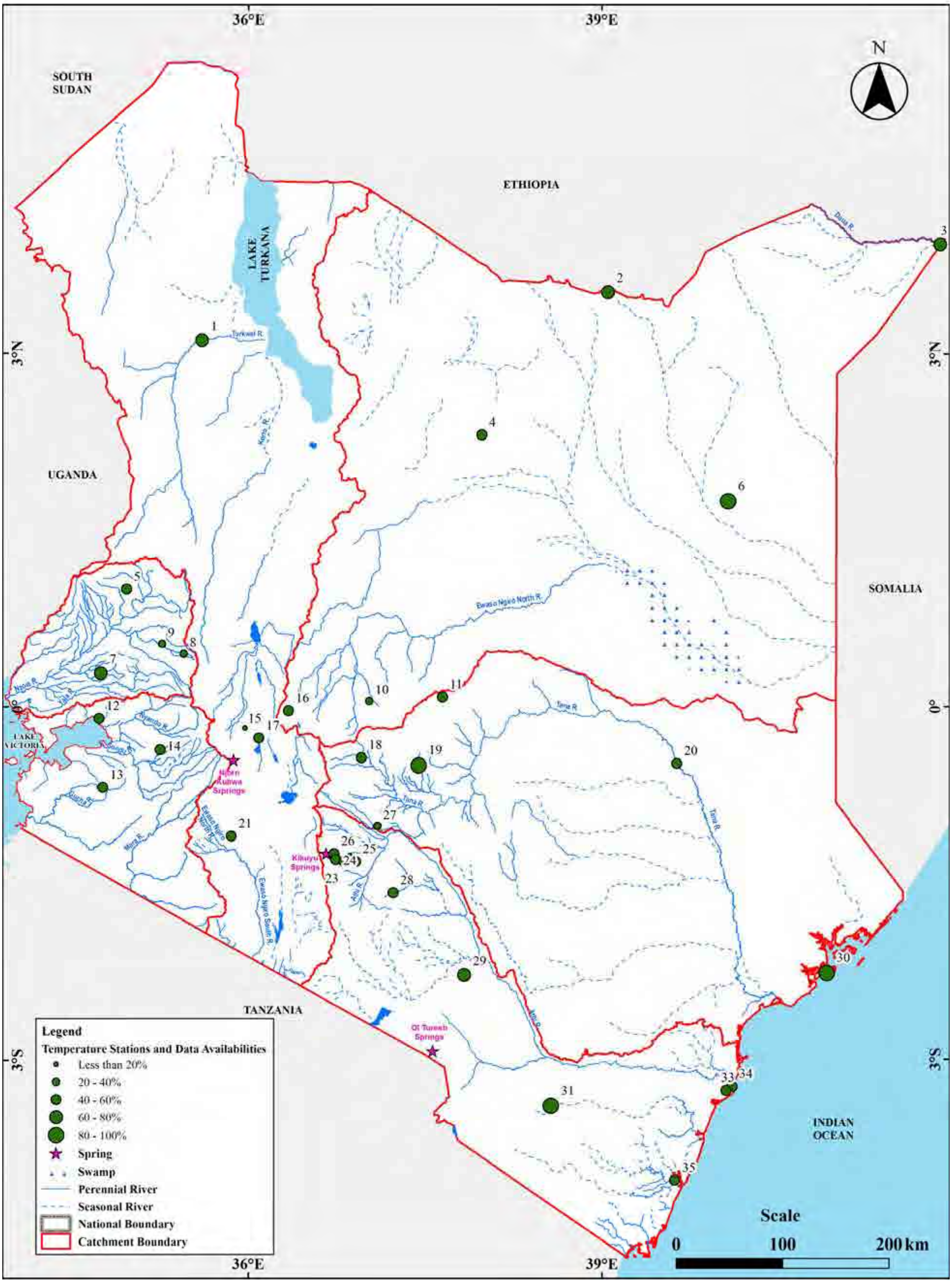
Source: JICA Study Team based on data from WRMA

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 1.3.2 Location of River Flow Gauging Stations**
JAPAN INTERNATIONAL COOPERATION AGENCY	



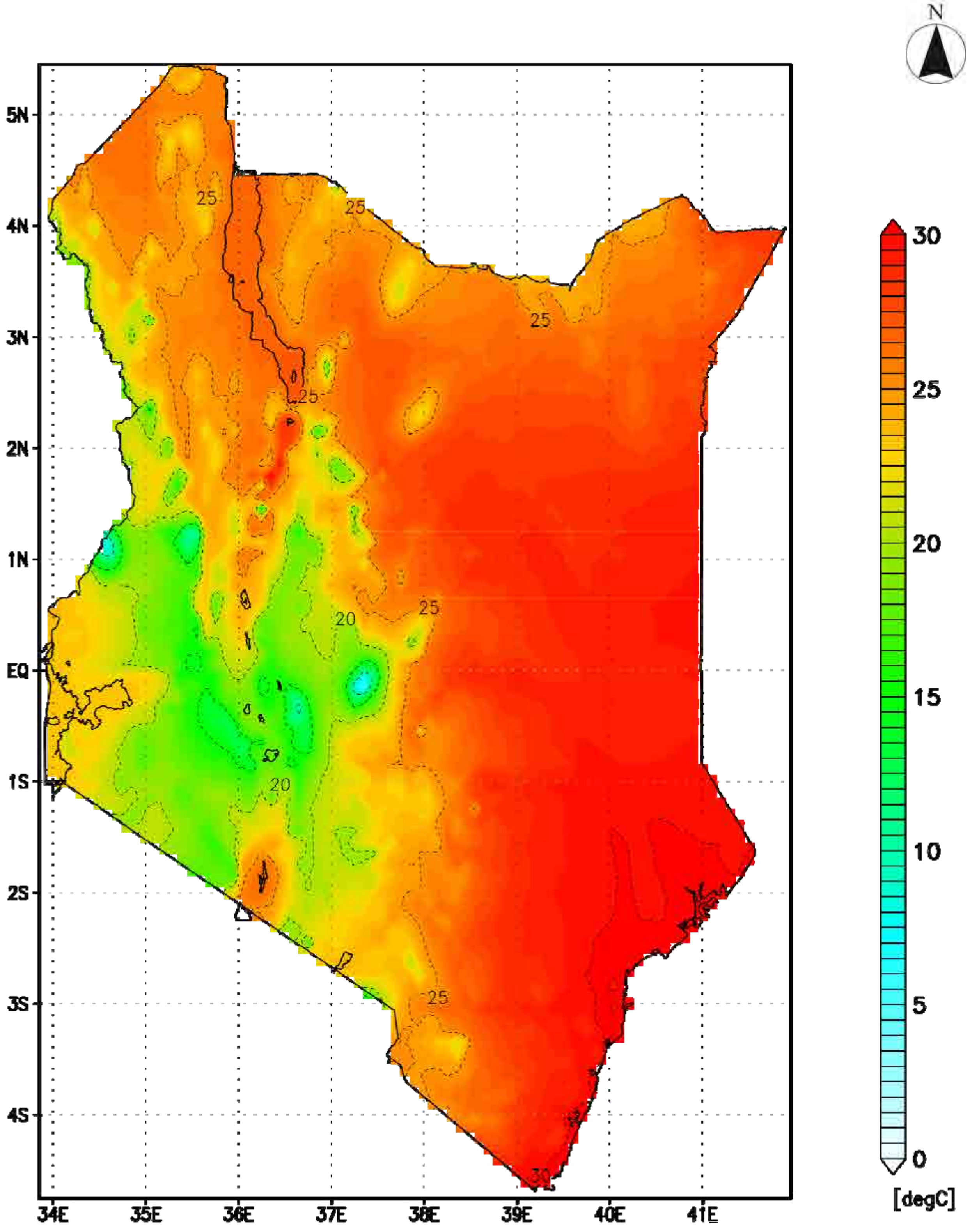
Source: JICA Study Team based on data from MWI

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 1.3.3 Transboundary Waters**
JAPAN INTERNATIONAL COOPERATION AGENCY	



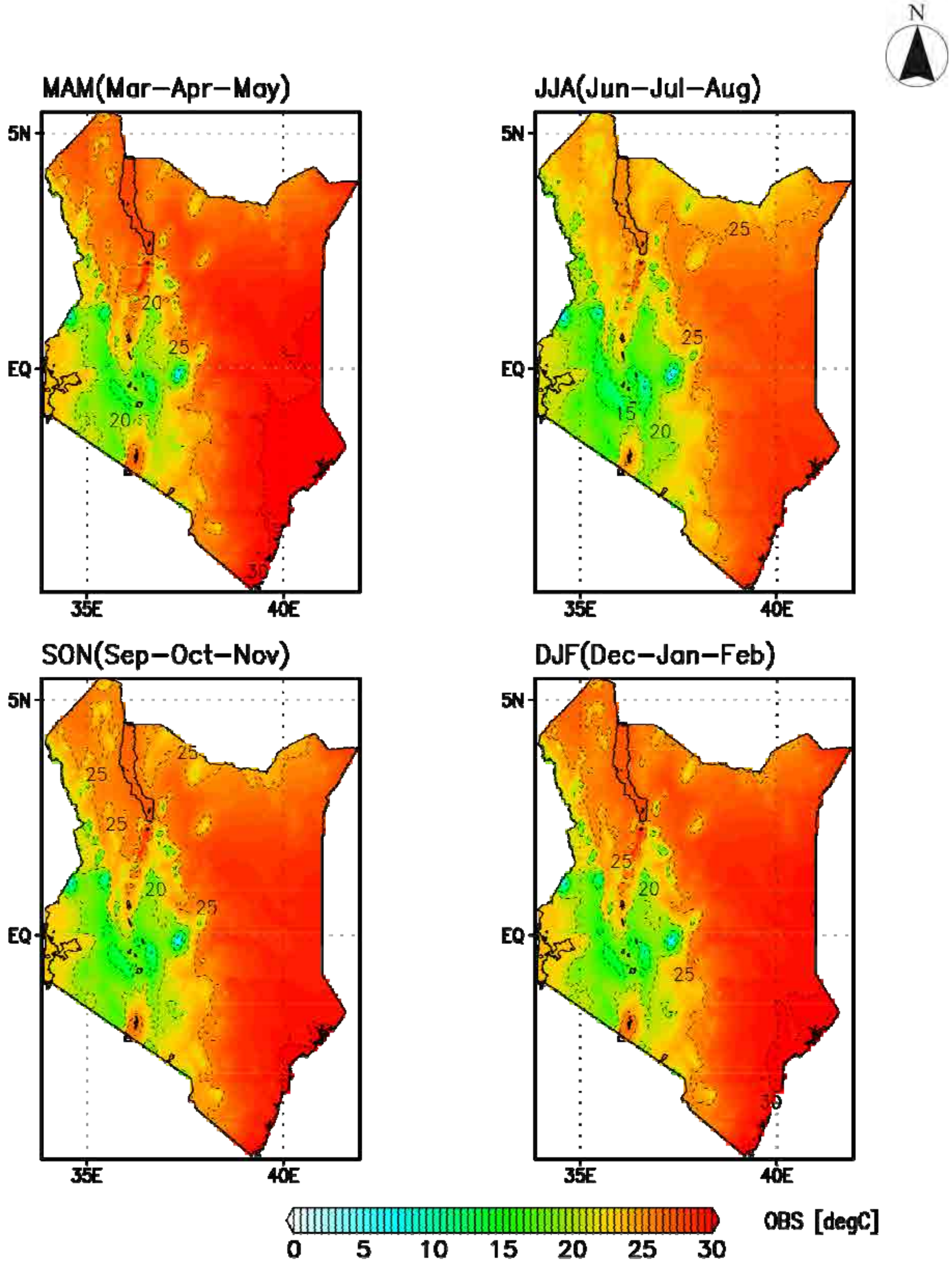
Source: JICA Study Team based on data from KMD
Note: Number is refer to the ID in Table 2.1.1

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 2.1.1 Distribution of Temperature Observation Stations Selected and Data Availabilities for 1979 - 2010**
JAPAN INTERNATIONAL COOPERATION AGENCY	



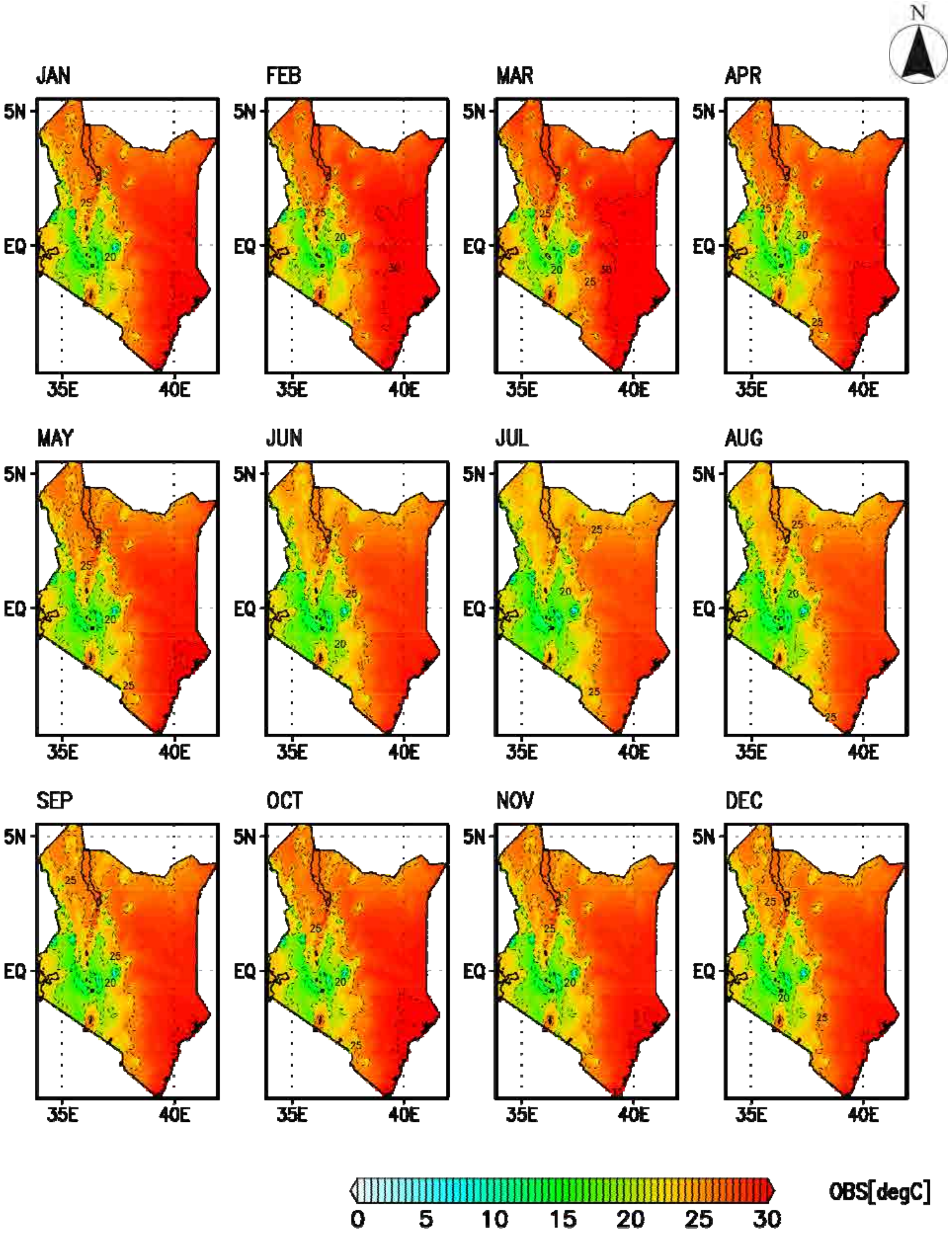
Source: JICA Study Team based on data from KMD

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 2.1.2** **Mean Annual Temperature for 1981 - 2010**
JAPAN INTERNATIONAL COOPERATION AGENCY	



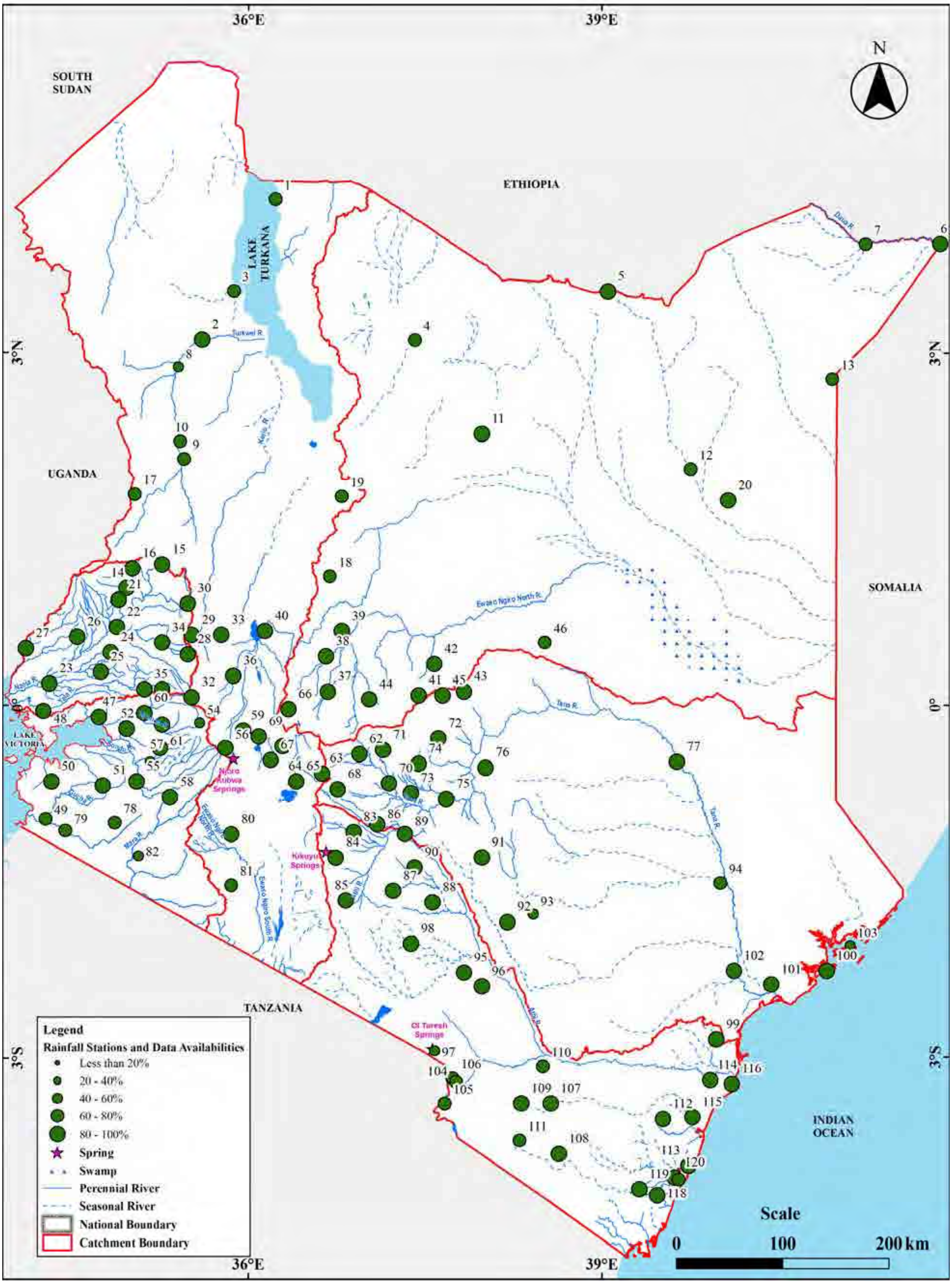
Source: JICA Study Team based on data from KMD

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 2.1.3** **Mean Seasonal Temperature for 1981 - 2010**
JAPAN INTERNATIONAL COOPERATION AGENCY	



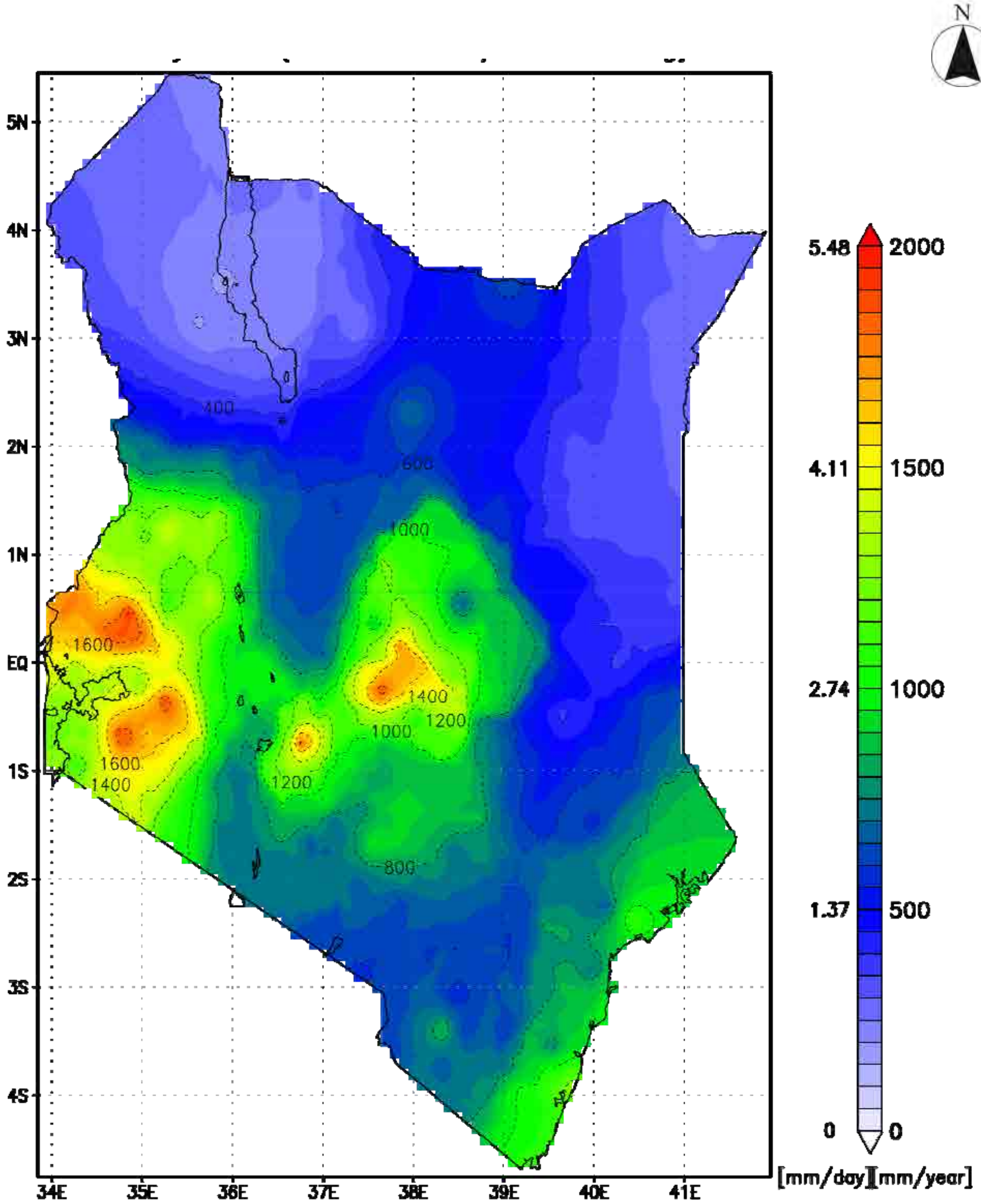
Source: JICA Study Team based on data from KMD

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 2.1.4 Mean Monthly Temperature for 1981 - 2010**
JAPAN INTERNATIONAL COOPERATION AGENCY	



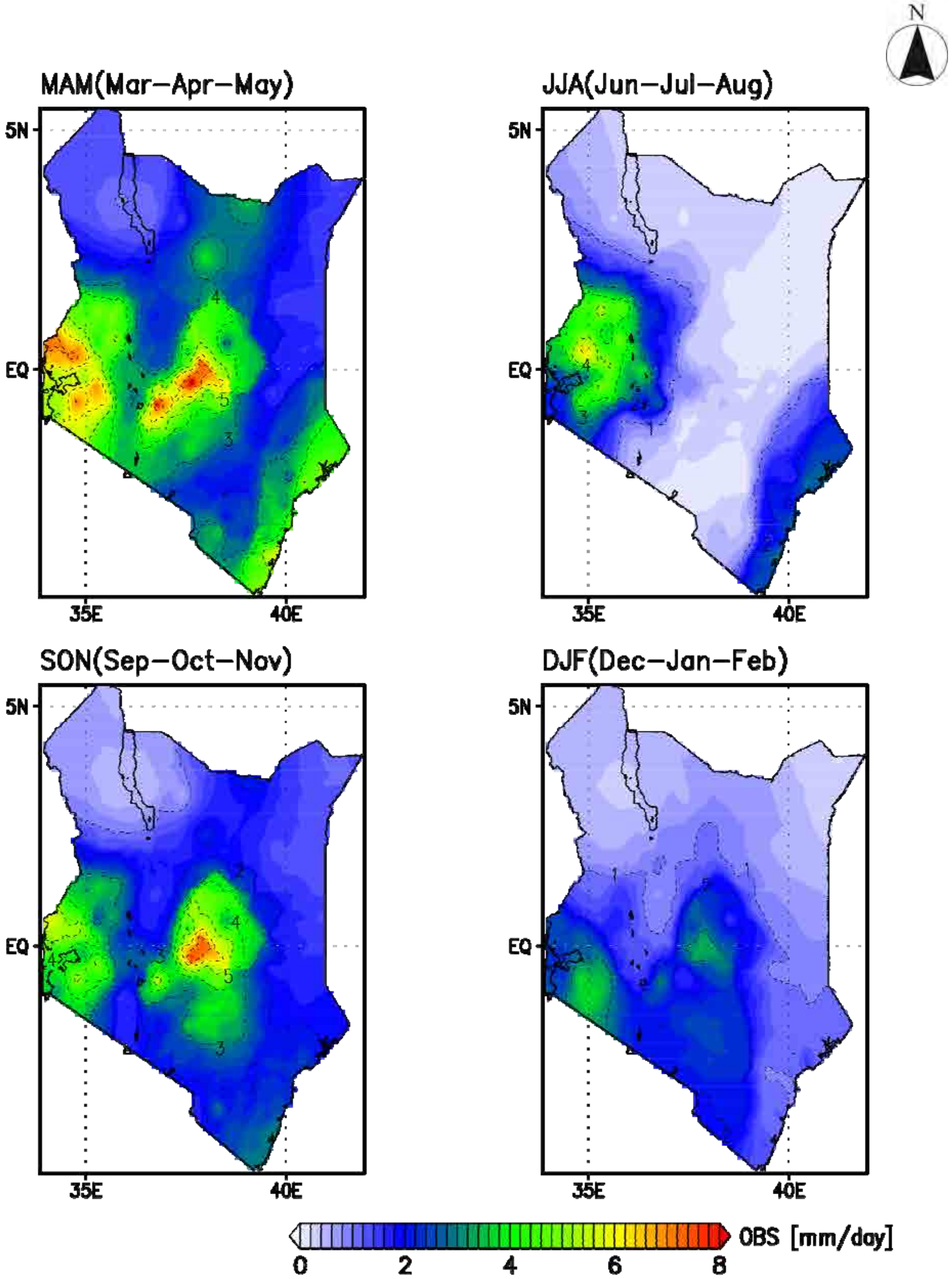
Source: JICA Study Team based on data from KMD
Note: Number is refer to the ID in Table 2.1.2

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 2.2.1**
JAPAN INTERNATIONAL COOPERATION AGENCY	**Distribution of Rainfall Observation Stations Selected and Data Availabilities for 1979-2010**



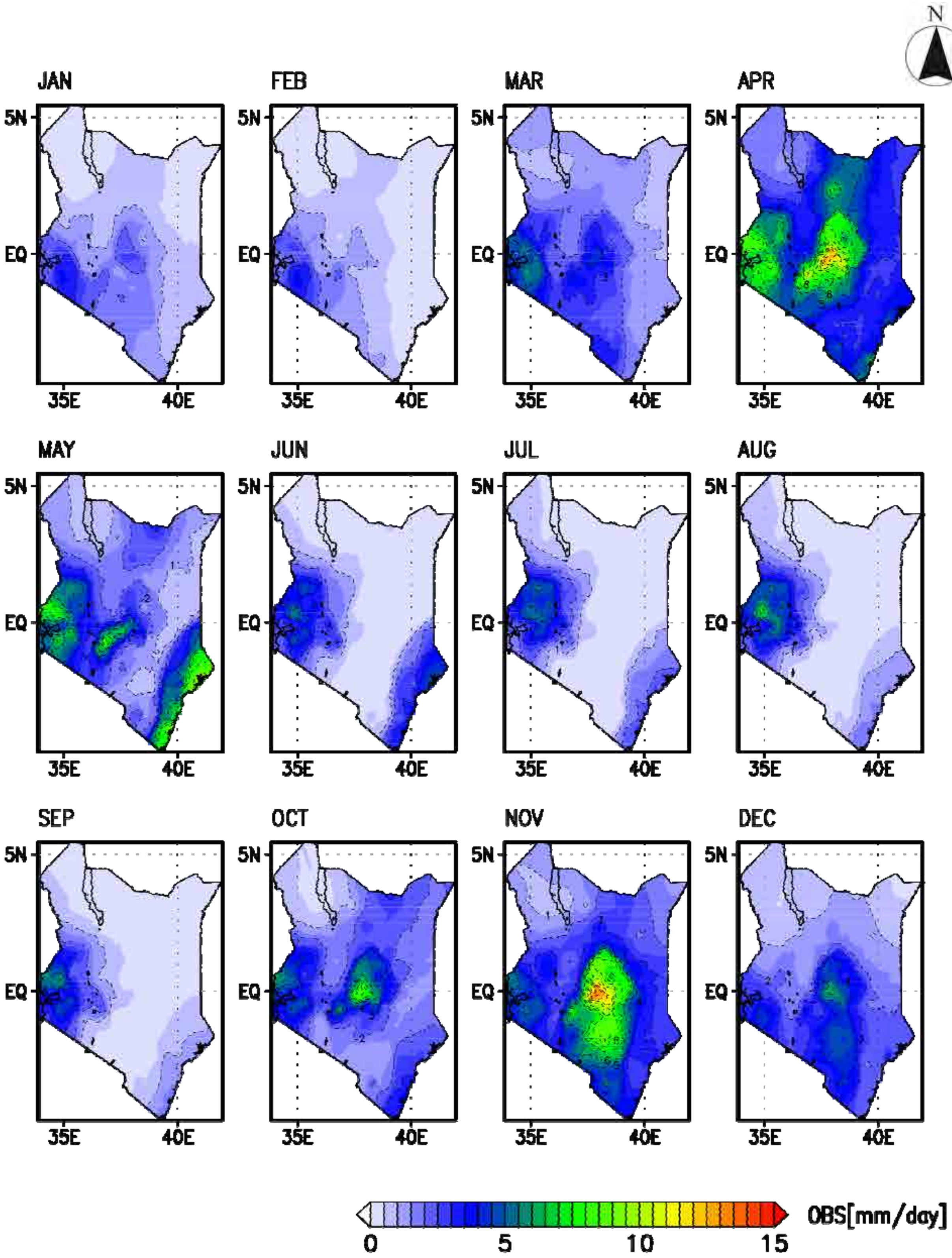
Source: JICA Study Team based on data from KMD

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 2.2.2** **Mean Annual Rainfall for** **1981 - 2010**
JAPAN INTERNATIONAL COOPERATION AGENCY	



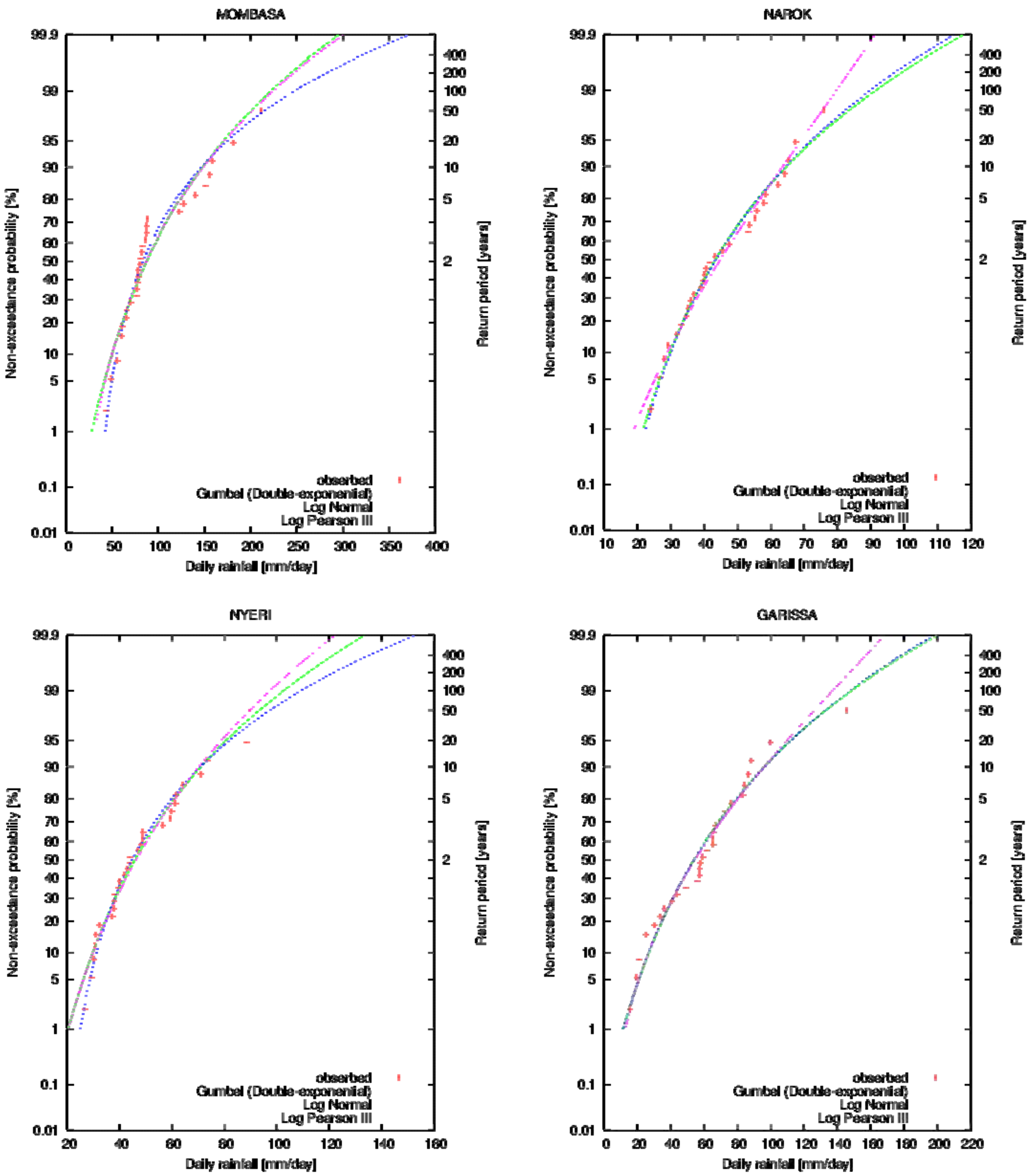
Source: JICA Study Team based on data from KMD

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 2.2.3** **Mean Seasonal Rainfall for** **1981 - 2010**
JAPAN INTERNATIONAL COOPERATION AGENCY	



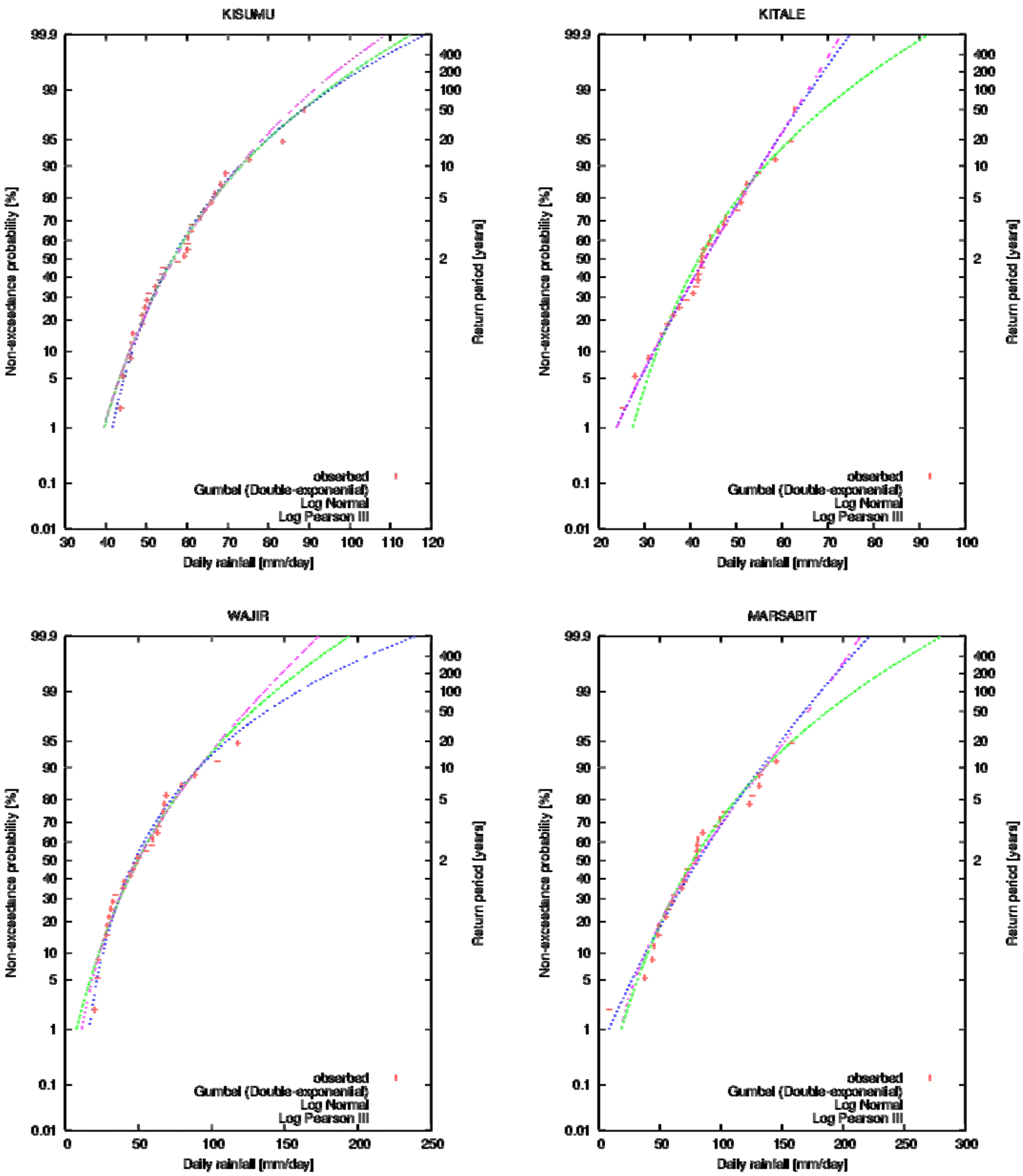
Source: JICA Study Team based on data from KMD

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 2.2.4 Mean Monthly Rainfall for 1981 - 2010**
JAPAN INTERNATIONAL COOPERATION AGENCY	



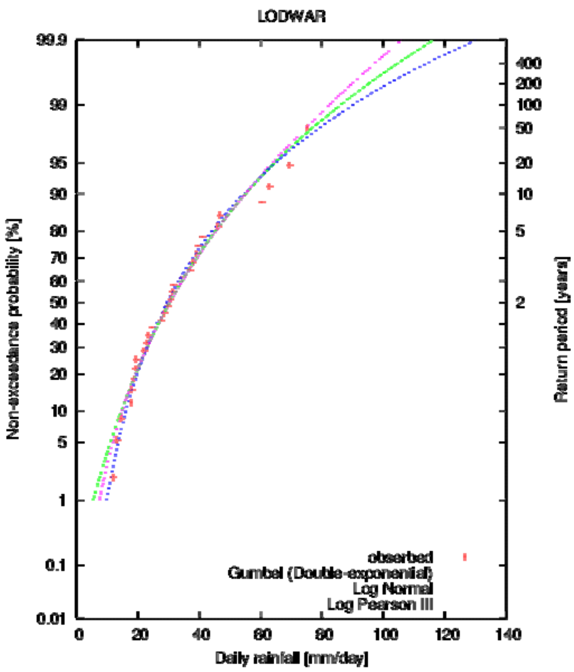
Source: JICA Study Team based on data from KMD

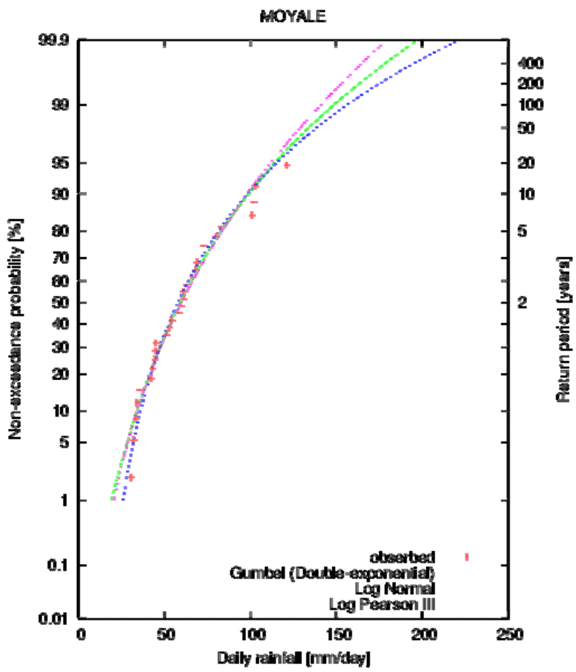
THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 2.2.5** **Frequency Analysis of Daily Rainfall (1/3)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



Source: JICA Study Team based on data from KMD

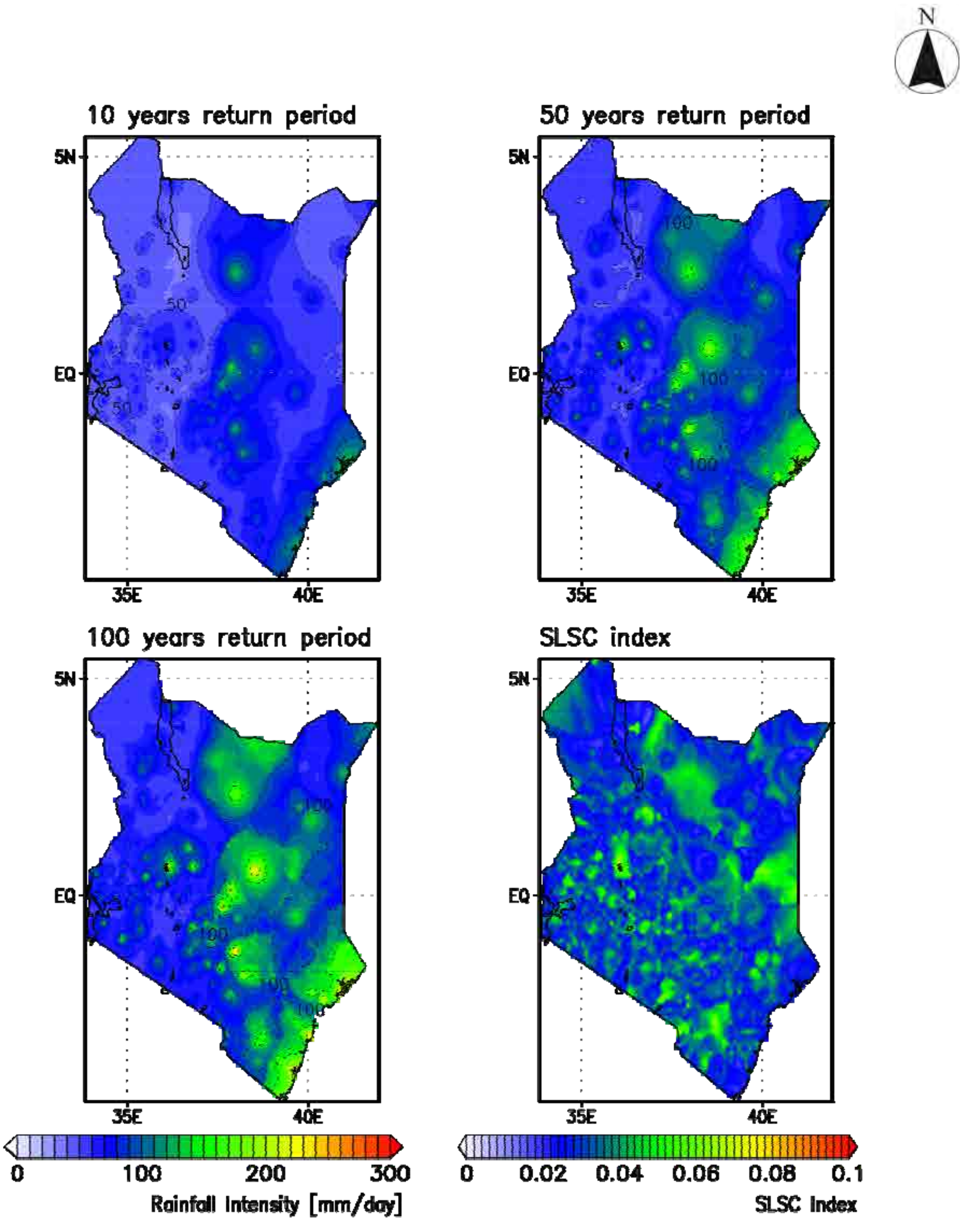
THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 2.2.5 Frequency Analysis of Daily Rainfall (2/3)**
JAPAN INTERNATIONAL COOPERATION AGENCY	





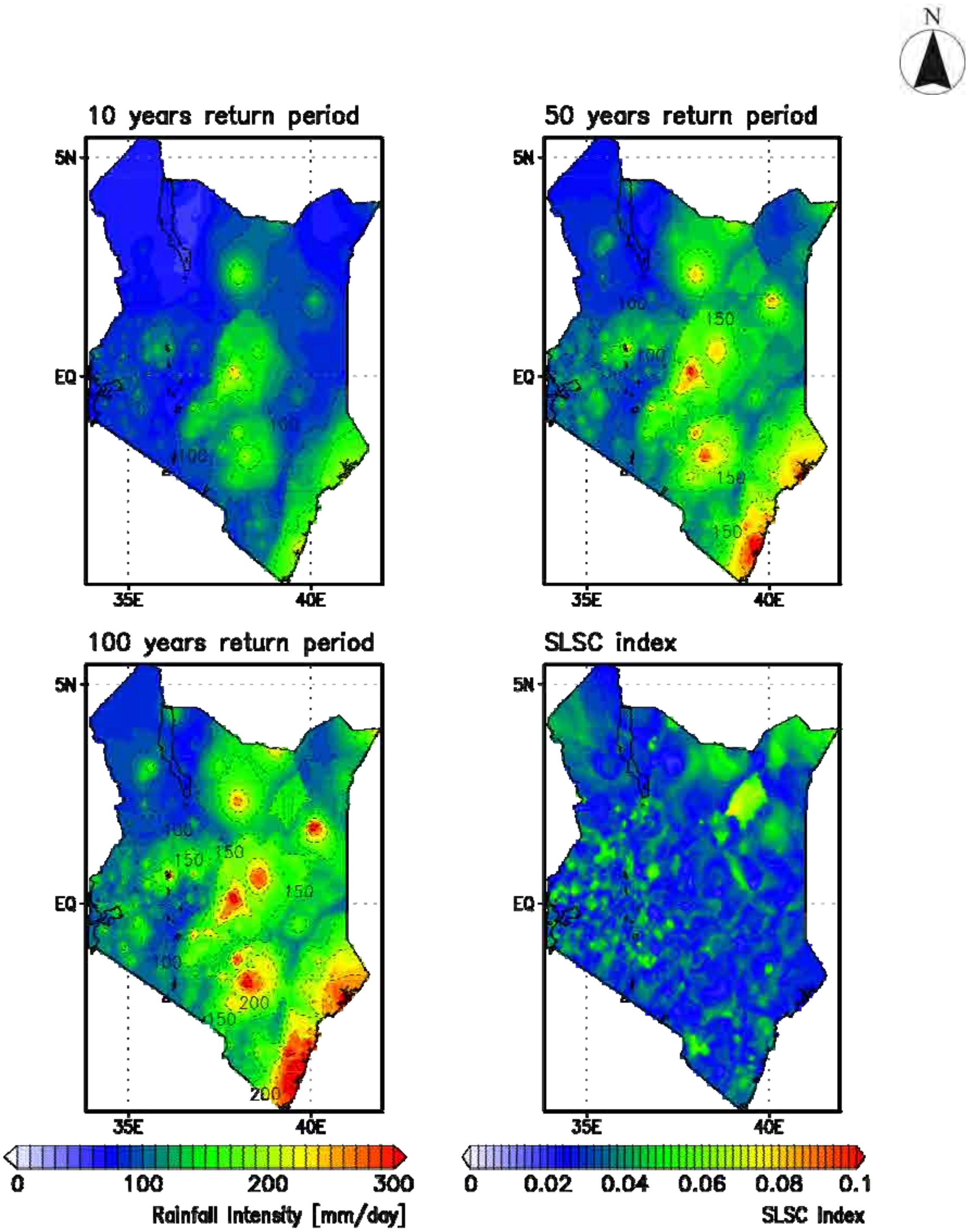
Source: JICA Study Team based on data from KMD

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 2.2.5** **Frequency Analysis of Daily Rainfall (3/3)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



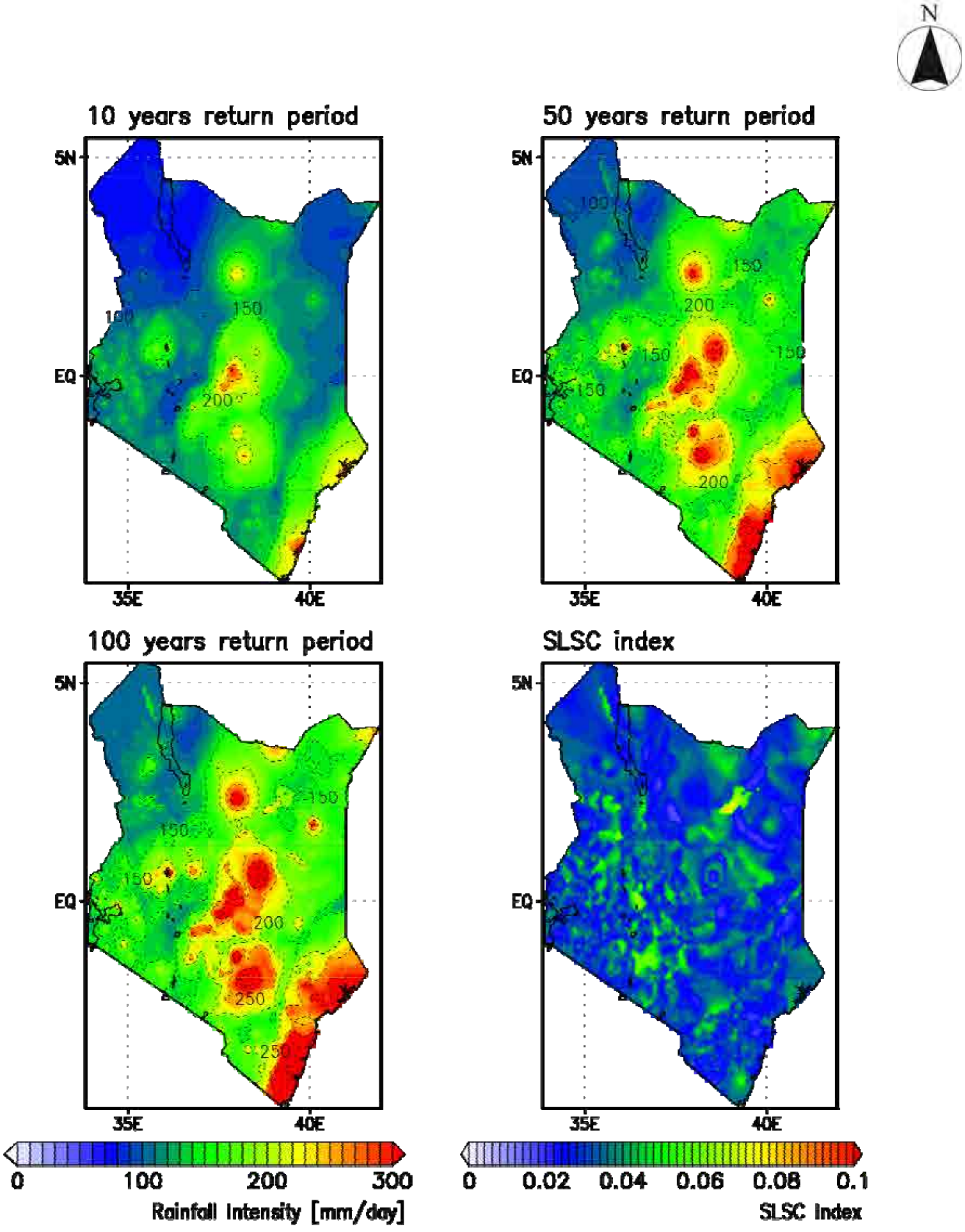
Note: SLSC: Standard Least-Squares Criterion
Source: JICA Study Team based on data from KMD

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 2.2.6** **Distribution of 1-Day Probable Rainfall Intensity for 1981 - 2010**
JAPAN INTERNATIONAL COOPERATION AGENCY	



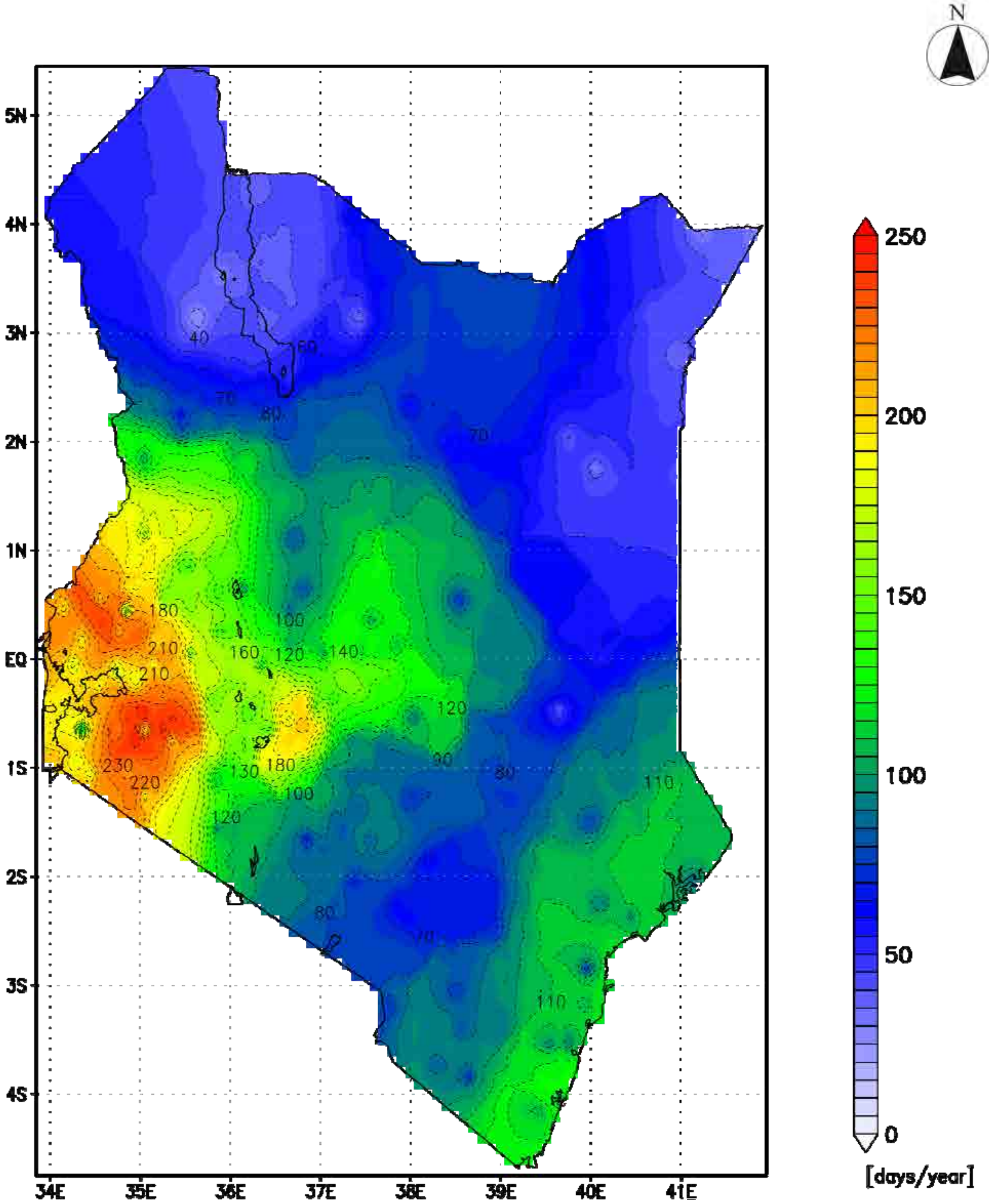
Note: SLSC: Standard Least-Squares Criterion
Source: JICA Study Team based on data from KMD

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 2.2.7 Distribution of the 3-Day Probable Rainfall Intensity for 1981 - 2010**
JAPAN INTERNATIONAL COOPERATION AGENCY	



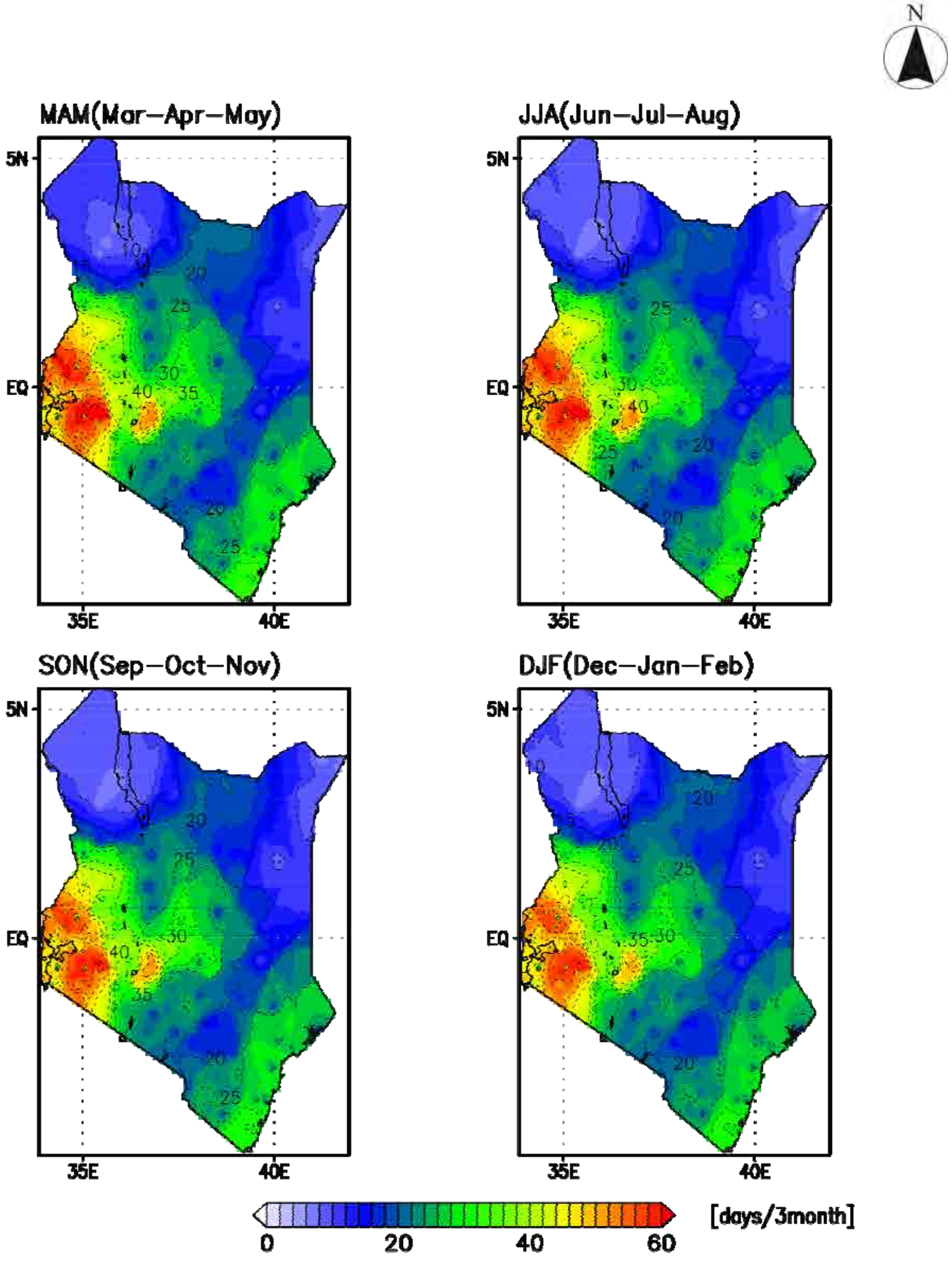
Note: SLSC: Standard Least-Squares Criterion
Source: JICA Study Team based on data from KMD

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 2.2.8** **Distribution of the 5-Day Probable Rainfall Intensity for 1981 - 2010**
JAPAN INTERNATIONAL COOPERATION AGENCY	



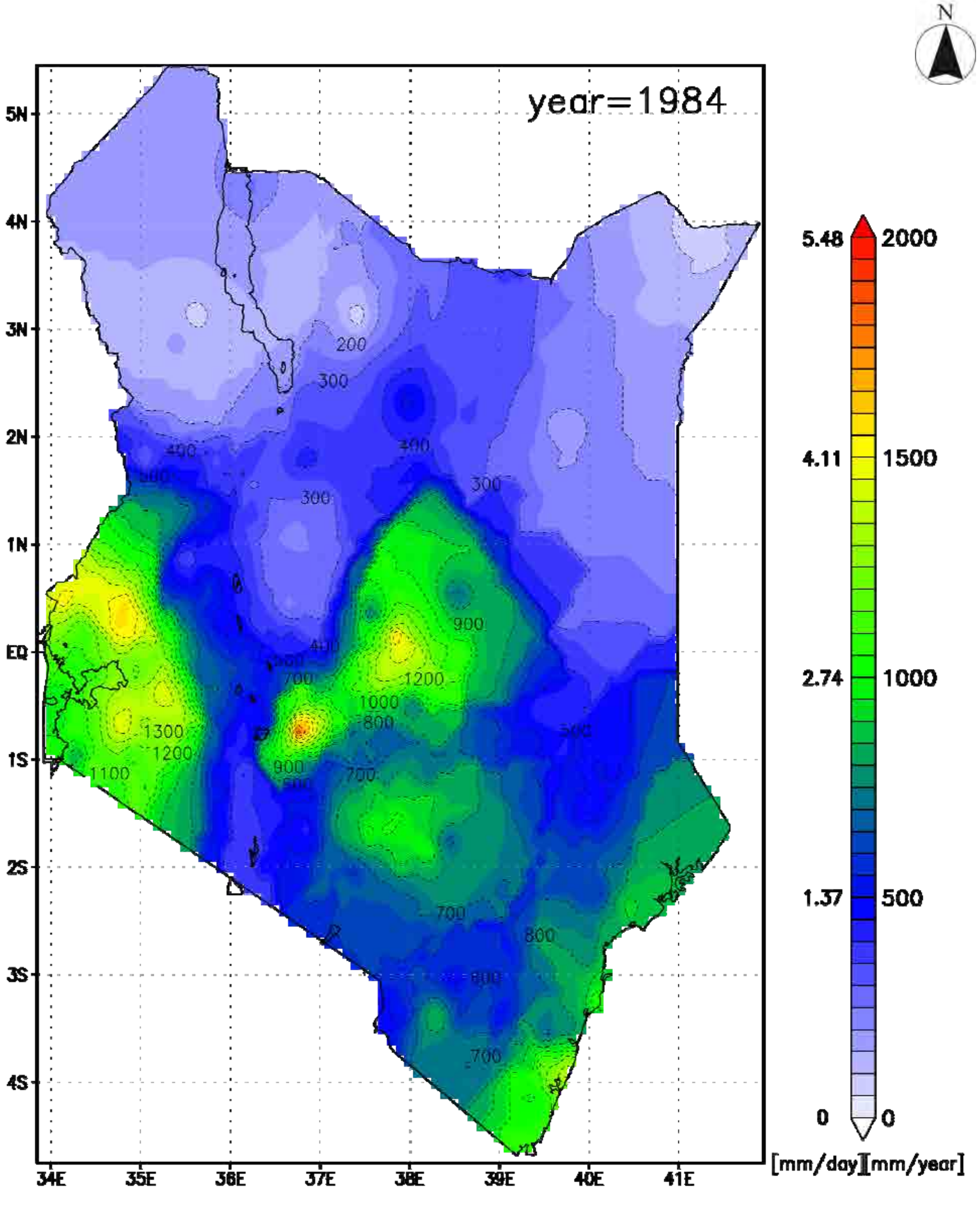
Note: SLSC: Standard Least-Squares Criterion
Source: JICA Study Team based on data from KMD

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 2.2.9 Annual Number of Rainy Days for 1981 - 2010**
JAPAN INTERNATIONAL COOPERATION AGENCY	



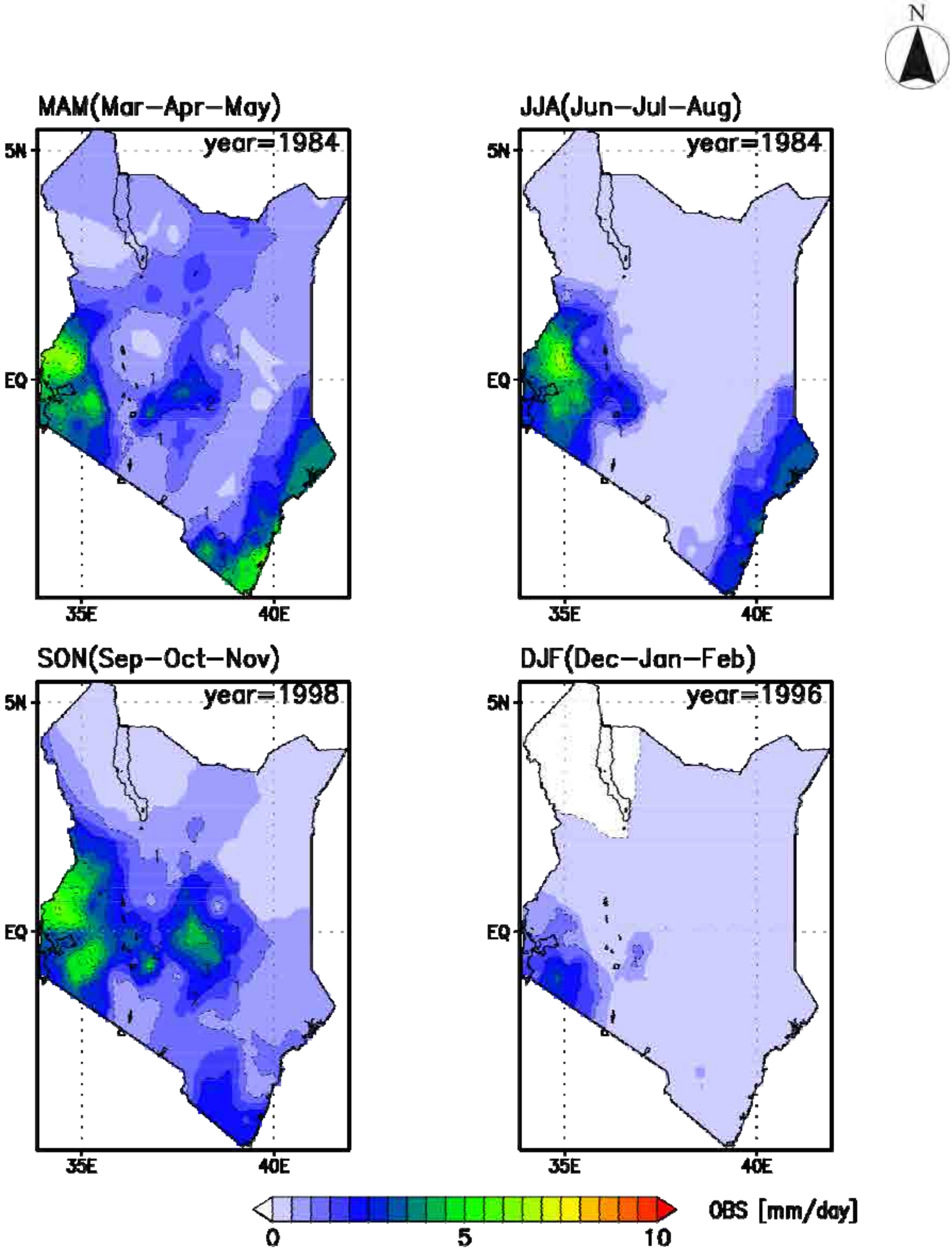
Note: SLSC: Standard Least-Squares Criterion
Source: JICA Study Team based on data from KMD

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 2.2.10** **Seasonal Rainy Days for 1981 - 2010**
JAPAN INTERNATIONAL COOPERATION AGENCY	



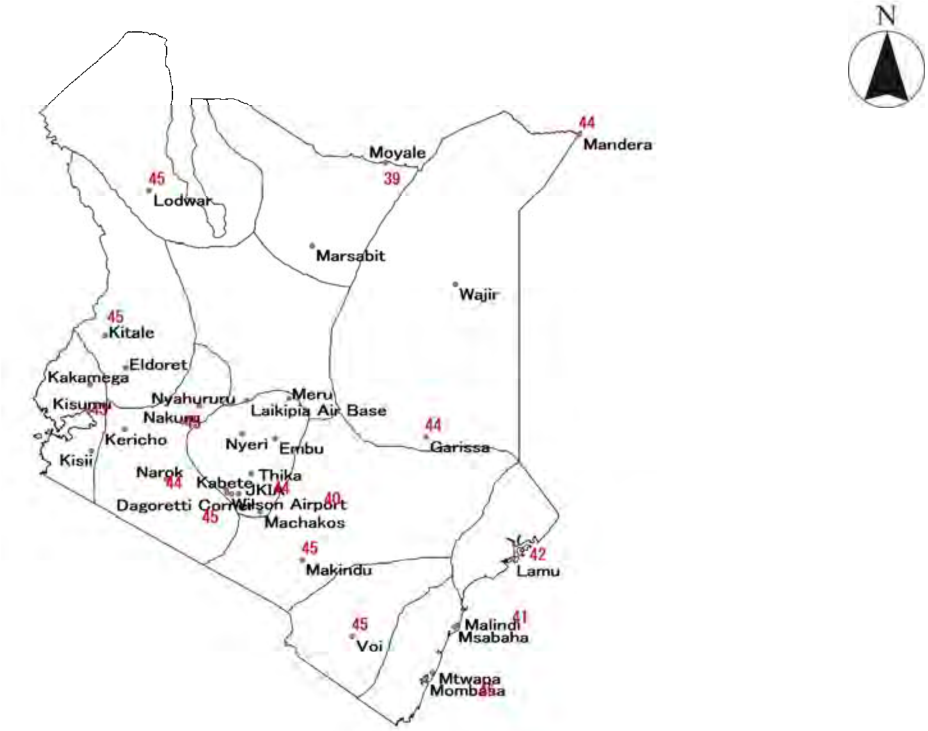
Source: JICA Study Team based on data from KMD

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 2.2.11** **Annual Rainfall of 1/10 Drought Year (1984) for 1981 - 2000**
JAPAN INTERNATIONAL COOPERATION AGENCY	

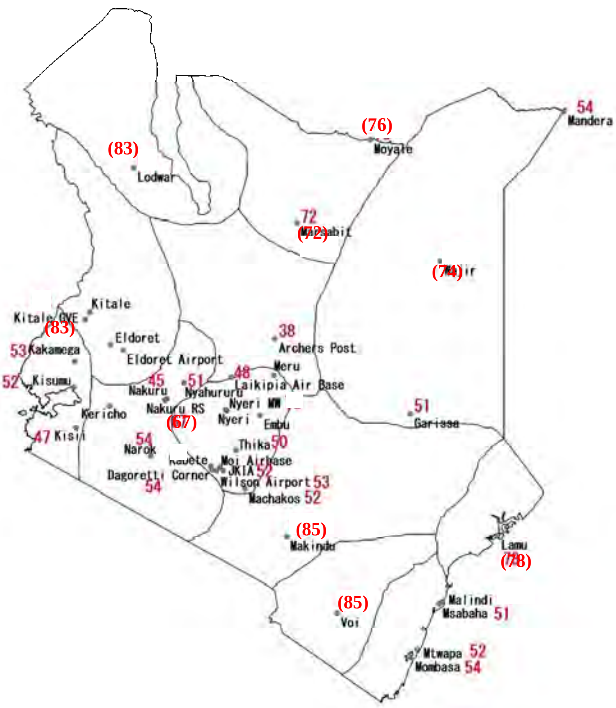


Source: JICA Study Team based on data from KMD

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 2.2.12** **Seasonal Rainfall of 1/10 Drought Year**
JAPAN INTERNATIONAL COOPERATION AGENCY	



[Selected Stations for Temperature Analysis]



[Selected Stations for Rainfall Analysis]

Source: JICA Study Team

Note: Number shown in both figure means the number of data available years.

(Bottom Figure) The number inside blanket is the period of 1920s to 2000s, and the other is the period of 1960s-2000s.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 3.2.1 Selected Stations for Trend Analysis**
JAPAN INTERNATIONAL COOPERATION AGENCY	

Station ID	Station Name	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
8635000	Lodwar Meteorological Station																						
8639000	Moyale Met. Station																						
8641000	Mandera Met Station																						
8737000	Marsabit Met Station																						
8840000	Wajir Met Station																						
8937022	Laikipia Air Base																						
9034025	Kisumu Meteorological Station																						
9039000	Garissa Met Station																						
9135001	Narok Meteorological Station																						
9136208	Kabete Agromet Station																						
9237000	Makindu Met. Station																						
9240001	Lamu Meteorological Station																						
9338001	Voi Meteorological Station																						
9439021	Mombasa Port Reitz Airport																						

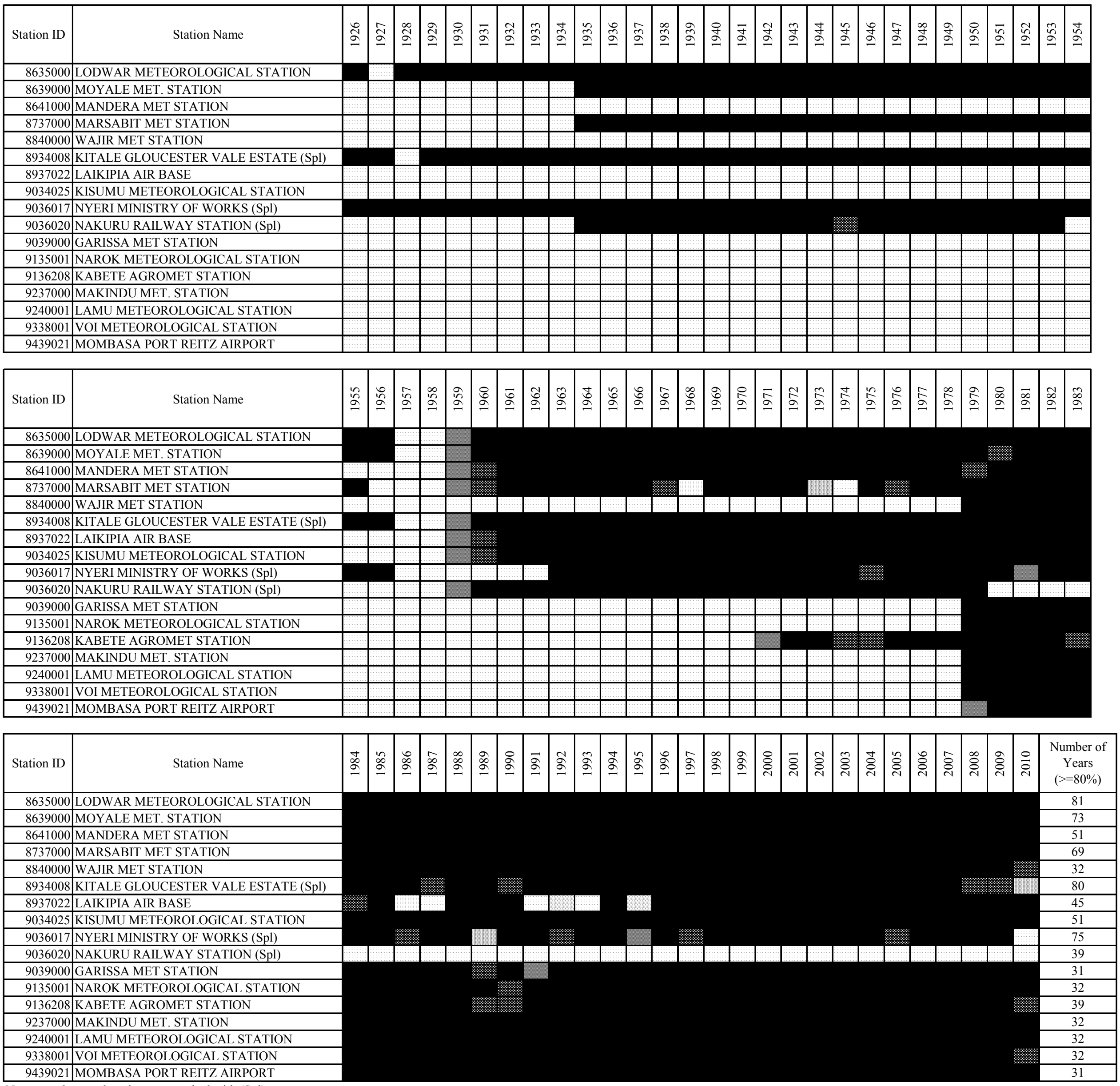
Station ID	Station Name	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Number of Years (>=80%)
8635000	Lodwar Meteorological Station																							26
8639000	Moyale Met. Station																							21
8641000	Mandera Met Station																							23
8737000	Marsabit Met Station																							15
8840000	Wajir Met Station																							23
8937022	Laikipia Air Base																							9
9034025	Kisumu Meteorological Station																							18
9039000	Garissa Met Station																							16
9135001	Narok Meteorological Station																							18
9136208	Kabete Agromet Station																							18
9237000	Makindu Met. Station																							20
9240001	Lamu Meteorological Station																							27
9338001	Voi Meteorological Station																							31
9439021	Mombasa Port Reitz Airport																							14

Legend

- 90% <= data availability
- 80% <= data availability < 90%
- 70% <= data availability < 80%
- 60% <= data availability < 70%
- 50% <= data availability < 60%
- 40% <= data availability < 50%
- data availability < 40%

Source: JICA Study Team with original data from KMD

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 3.2.2 Availability of Temperature Data**
JAPAN INTERNATIONAL COOPERATION AGENCY	



Station ID	Station Name	Number of Years (>=80%)
8635000	LODWAR METEOROLOGICAL STATION	81
8639000	MOYALE MET. STATION	73
8641000	MANDERA MET STATION	51
8737000	MARSABIT MET STATION	69
8840000	WAJIR MET STATION	32
8934008	KITALE GLOUCESTER VALE ESTATE (Spl)	80
8937022	LAIKIPIA AIR BASE	45
9034025	KISUMU METEOROLOGICAL STATION	51
9036017	NYERI MINISTRY OF WORKS (Spl)	75
9036020	NAKURU RAILWAY STATION (Spl)	39
9039000	GARISSA MET STATION	31
9135001	NAROK METEOROLOGICAL STATION	32
9136208	KABETE AGROMET STATION	39
9237000	MAKINDU MET. STATION	32
9240001	LAMU METEOROLOGICAL STATION	32
9338001	VOI METEOROLOGICAL STATION	32
9439021	MOMBASA PORT REITZ AIRPORT	31

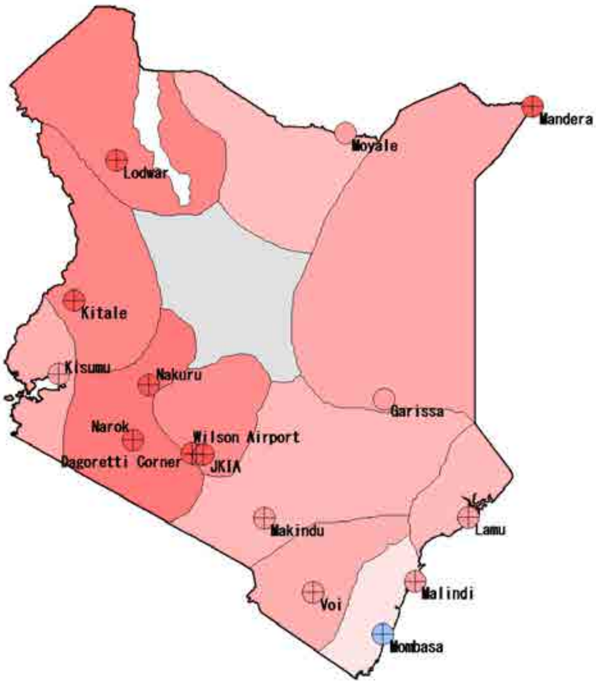
Note: supplemental stations are marked with (Spl)

Legend

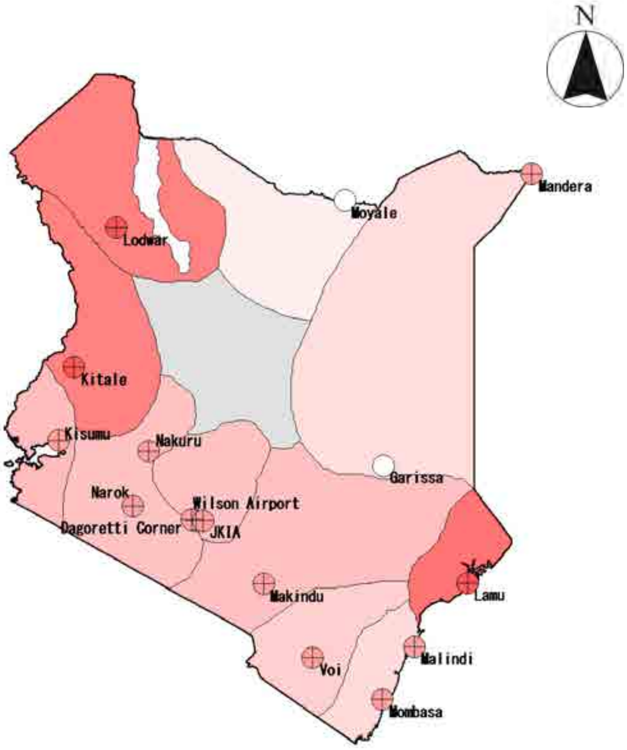
- 90% <= data availability
- 80% <= data availability < 90%
- 70% <= data availability < 80%
- 60% <= data availability < 70%
- 50% <= data availability < 60%
- 40% <= data availability < 50%
- data availability < 40%

Source: JICA Study Team with original data from KMD

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 3.2.3 Availability of Rainfall Data**
JAPAN INTERNATIONAL COOPERATION AGENCY	

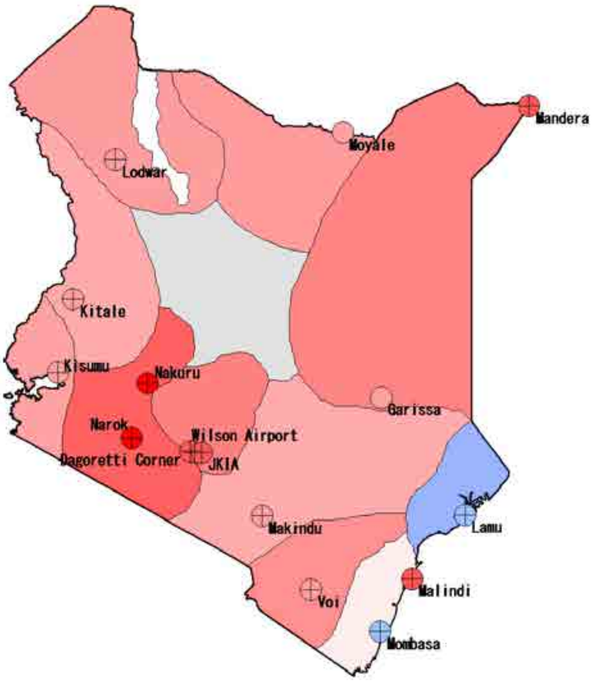


[Annual Mean Temperature]



[Annual Mean Maximum Temperature]

Legend
Climate Zone
Significant Trend
Rate [degree per 20 years]
1.0 –
0.5 – 1.0
0.1 – 0.5
-0.1 – 0.1
-0.5 – -0.1
-1.0 – -0.5
– -1.0



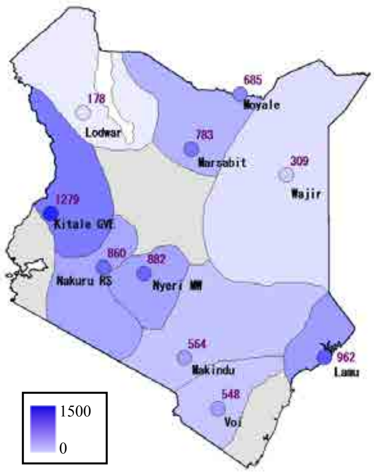
[Annual Mean Minimum Temperature]

Source: JICA Study Team

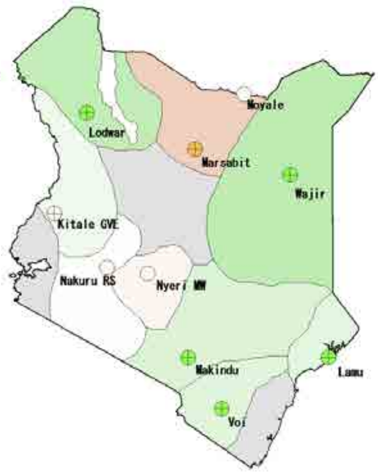
Note: Color of a zone is derived from average value of stations which are located in the zone. Gray color of a zone means that there is no station in the zone.

Source: JICA Study Team

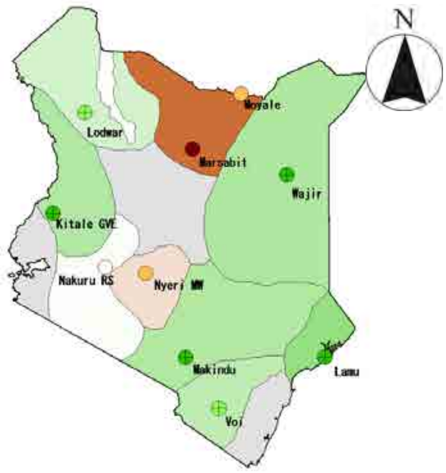
THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 3.3.1 Spatial Distribution of Temperature Trend**
JAPAN INTERNATIONAL COOPERATION AGENCY	



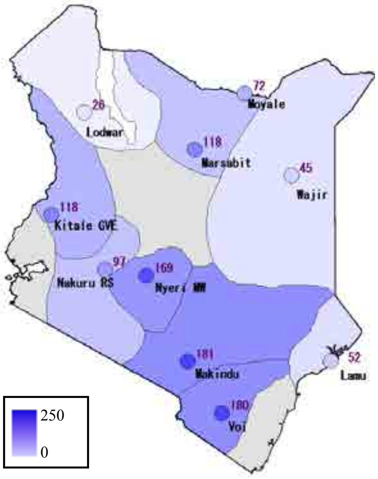
[Annual Rainfall (unit: mm)]



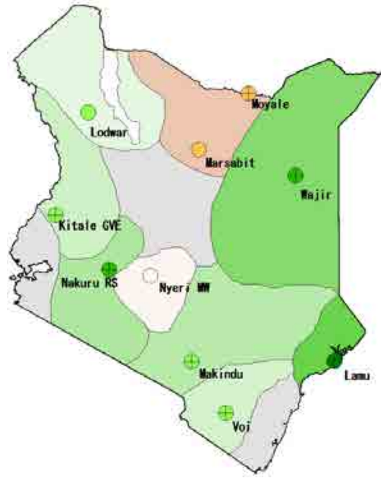
[Annual Trend (unit: % per 20years)]



[Annual Trend (unit: mm per 20years)]

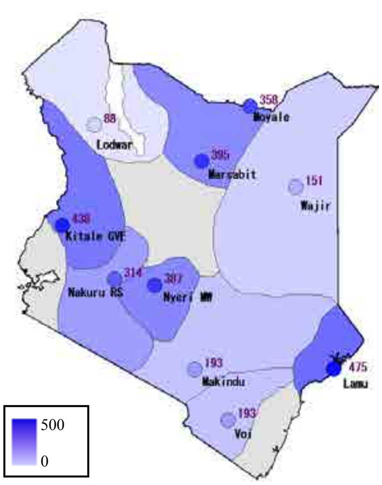


[DJF Rainfall (unit: mm)]



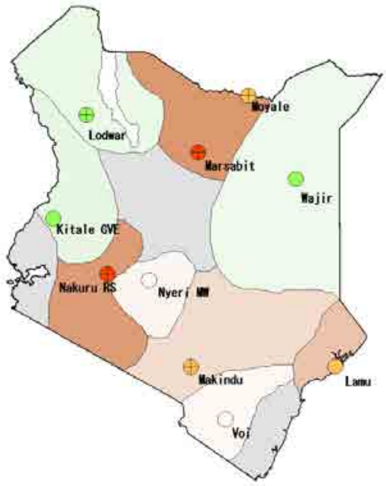
[DJF Trend (unit: % per 20years)]

[DJF Trend (unit: mm per 20years)]



[MAM Rainfall (unit: mm)]

[MAM Trend (unit: % per 20years)]



[MAM Trend (unit: mm per 20years)]

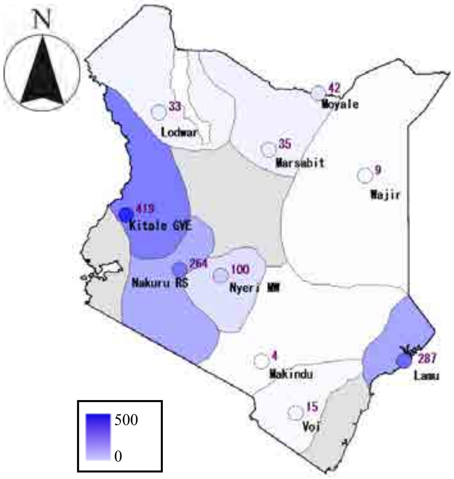
Climate Zone	
Significant Trend	
Rate [% per 20 years]	
20% –	-10% – -2%
10% – 20%	-20% – -10%
2% – 10%	– -20%
-2% – 2%	

Climate Zone	
Significant Trend	
Rate [mm per 20 years]	
50 –	-25 – -5
25 – 50	-50 – -25
5 – 25	– -50
-5 – 5	

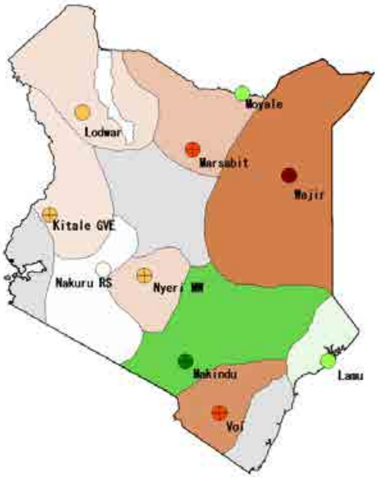
Source: JICA Study Team

Note: The percentage is based on the means for the 1920s to 2000s period. Color of a zone is derived from average value of stations which are located in the zone. Gray color of a zone means that there is no station in the zone.

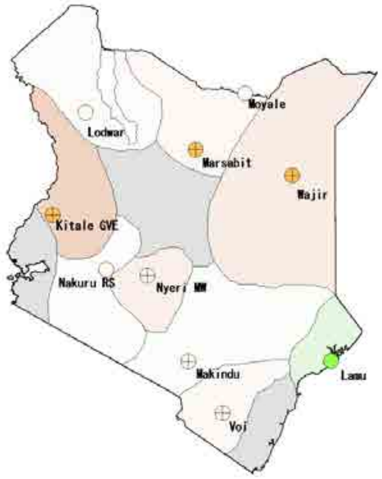
THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 3.3.2 Spatial Distribution of Rainfall Trend (1/2)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



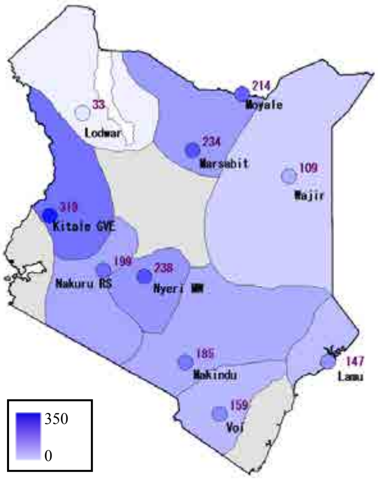
[JJA Rainfall (unit: mm)]



[JJA Trend (unit: % per 20years)]



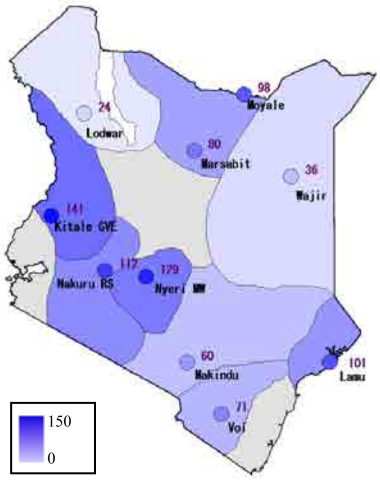
[JJA Trend (unit: mm per 20years)]



[SON Rainfall (unit: mm)]

[SON Trend (unit: % per 20years)]

[SON Trend (unit: mm per 20years)]



[Rainy Days (unit: day)]

[Rainy Days Trend (unit: % per 20years)]

[Rainy Days Trend (unit: day per 20years)

□ Climate Zone
+ Significant Trend
Rate [% per 20 years]

● 20% –	● -10% – -2%
● 10% – 20%	● -20% – -10%
● 2% – 10%	● – -20%
○ -2% – 2%	

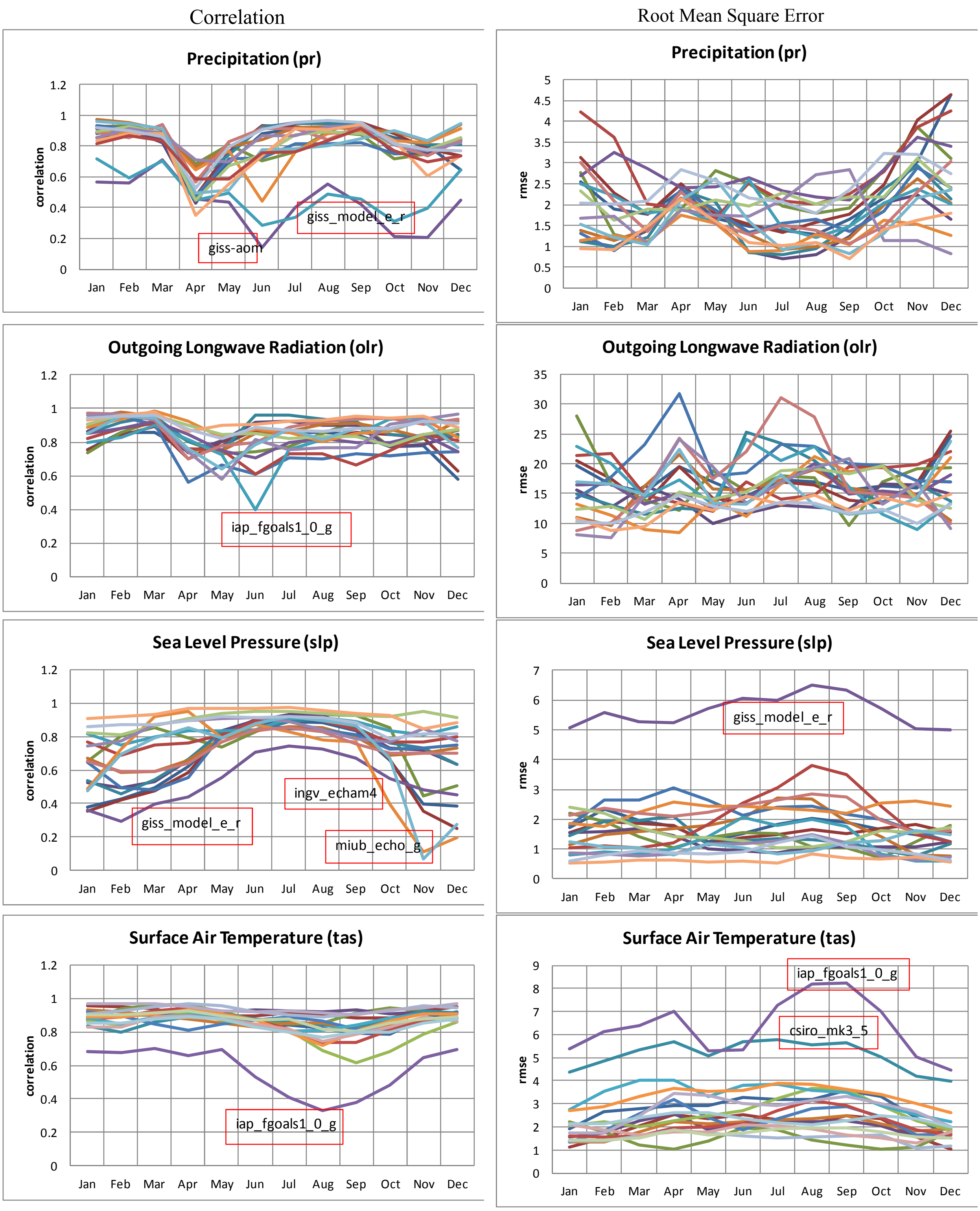
+ Significant Trend □ Climate Zone

Rate [mm per 20 years]		Rate [day per 20 years]	
● 50 –	● -25 – -5	● 10 –	● -5 – -1
● 25 – 50	● -50 – -25	● 5 – 10	● -10 – -5
● 5 – 25	● – -50	● 1 – 5	● – -10
○ -5 – 5		○ -1 – 1	

Source: JICA Study Team

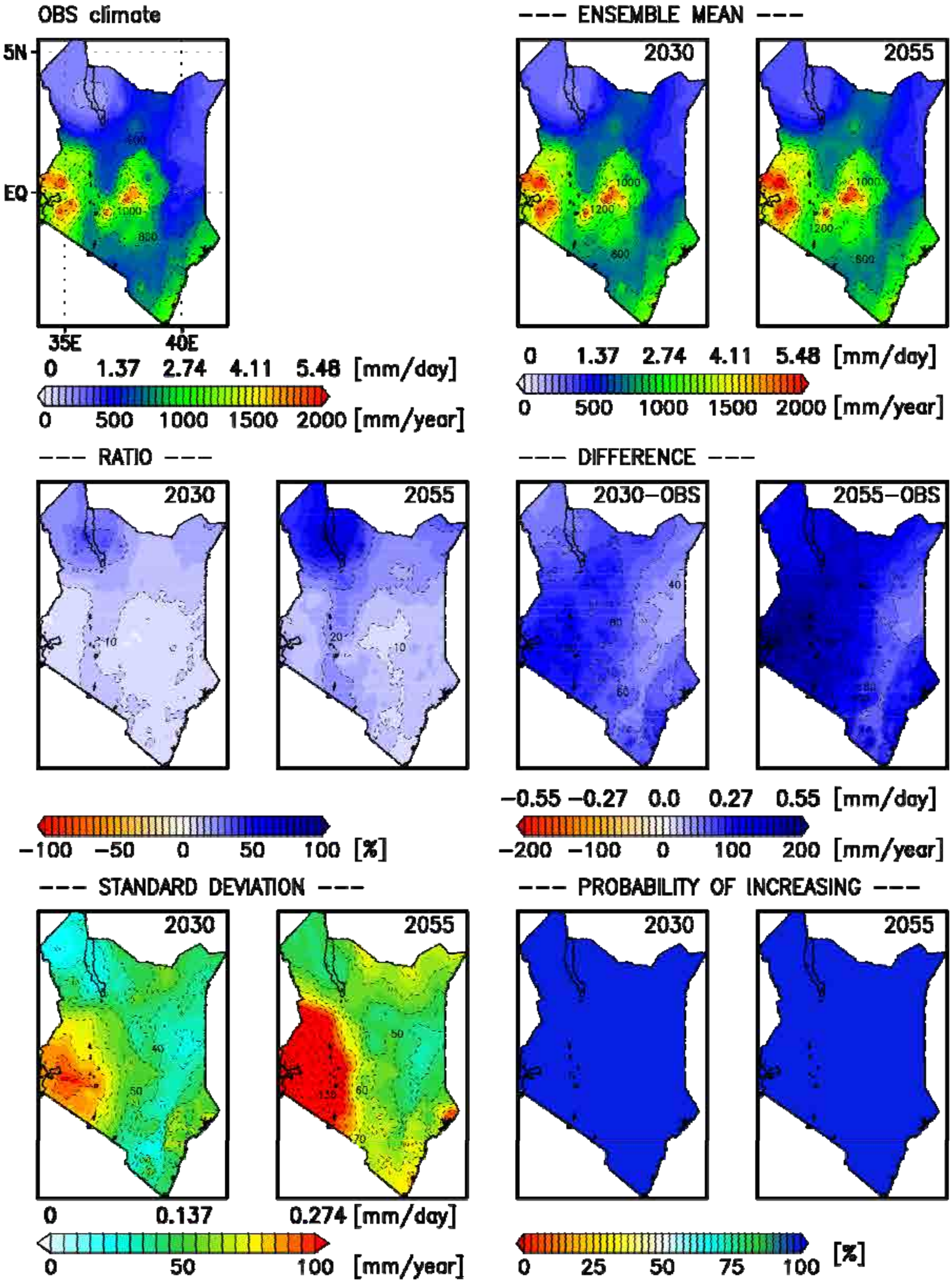
Note: The percentage is based on the means for the 1920s to 2000s period. Color of a zone is derived from average value of stations which are located in the zone. Gray color of a zone means that there is no station in the zone.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 3.3.2** **Spatial Distribution of Rainfall Trend (2/2)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



Source: Analysis by JICA Study Team with the data provided by Kenya Meteorological Department, The Data Integration, and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

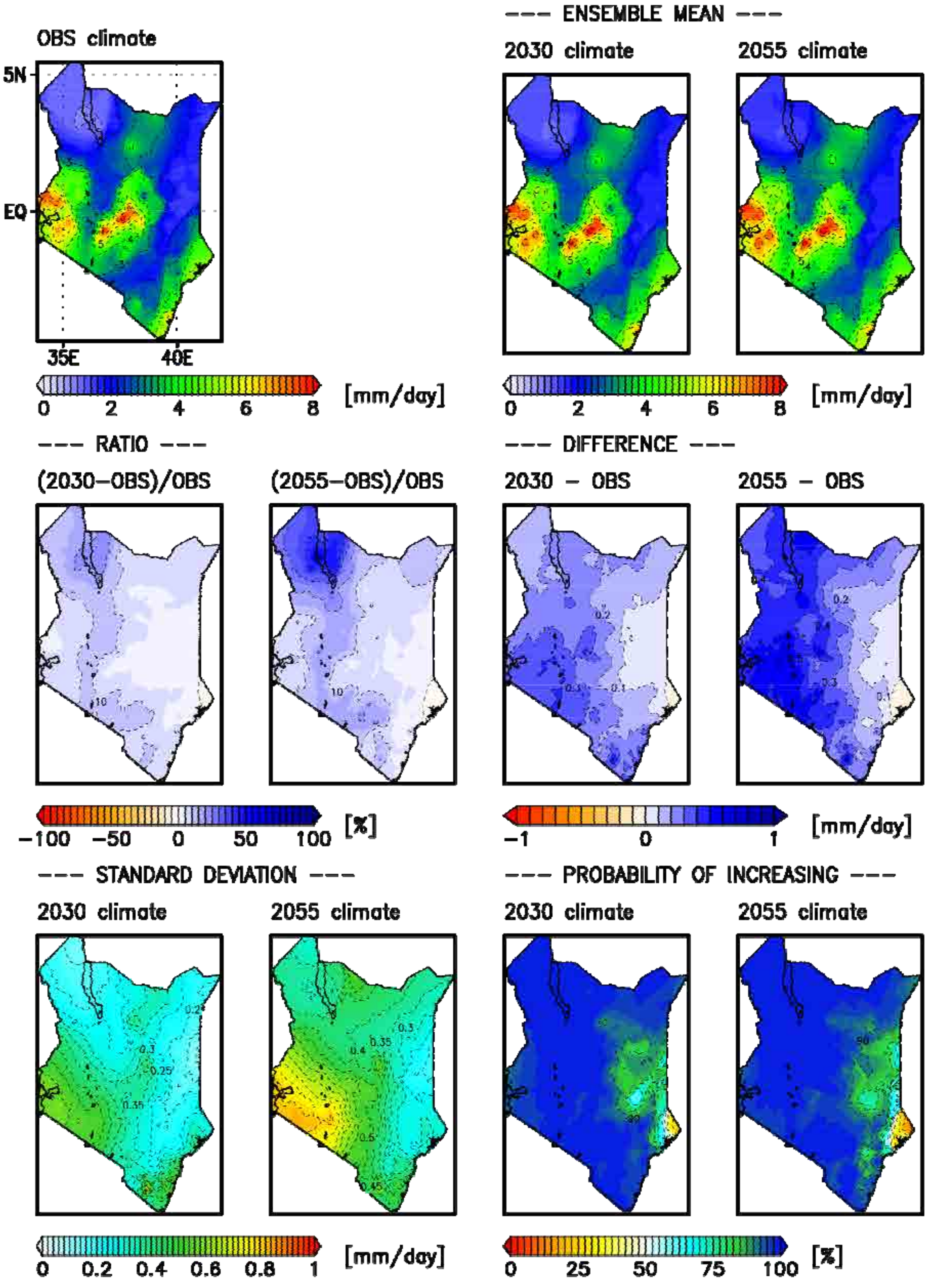
THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.4.1 Evaluation of the Reproducibility of GCMs and Selection of the Appropriate Models**
JAPAN INTERNATIONAL COOPERATION AGENCY	



Note : OBS means Observation

Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

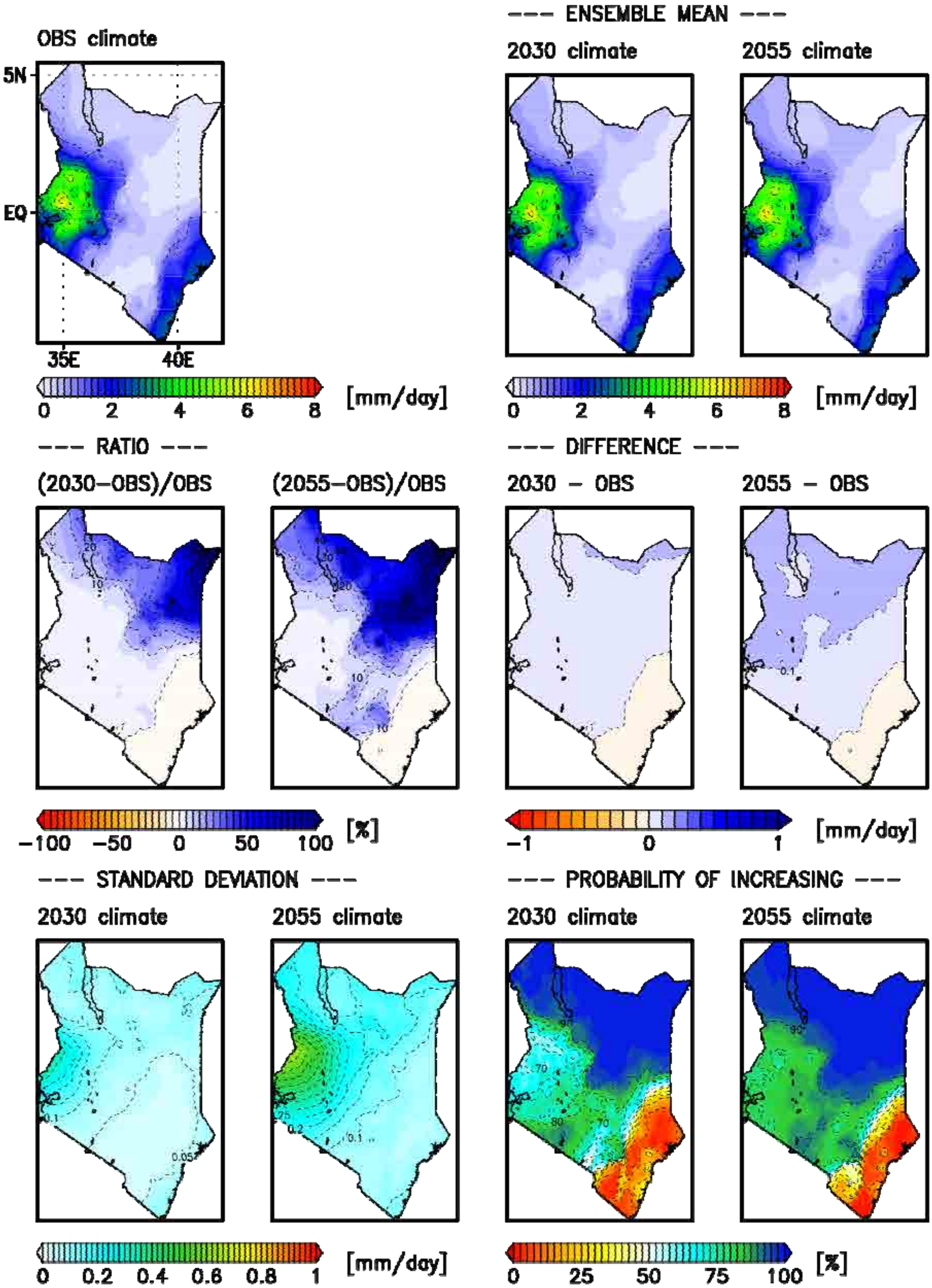
THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.8.1** **Spatial Distribution of Mean Annual Rainfall**
JAPAN INTERNATIONAL COOPERATION AGENCY	



Note : OBS means Observation

Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

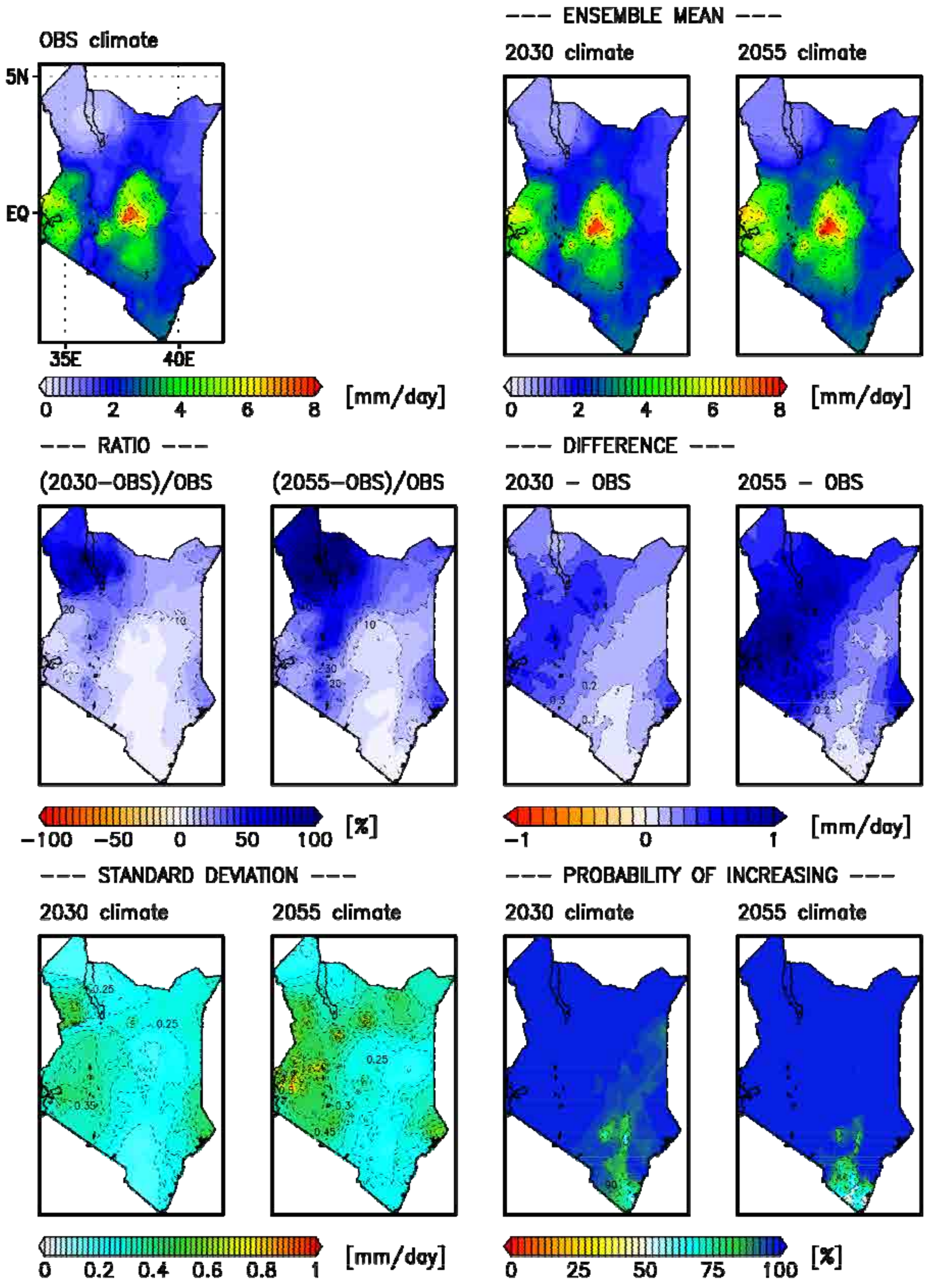
THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.8.2** **Spatial Distribution of Mean Seasonal Rainfall (MAM)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



Note : OBS means Observation

Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

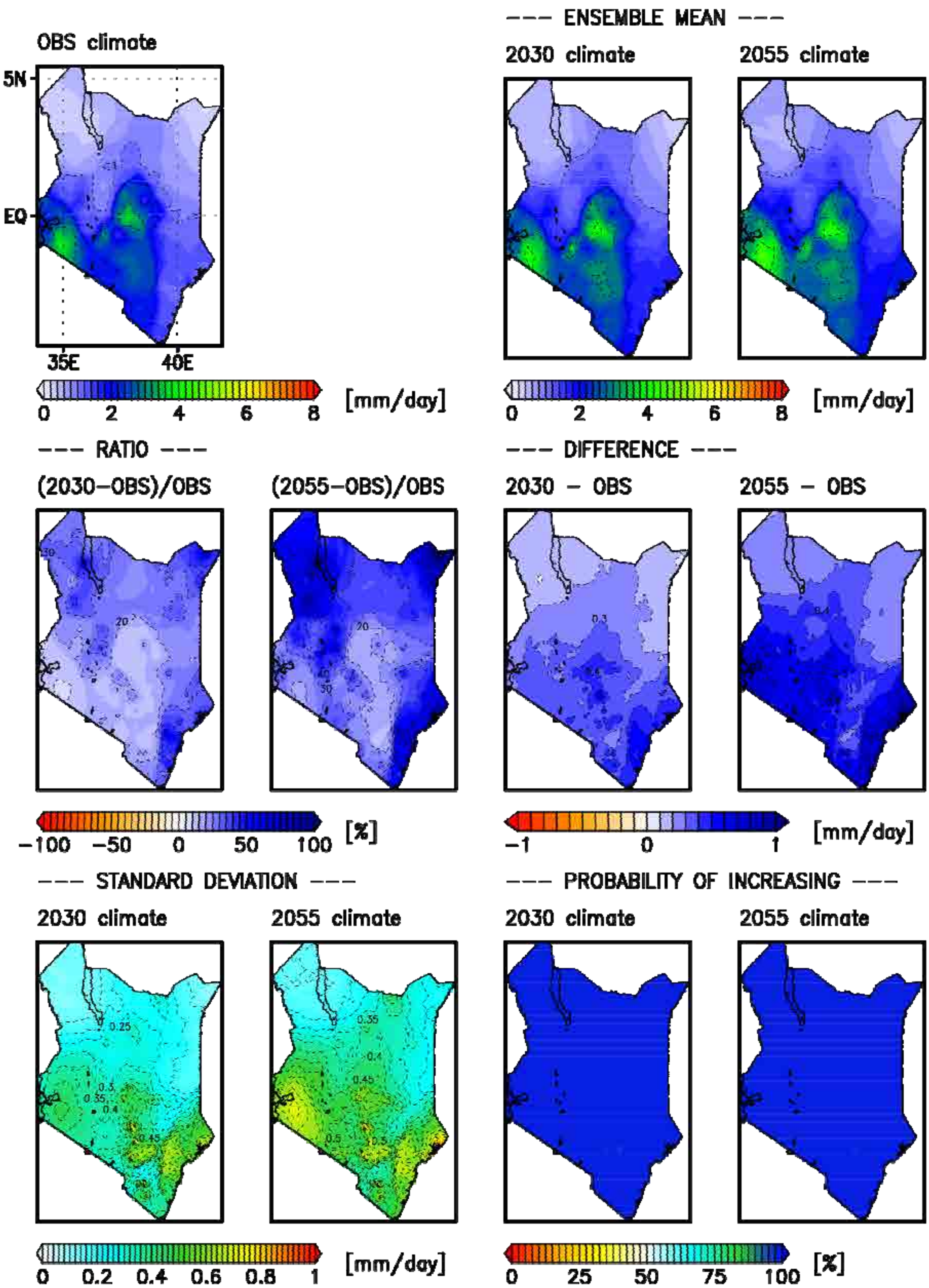
THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.8.3** **Spatial Distribution of** **Mean Seasonal Rainfall (JJA)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



Note : OBS means Observation

Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

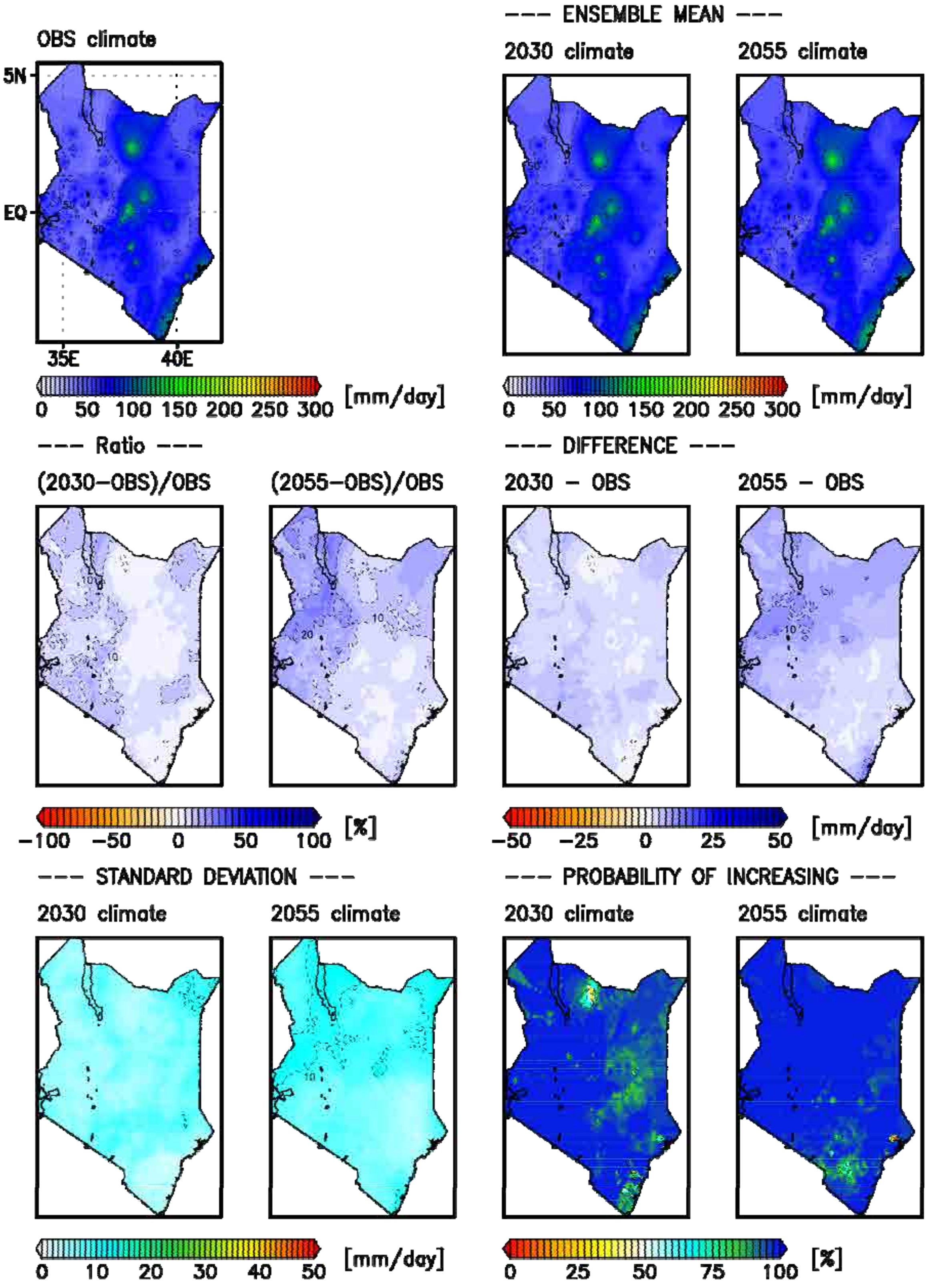
THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.8.4** **Spatial Distribution of Mean Seasonal Rainfall (SON)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



Note : OBS means Observation

Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

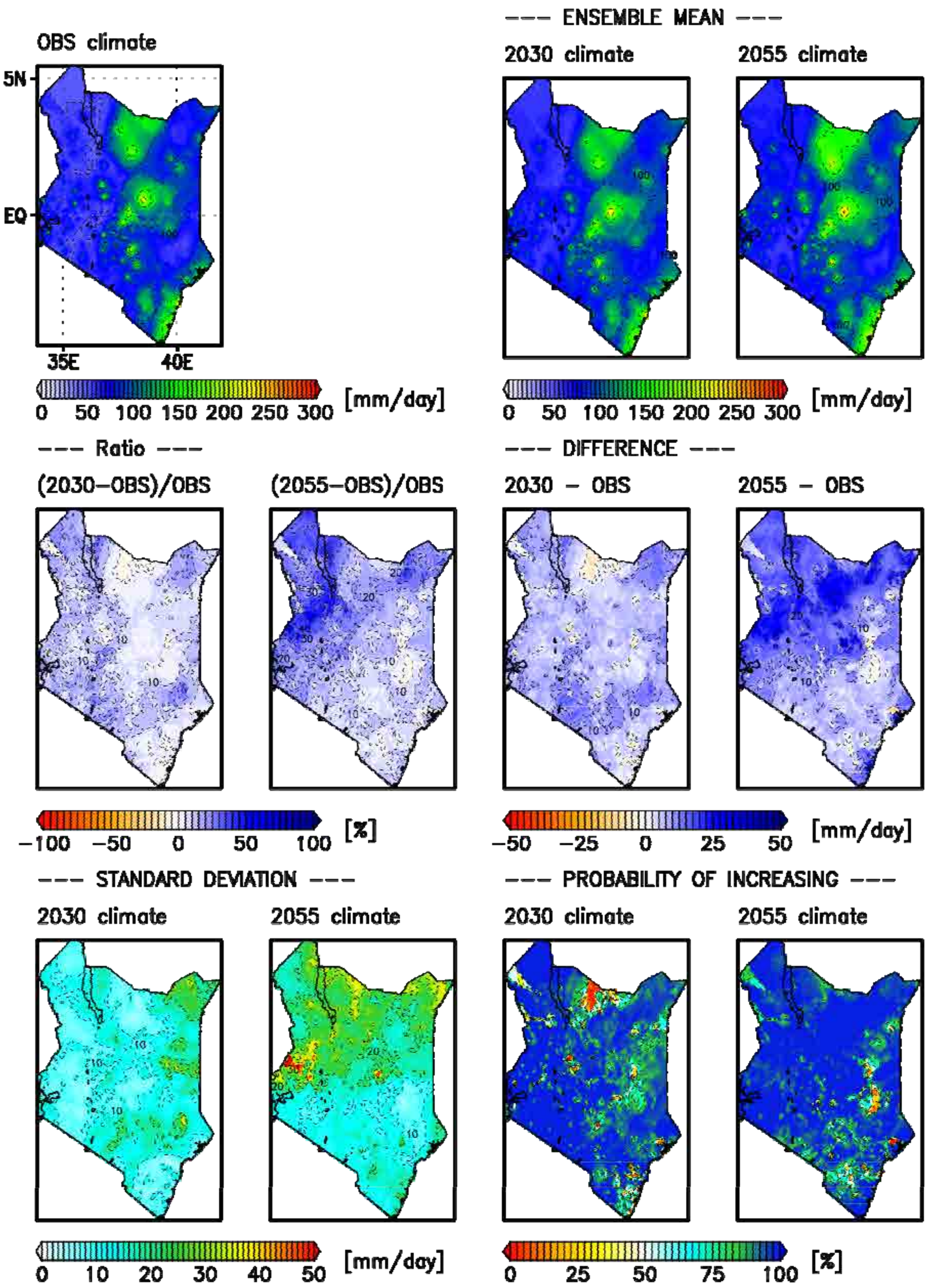
THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.8.5** **Spatial Distribution of** **Mean Seasonal Rainfall (DJF)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



Note : OBS means Observation

Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

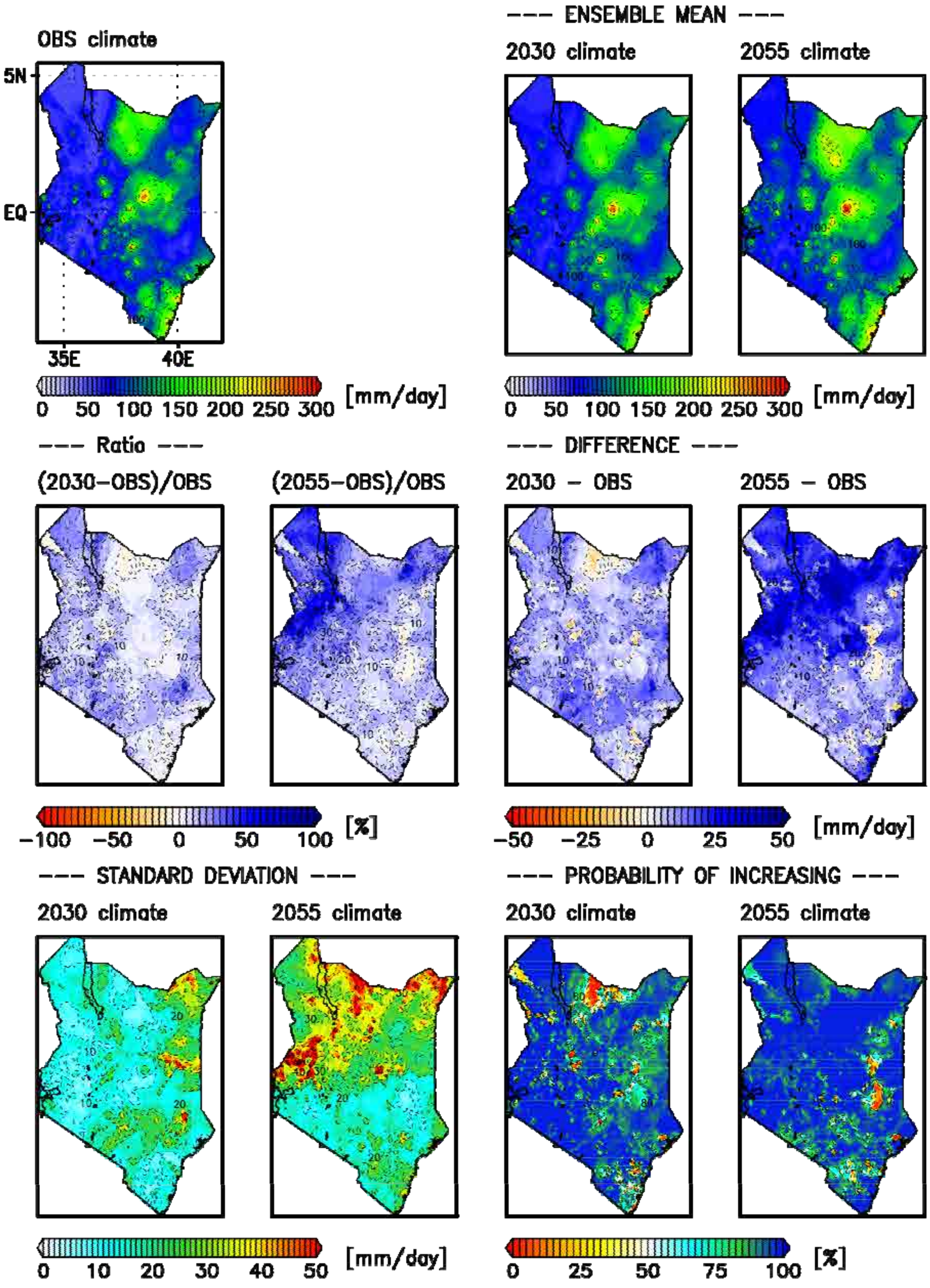
THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.8.6** **Spatial Distribution of Daily Rainfall Intensity for 10 years return period**
JAPAN INTERNATIONAL COOPERATION AGENCY	



Note : OBS means Observation

Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

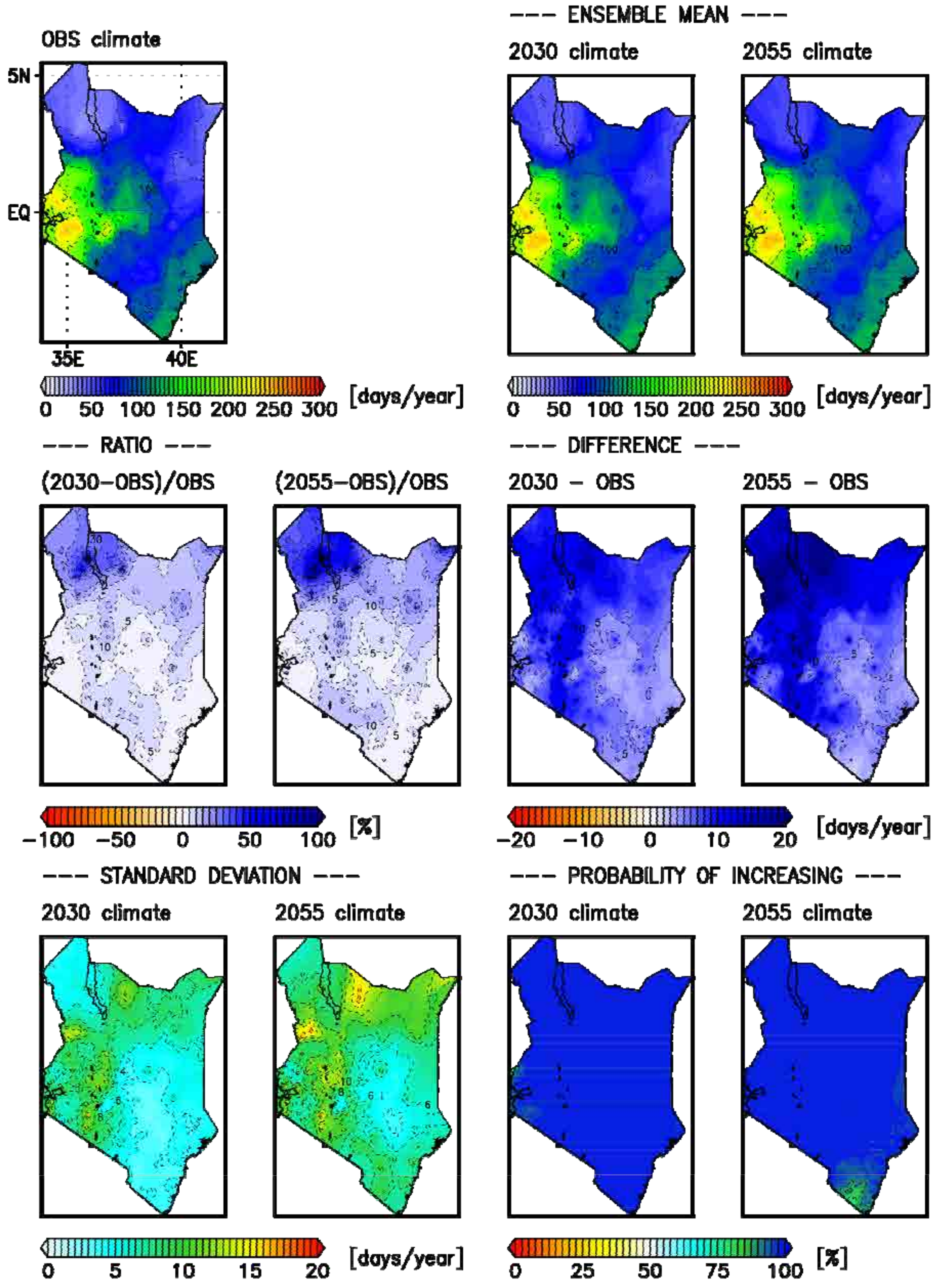
THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.8.7** **Spatial Distribution of Daily Rainfall Intensity for 50 years return period**
JAPAN INTERNATIONAL COOPERATION AGENCY	



Note : OBS means Observation

Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

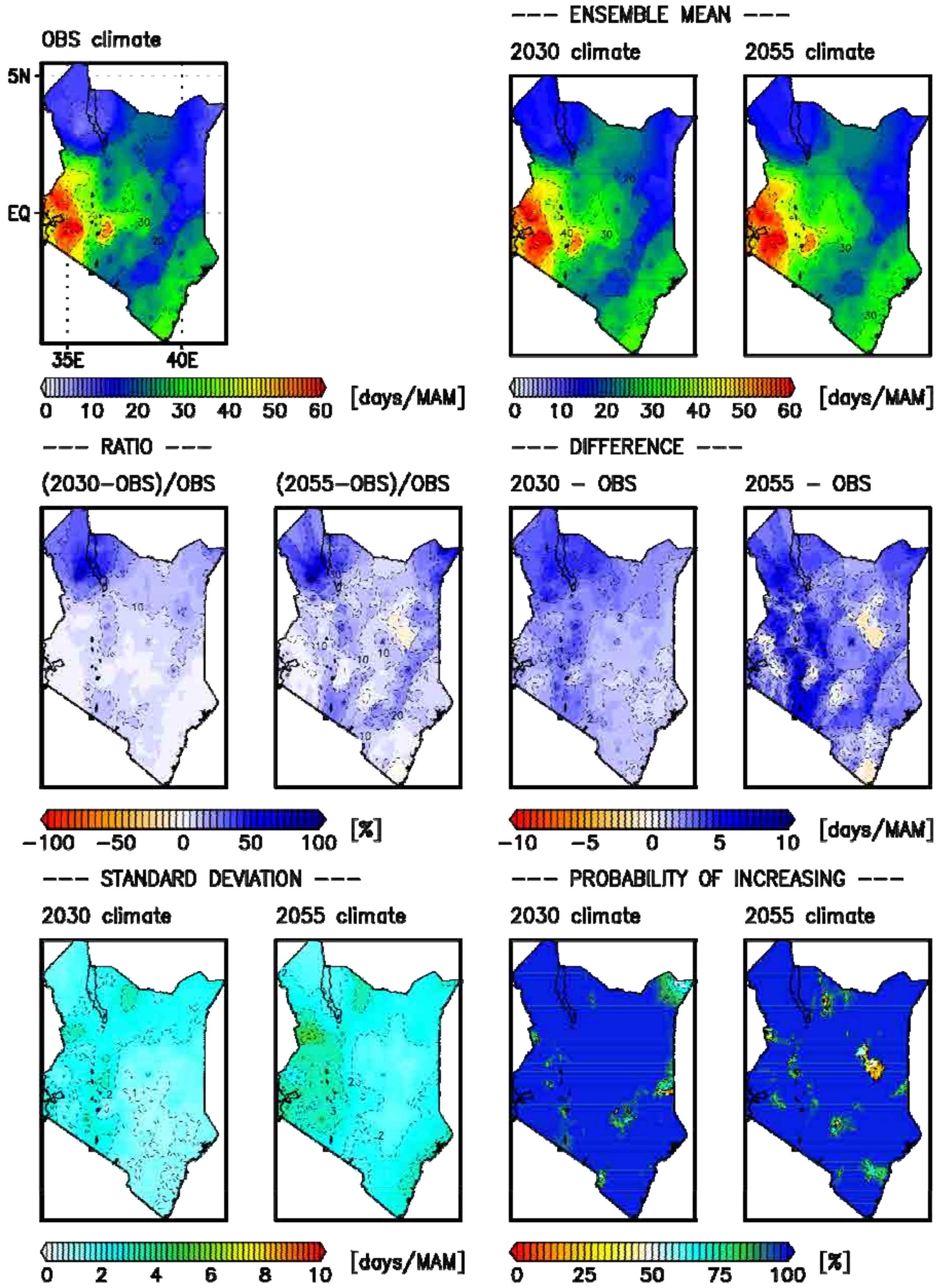
THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.8.8** **Spatial Distribution of Daily Rainfall Intensity for 100 years return period**
JAPAN INTERNATIONAL COOPERATION AGENCY	



Note : OBS means Observation

Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

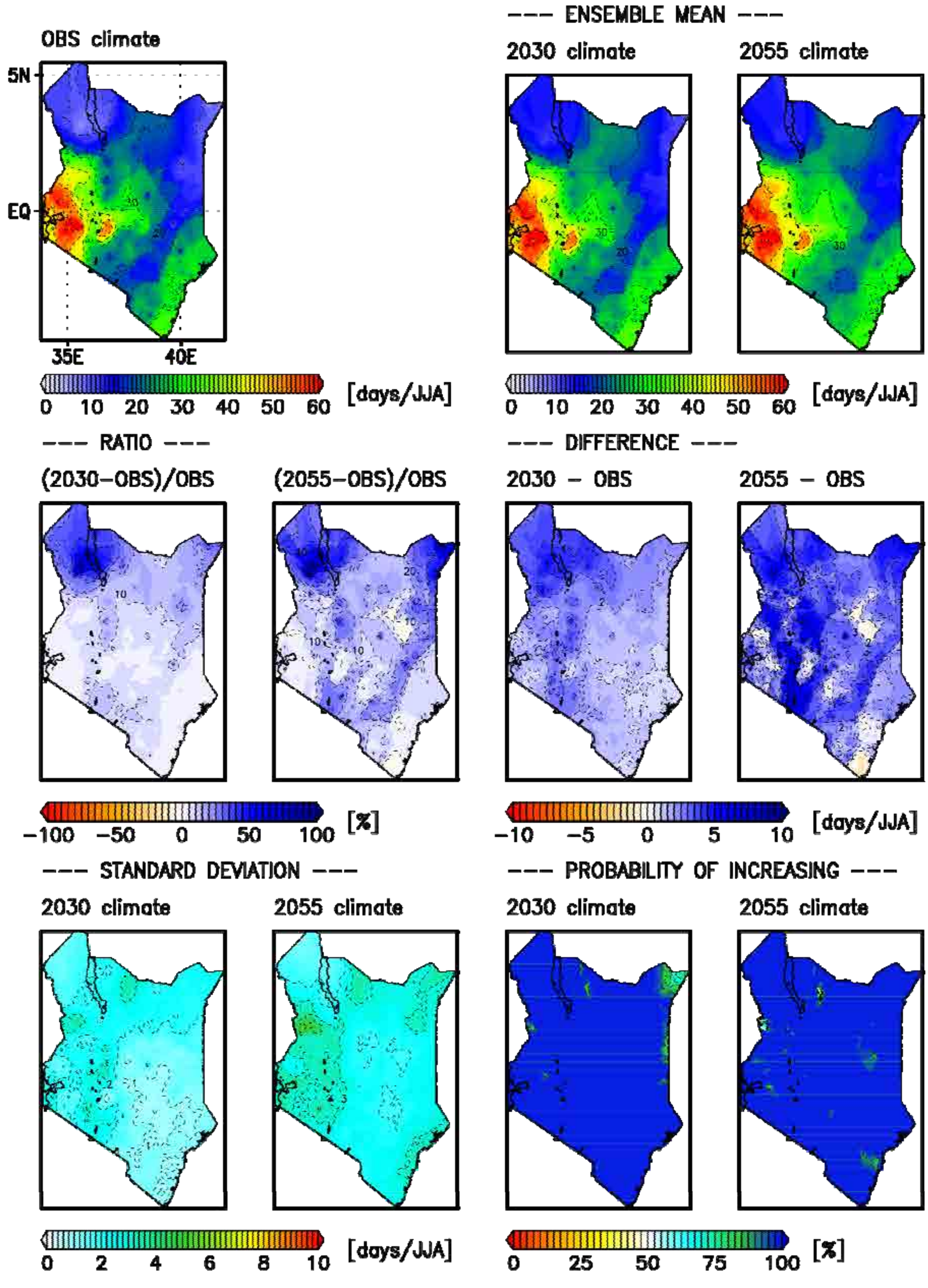
THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.8.9** **Spatial Distribution of** **Number of Rainy Days per Year**
JAPAN INTERNATIONAL COOPERATION AGENCY	



Note : OBS means Observation

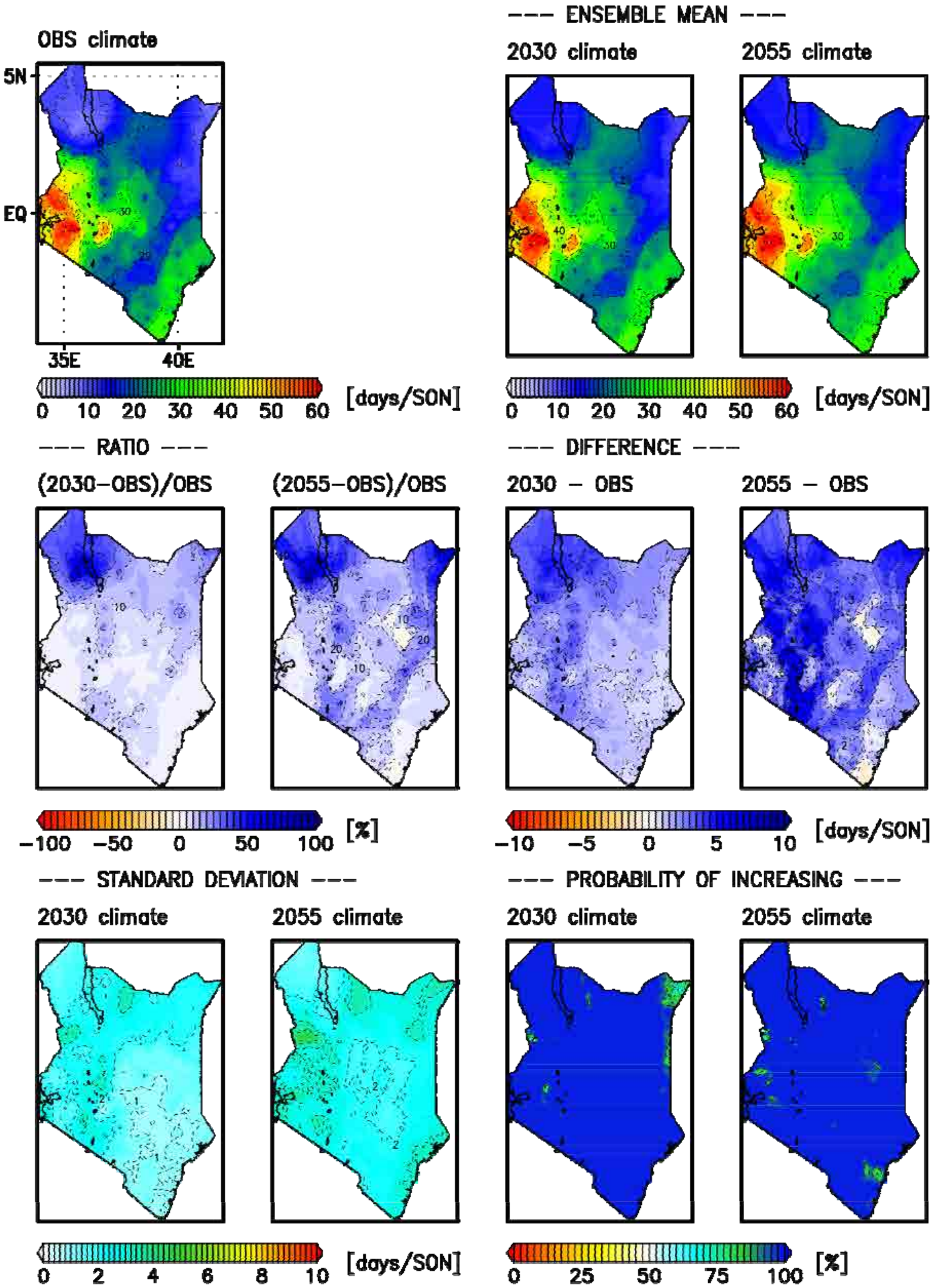
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.8.10 Spatial Distribution of Number of Rainy Days per Season (MAM)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



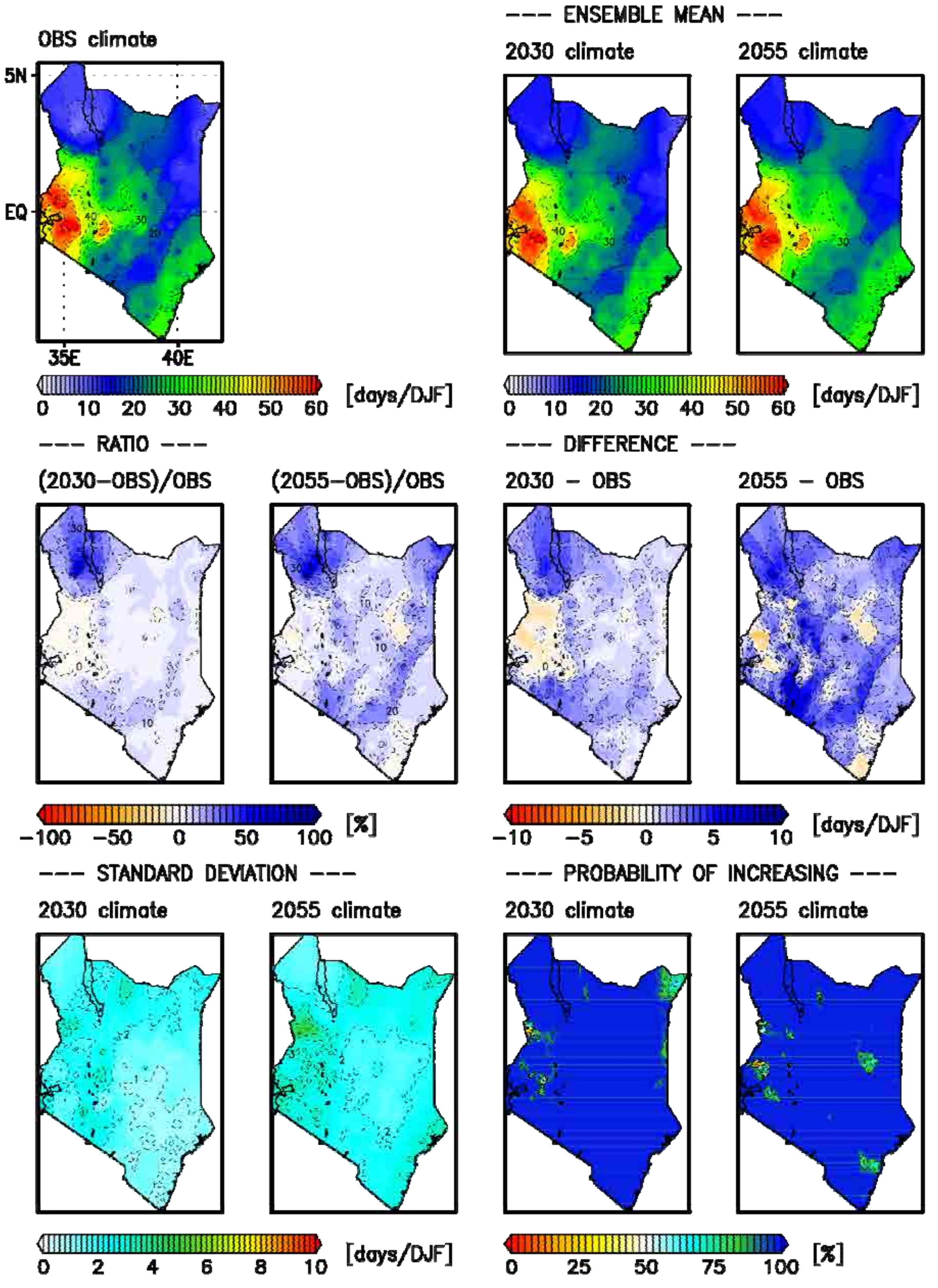
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.8.11** **Spatial Distribution of Number of Rainy Days per Season (JJA)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



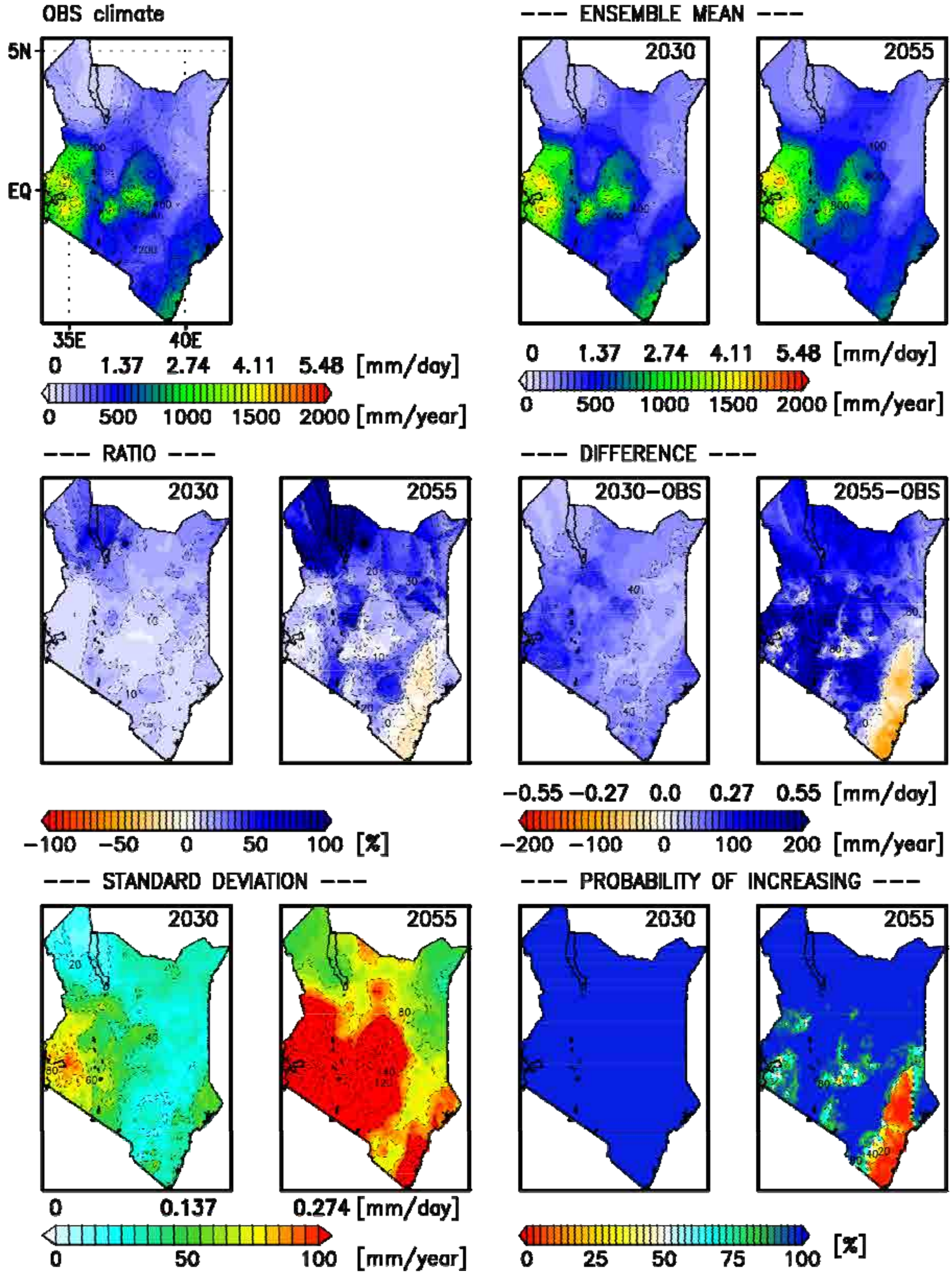
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.8.12** **Spatial Distribution of Number of Rainy Days per Season (SON)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



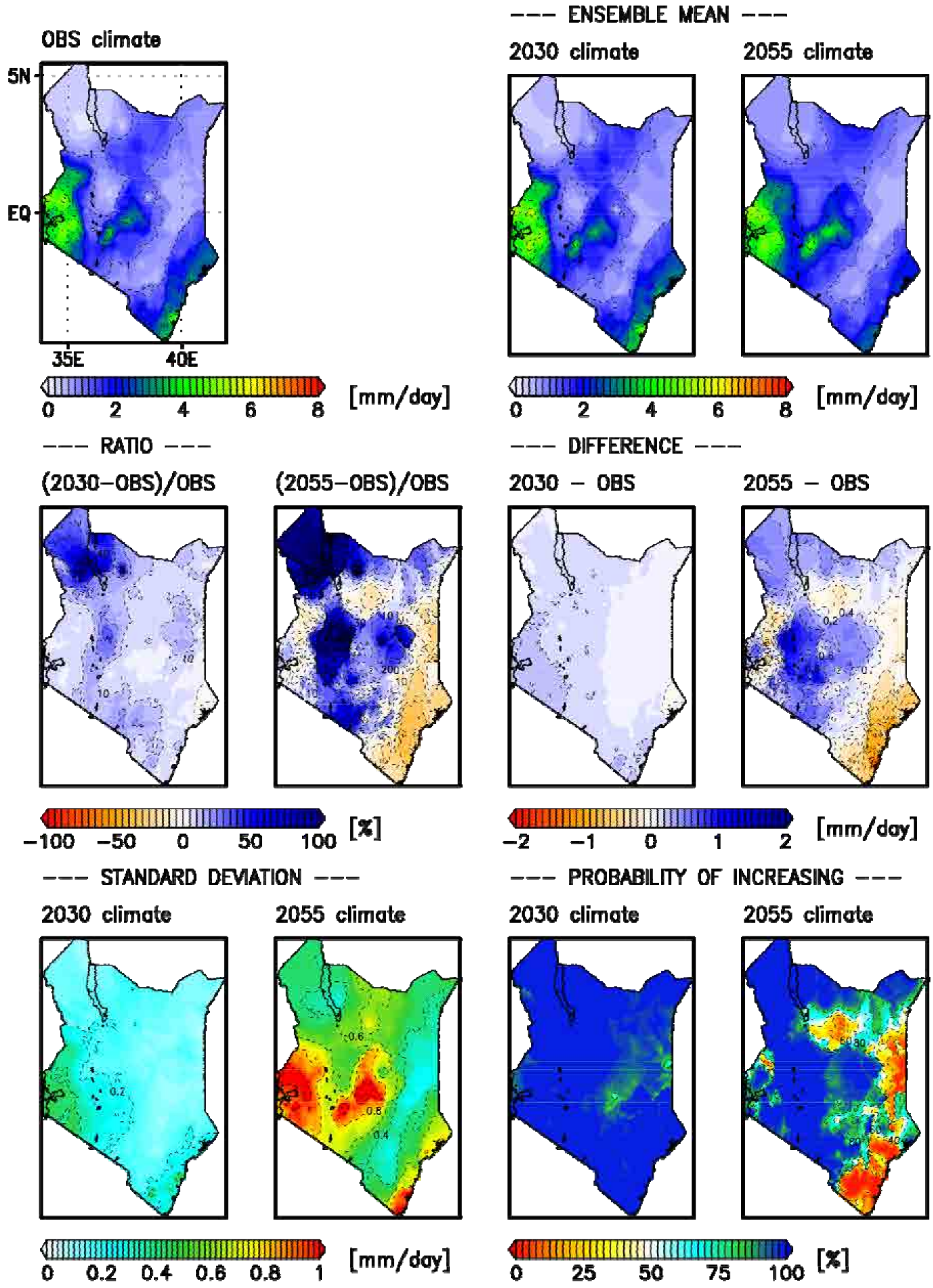
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.8.13** **Spatial Distribution of Number of Rainy Days per Season (DJF)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



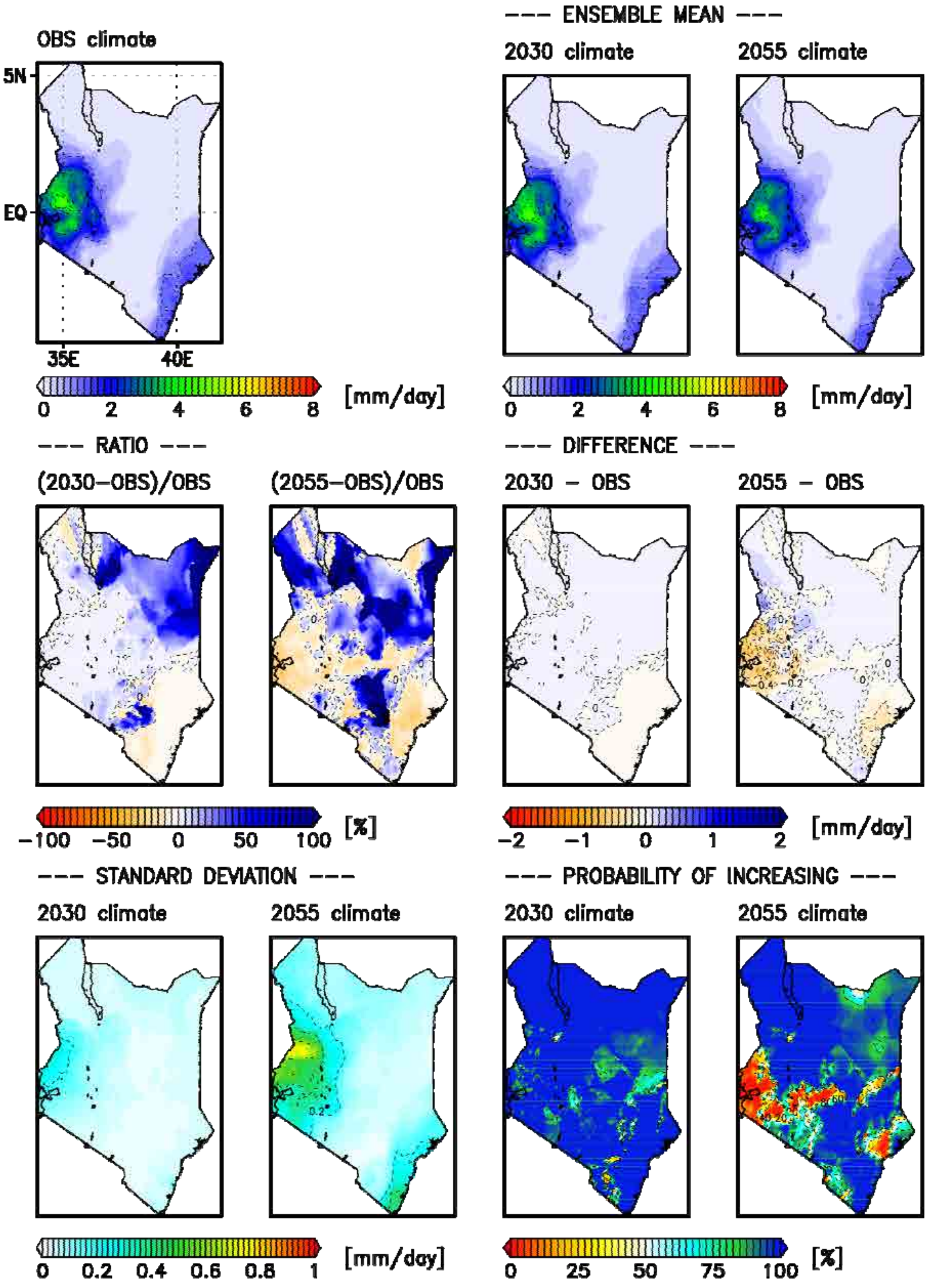
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.8.14** **Spatial Distribution of Mean Annual Rainfall of Drought Year for 10 years Return Period**
JAPAN INTERNATIONAL COOPERATION AGENCY	



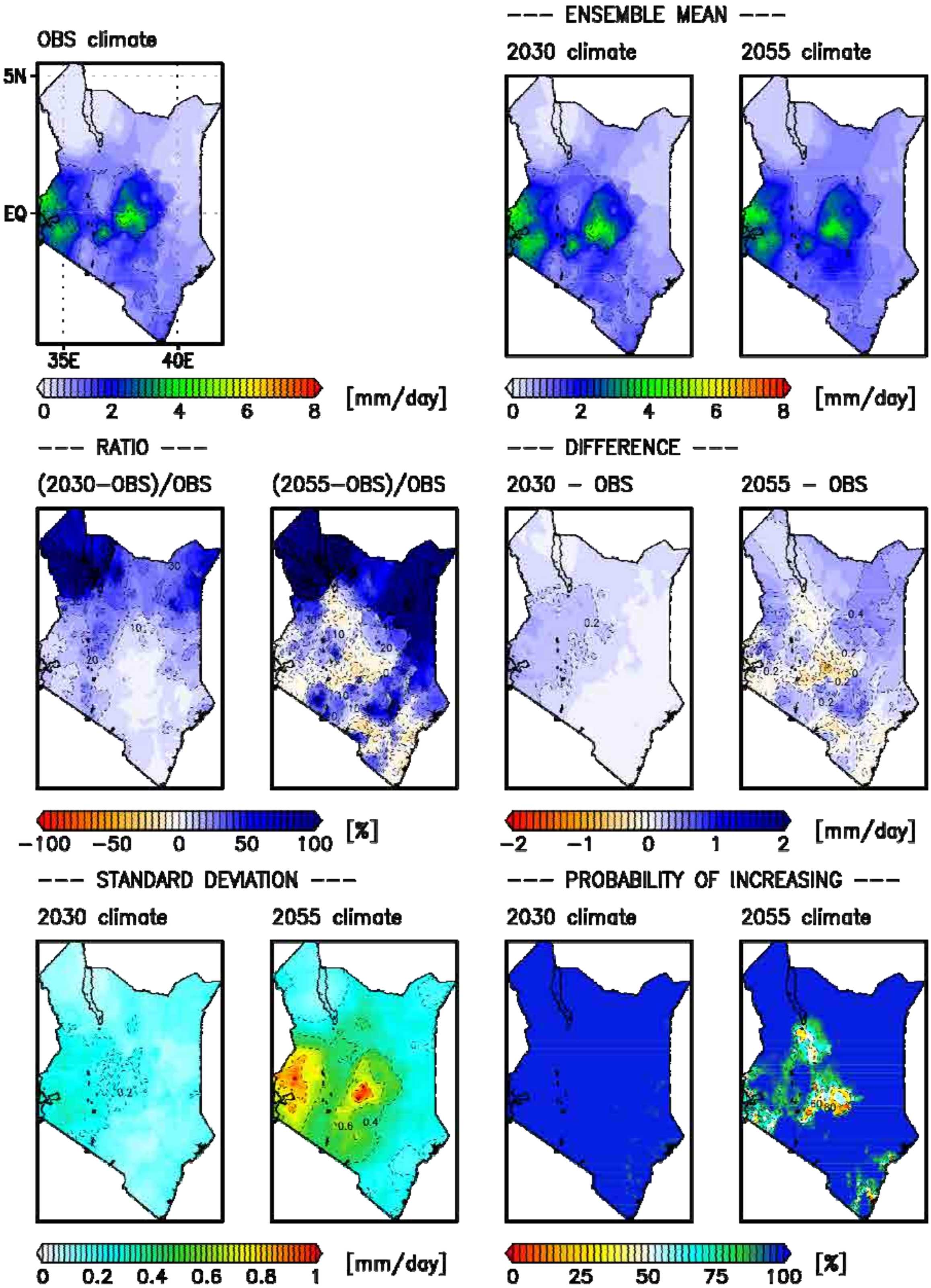
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.8.15 Spatial Distribution of Mean Seasonal Rainfall of Drought Year for 10 Years Return Period (MAM)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



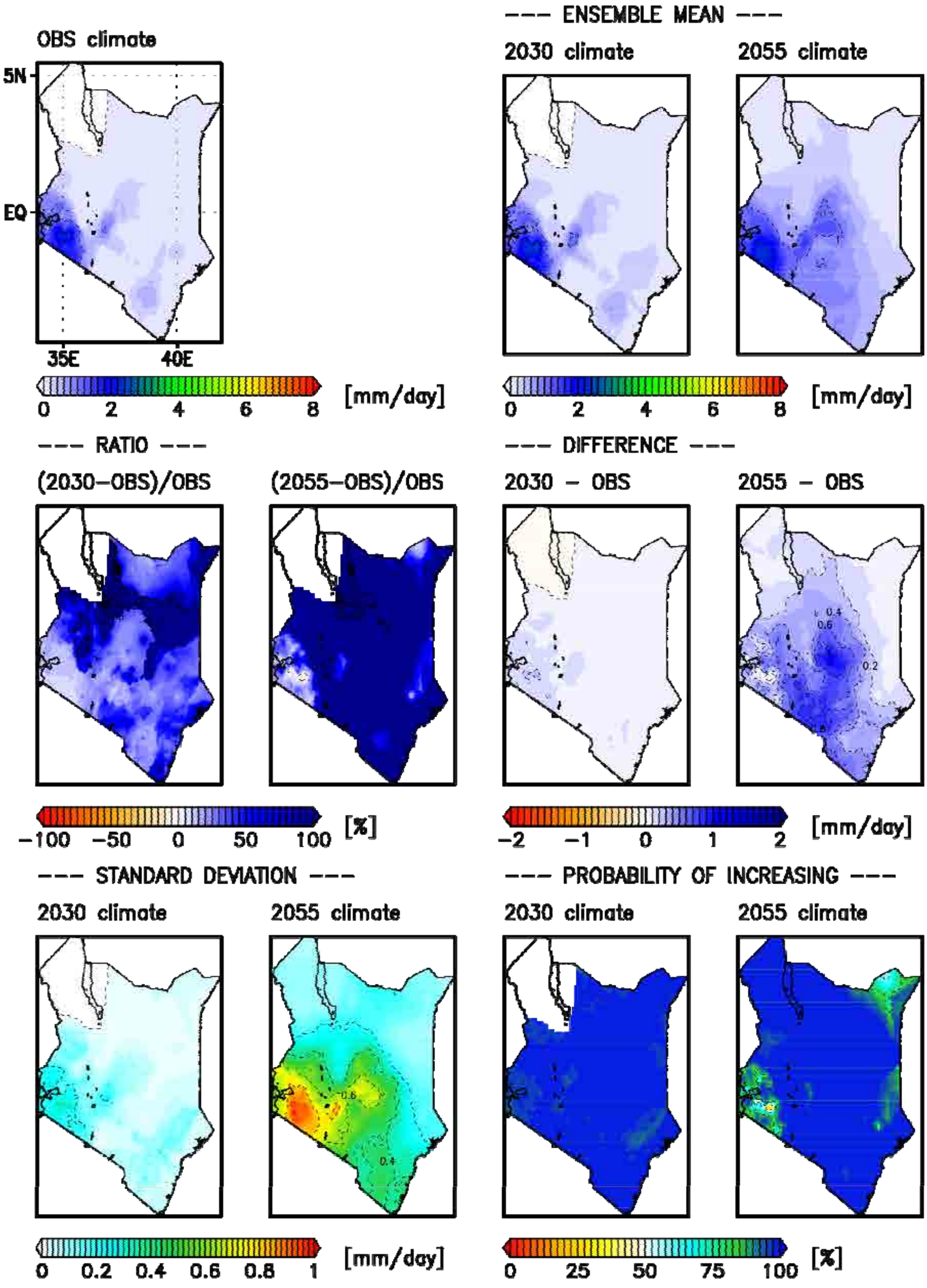
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.8.16**
JAPAN INTERNATIONAL COOPERATION AGENCY	**Spatial Distribution of Mean Seasonal Rainfall of Drought Year for 10 Years Return Period (JJA)**



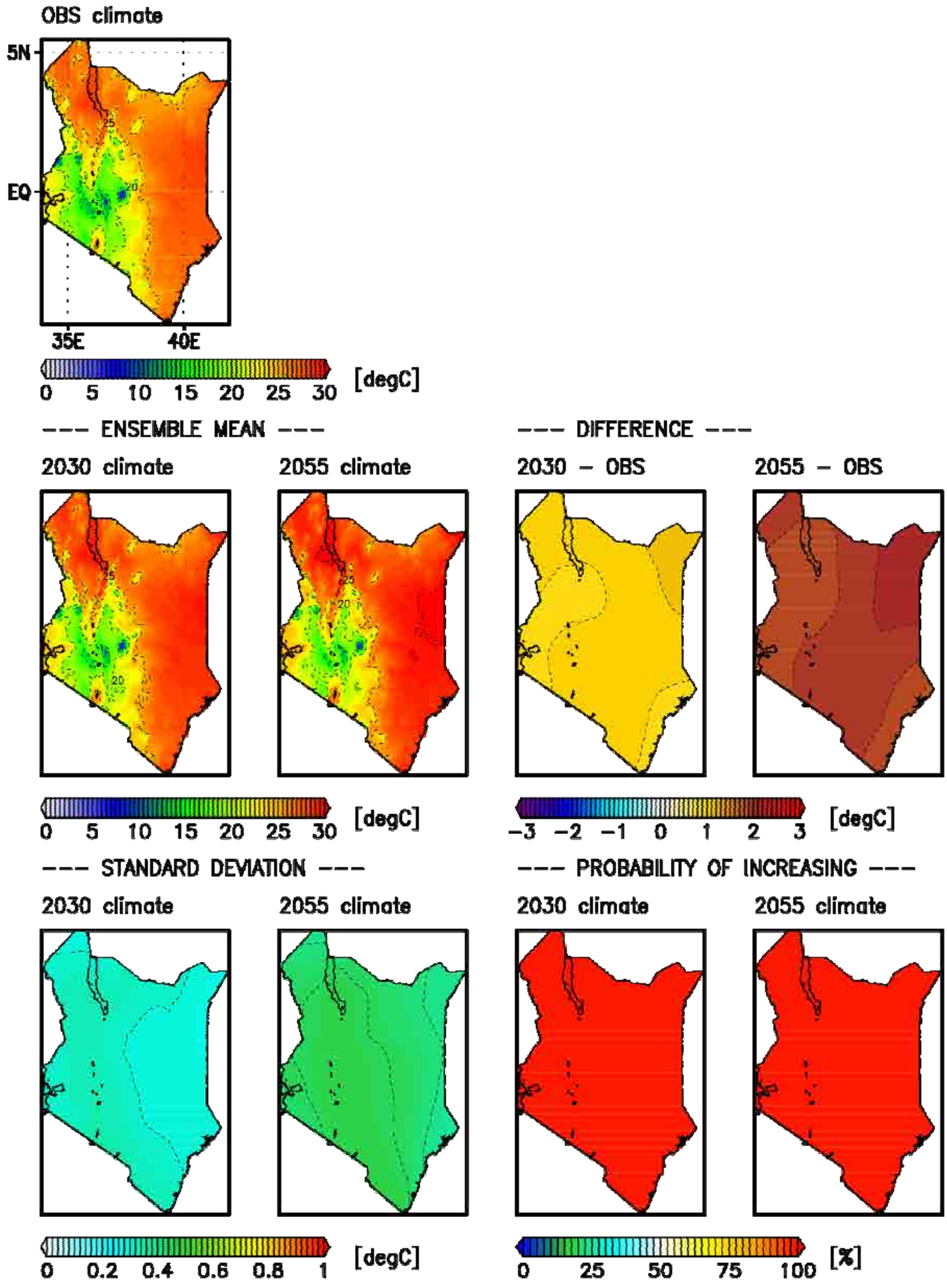
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.8.17**
JAPAN INTERNATIONAL COOPERATION AGENCY	**Spatial Distribution of Mean Seasonal Rainfall of Drought Year for 10 Years Return Period (SON)**



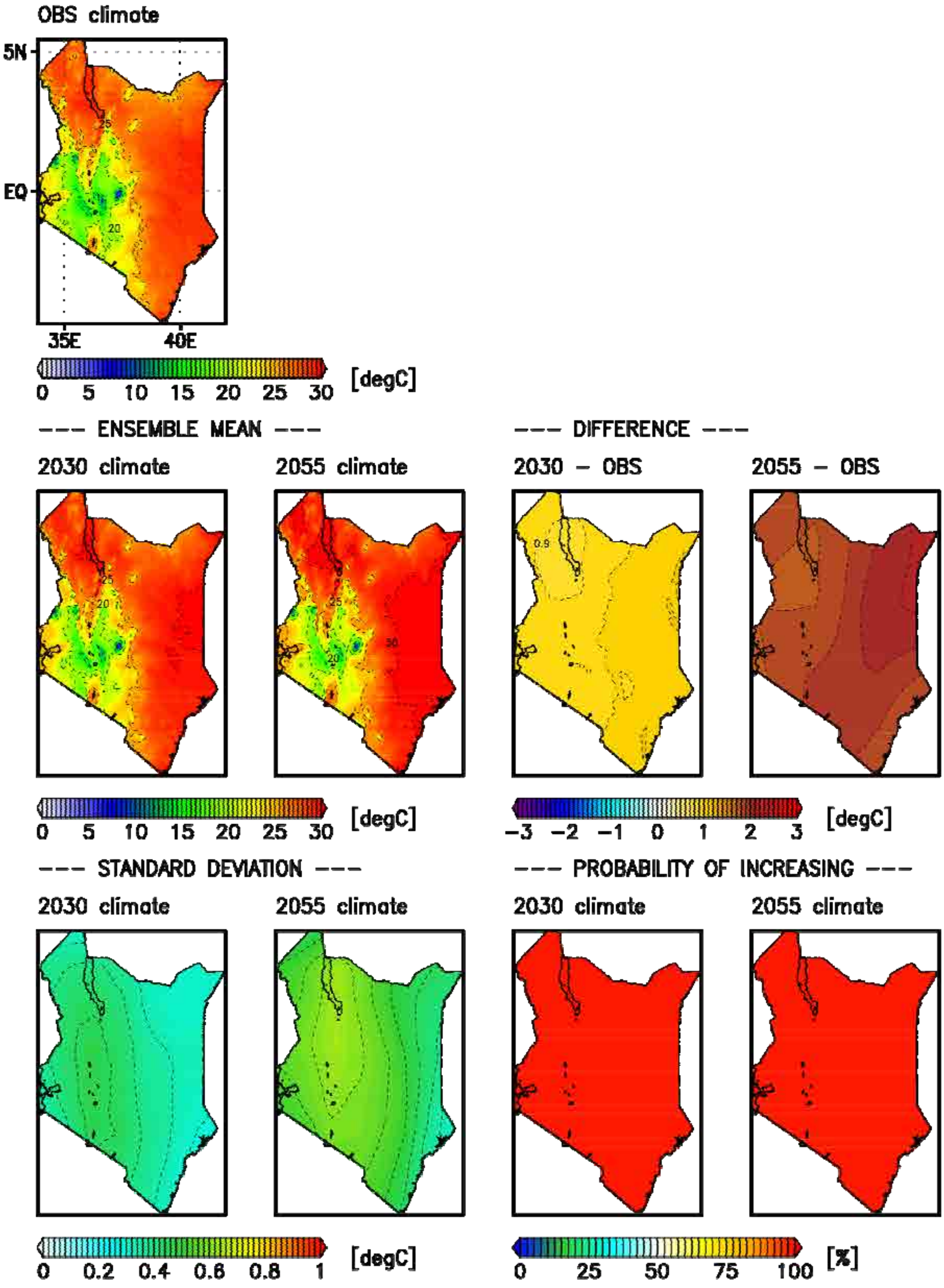
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.8.18** **Spatial Distribution of** **Mean Seasonal Rainfall of Drought Year for 10 Years Return Period (DJF)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



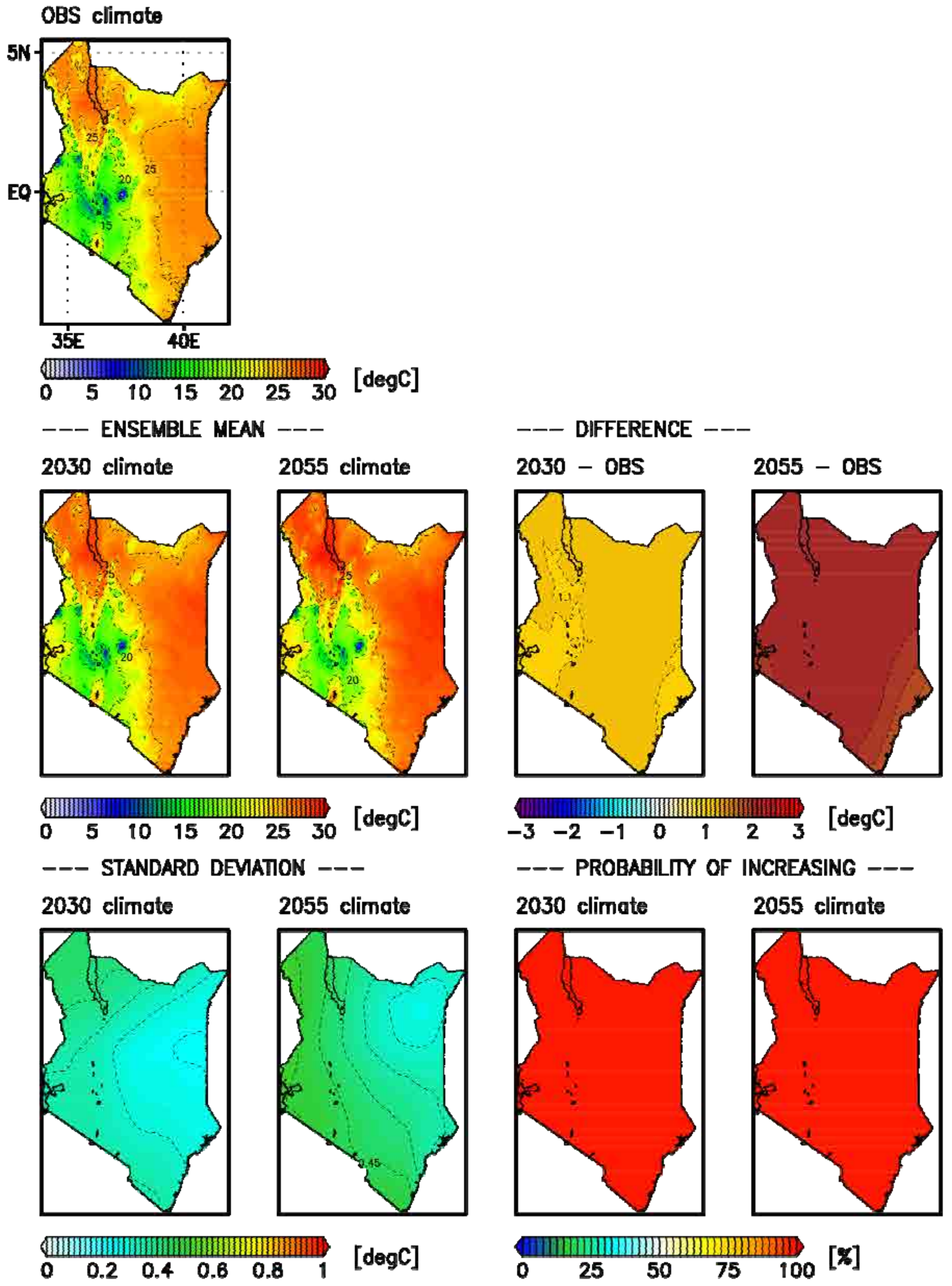
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.8.19** **Spatial Distribution of Mean Annual Surface Air Temperature**
JAPAN INTERNATIONAL COOPERATION AGENCY	



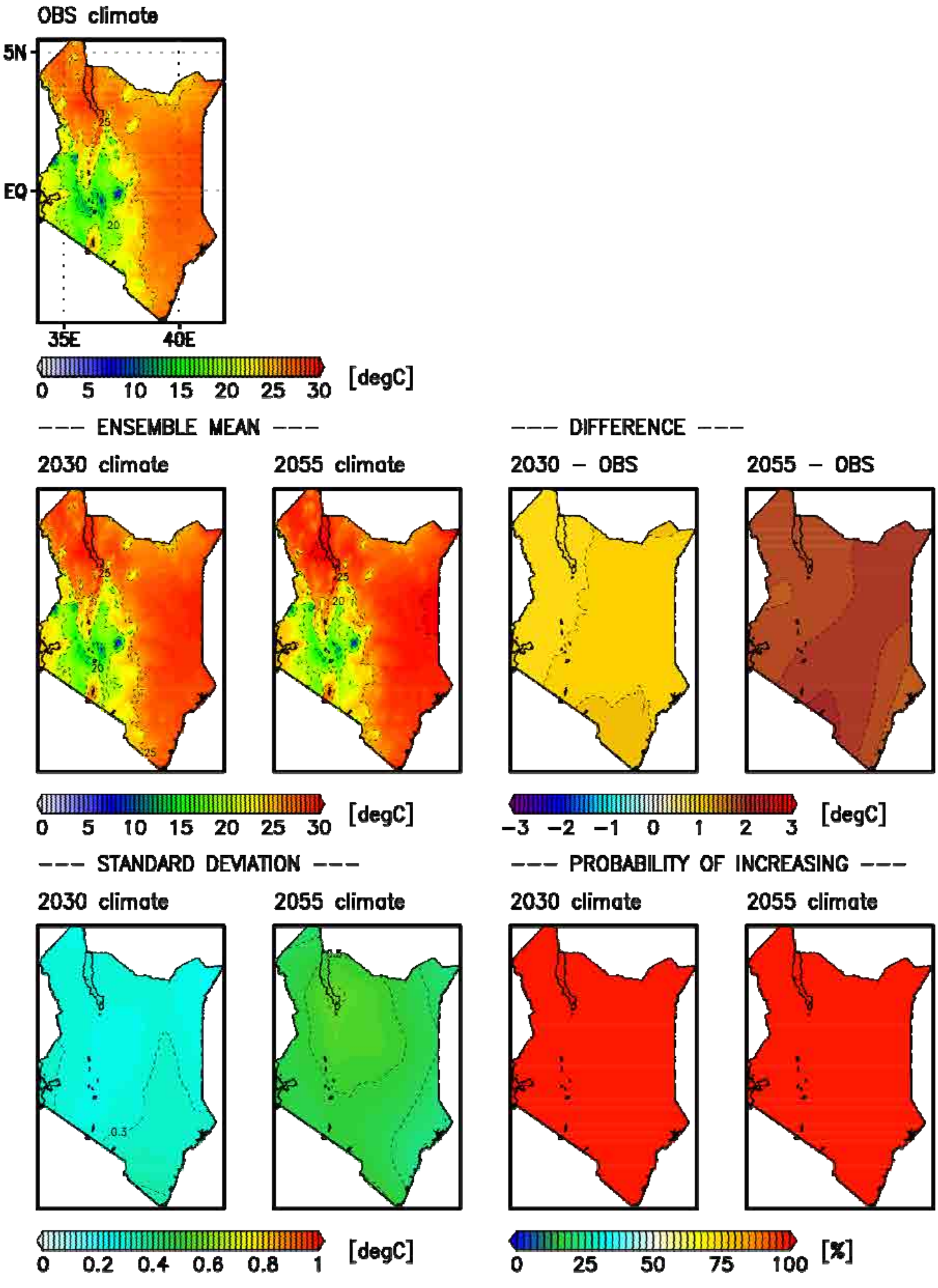
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.8.20** **Spatial Distribution of Mean Seasonal Surface Air Temperature (MAM)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



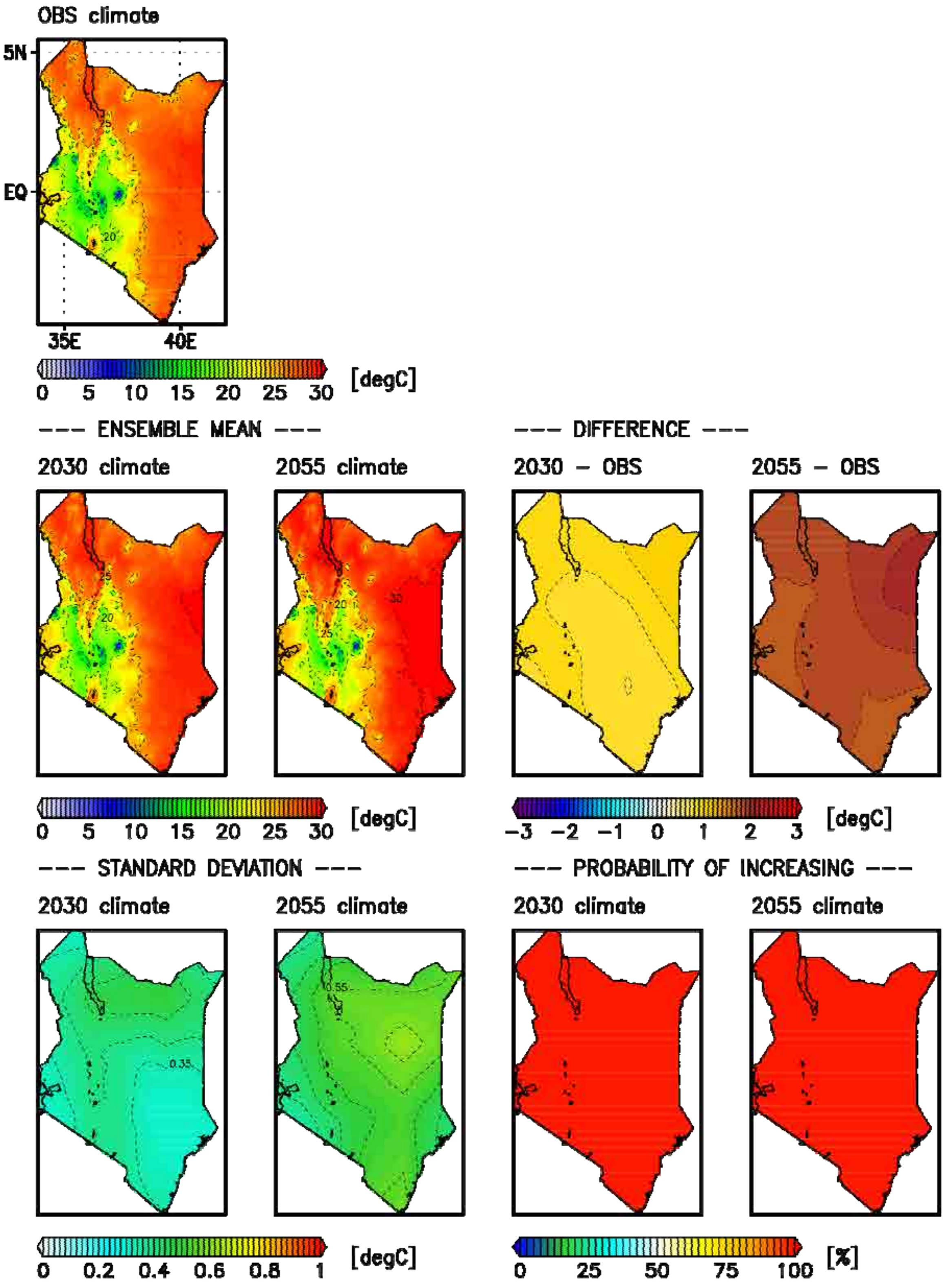
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.8.21 Spatial Distribution of Mean Seasonal Surface Air Temperature (JJA)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



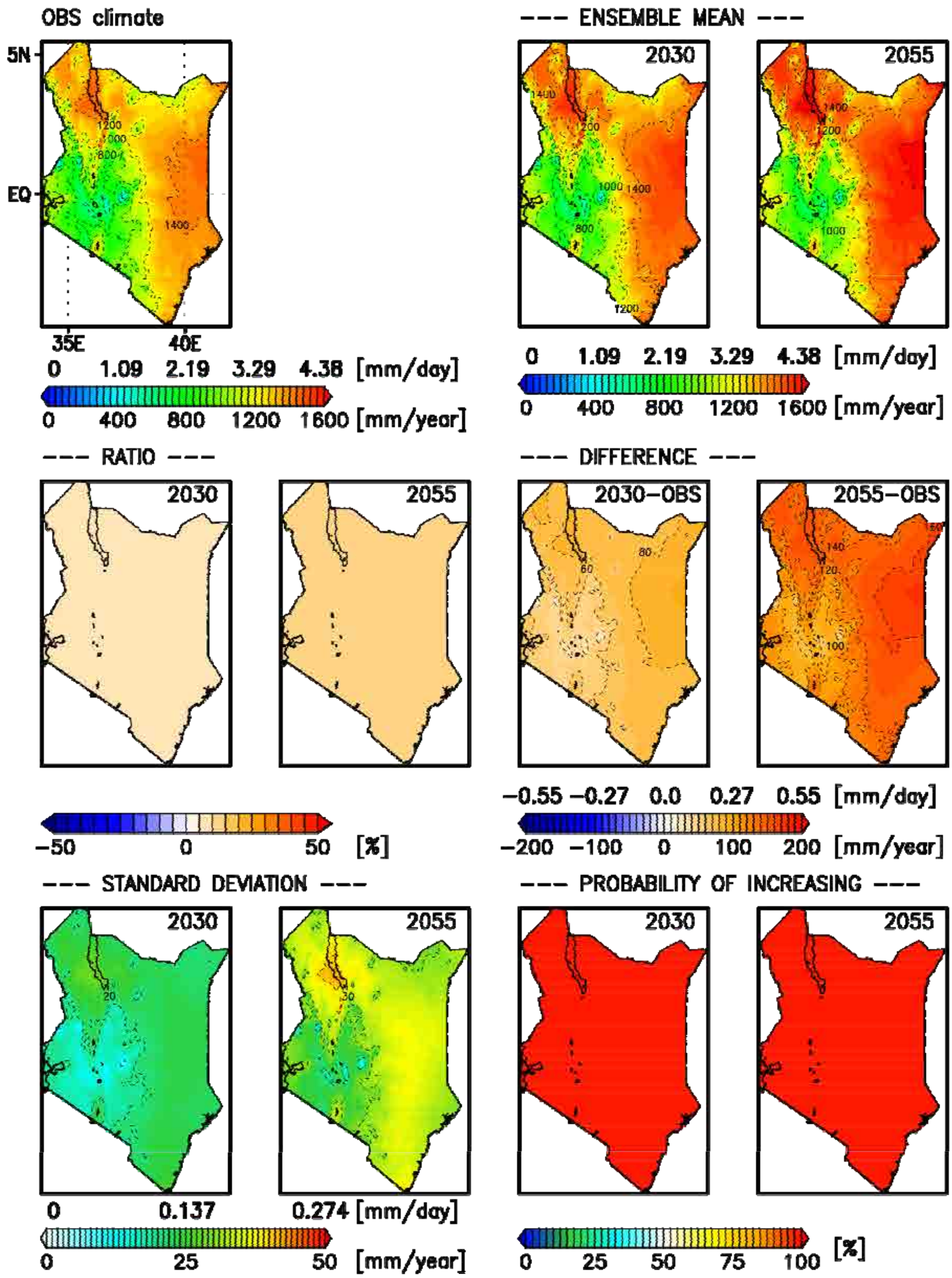
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.8.22 Spatial Distribution of Mean Seasonal Surface Air Temperature (SON)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



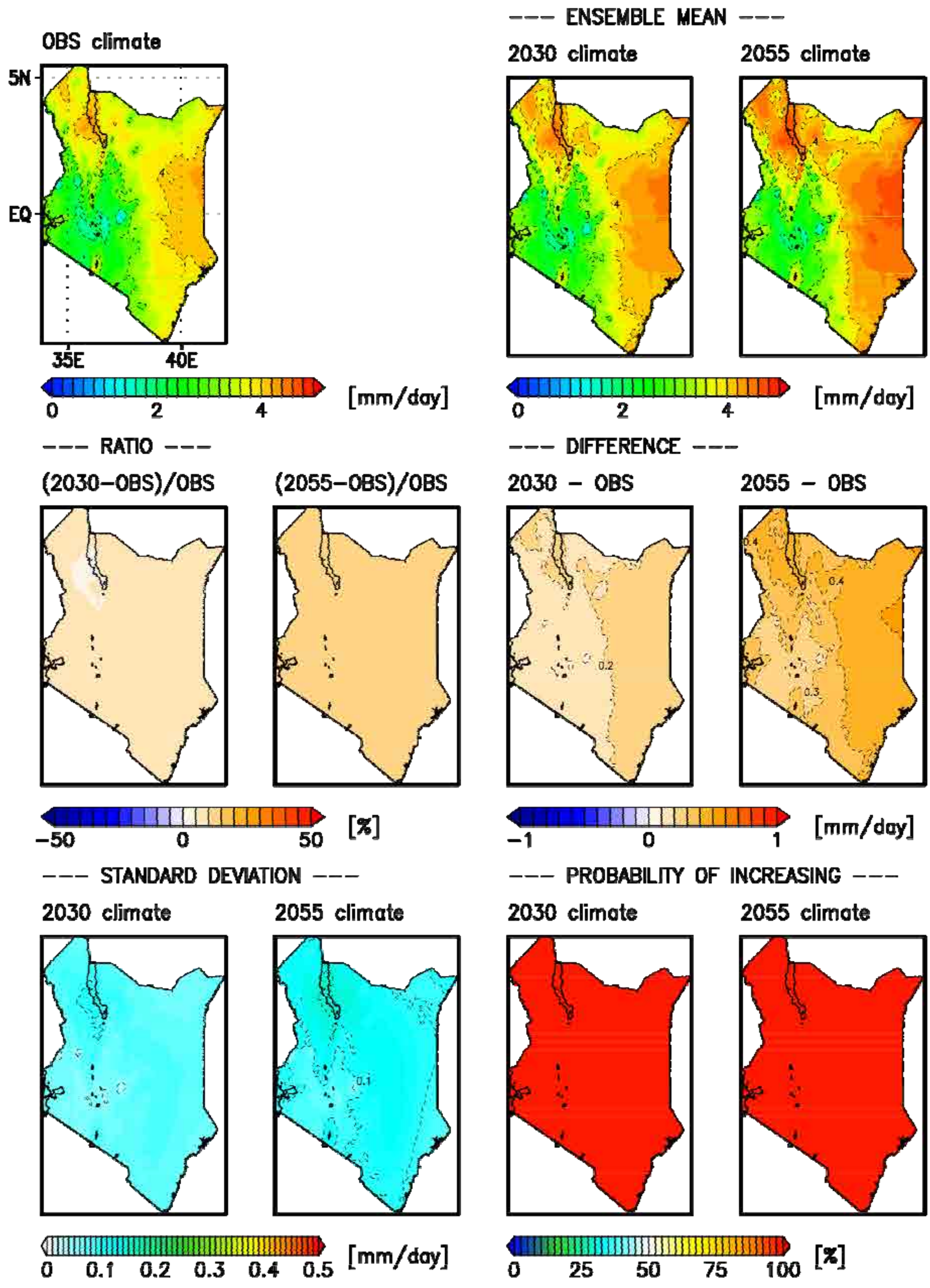
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.8.23** **Spatial Distribution of Mean Seasonal Surface Air Temperature (DJF)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



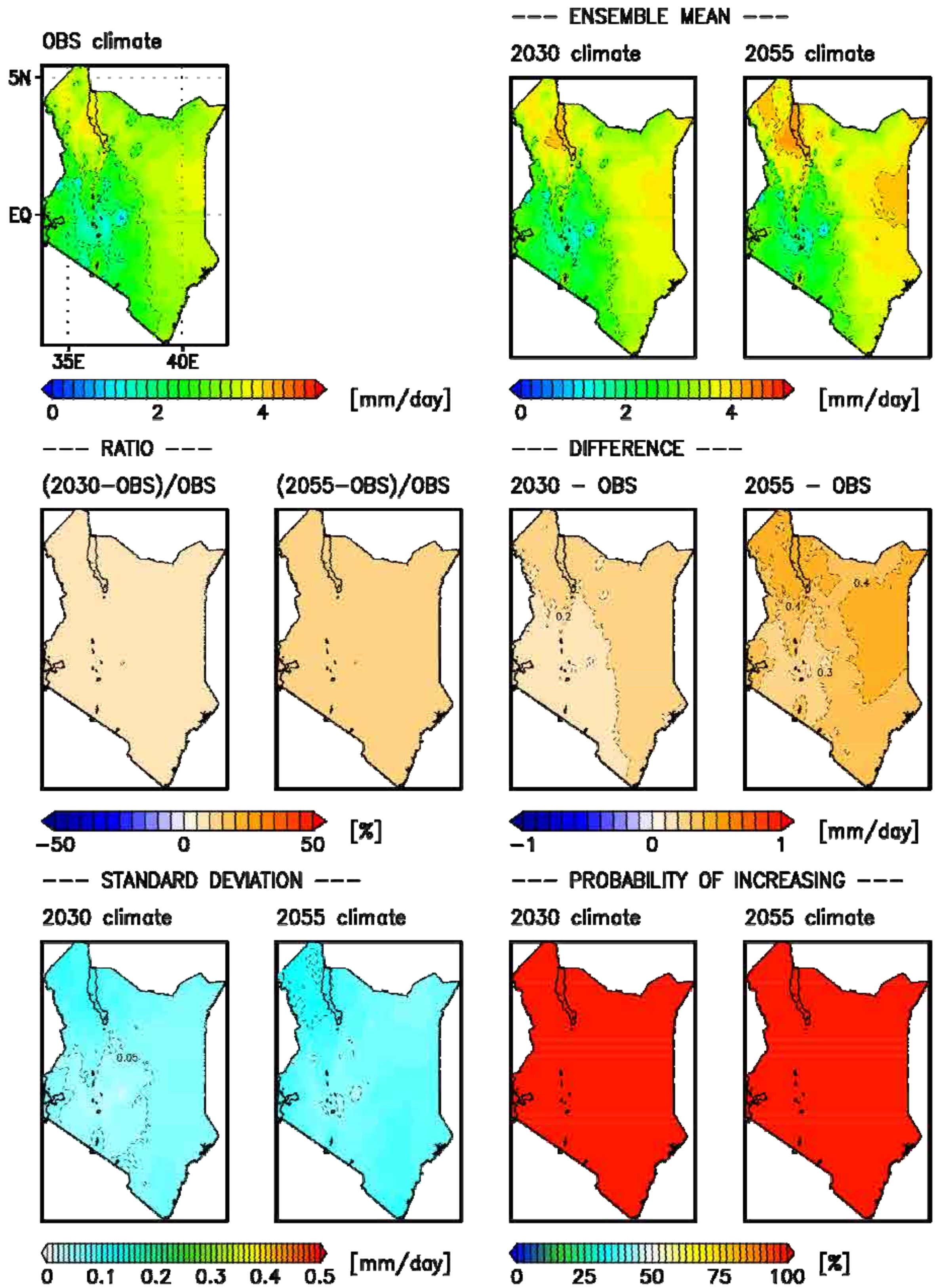
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.9.1 Spatial Distribution of Mean Annual Potential Evapotranspiration (Hamon Method)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



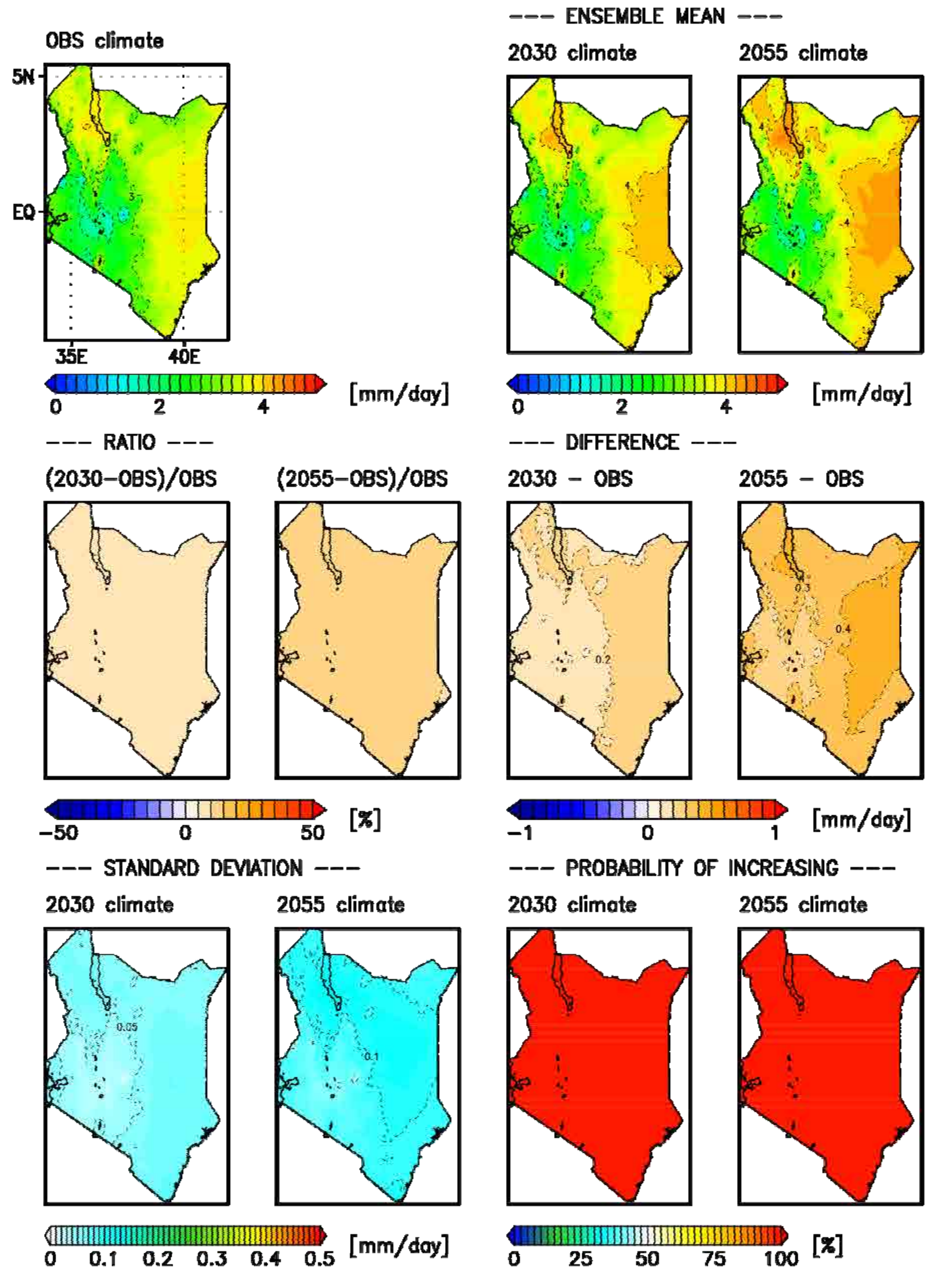
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.9.2 Spatial Distribution of Mean Seasonal Potential Evapotranspiration (MAM, Hamon Method)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



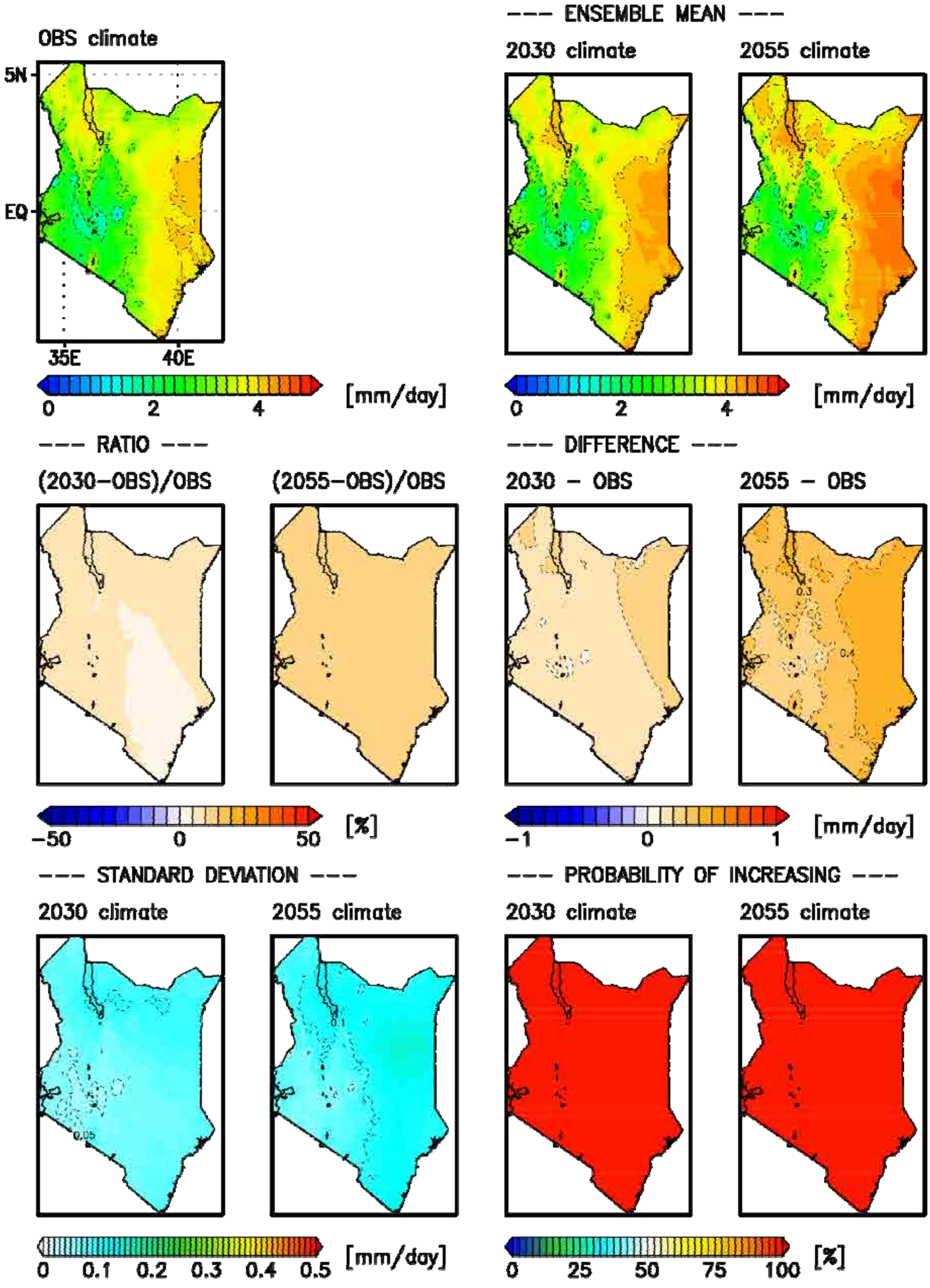
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.9.3 Spatial Distribution of Mean Seasonal Potential Evapotranspiration (JJA, Hamon Method)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



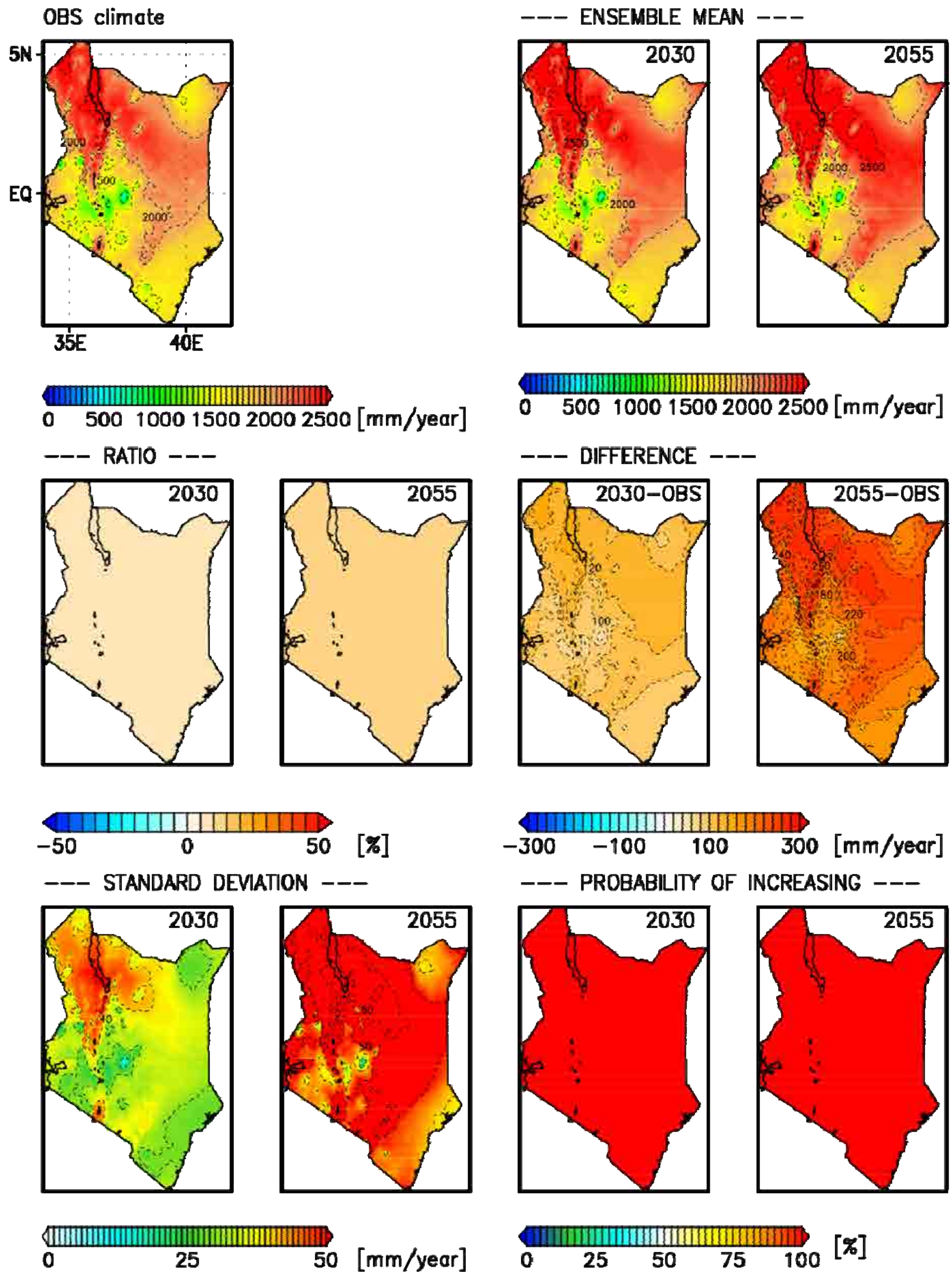
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.9.4 Spatial Distribution of Mean Seasonal Potential Evapotranspiration (SON, Hamon Method)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



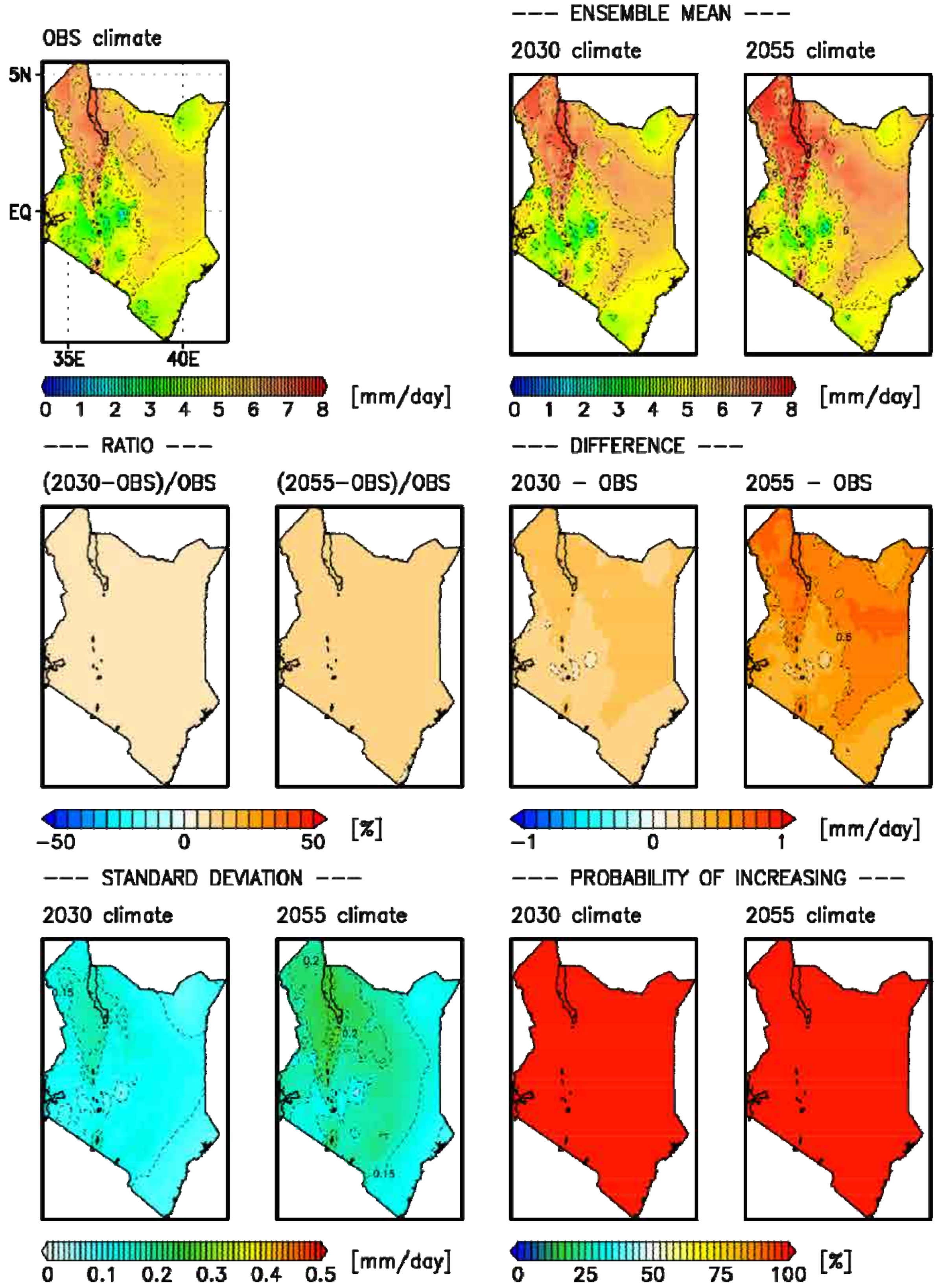
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.9.5 Spatial Distribution of Mean Seasonal Potentia Evapotranspiration (DEC, Hamon Method)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



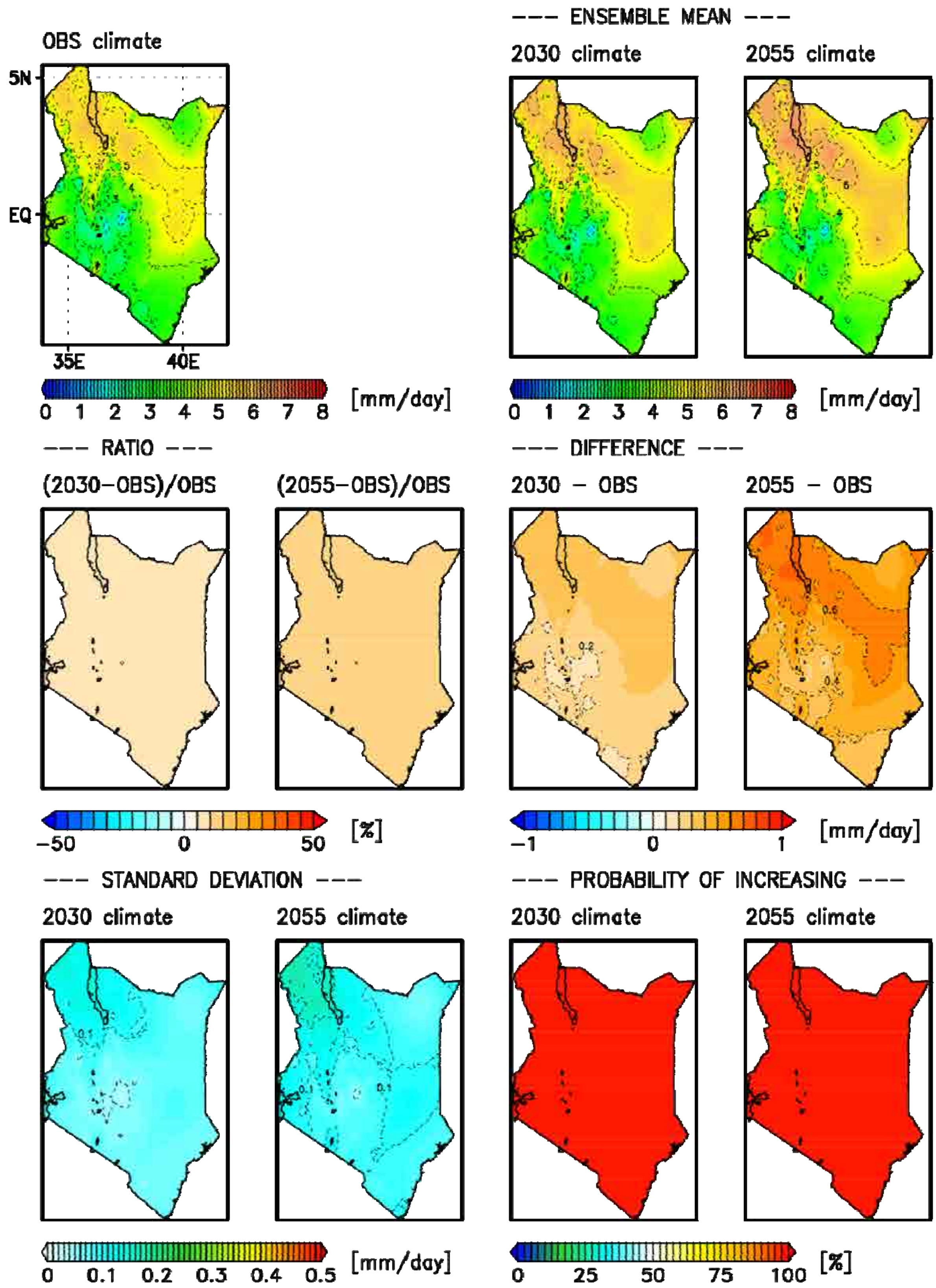
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.9.6 Spatial Distribution of Mean Annual Potential Evapotranspiration (FAO Penman – Monteith Method)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



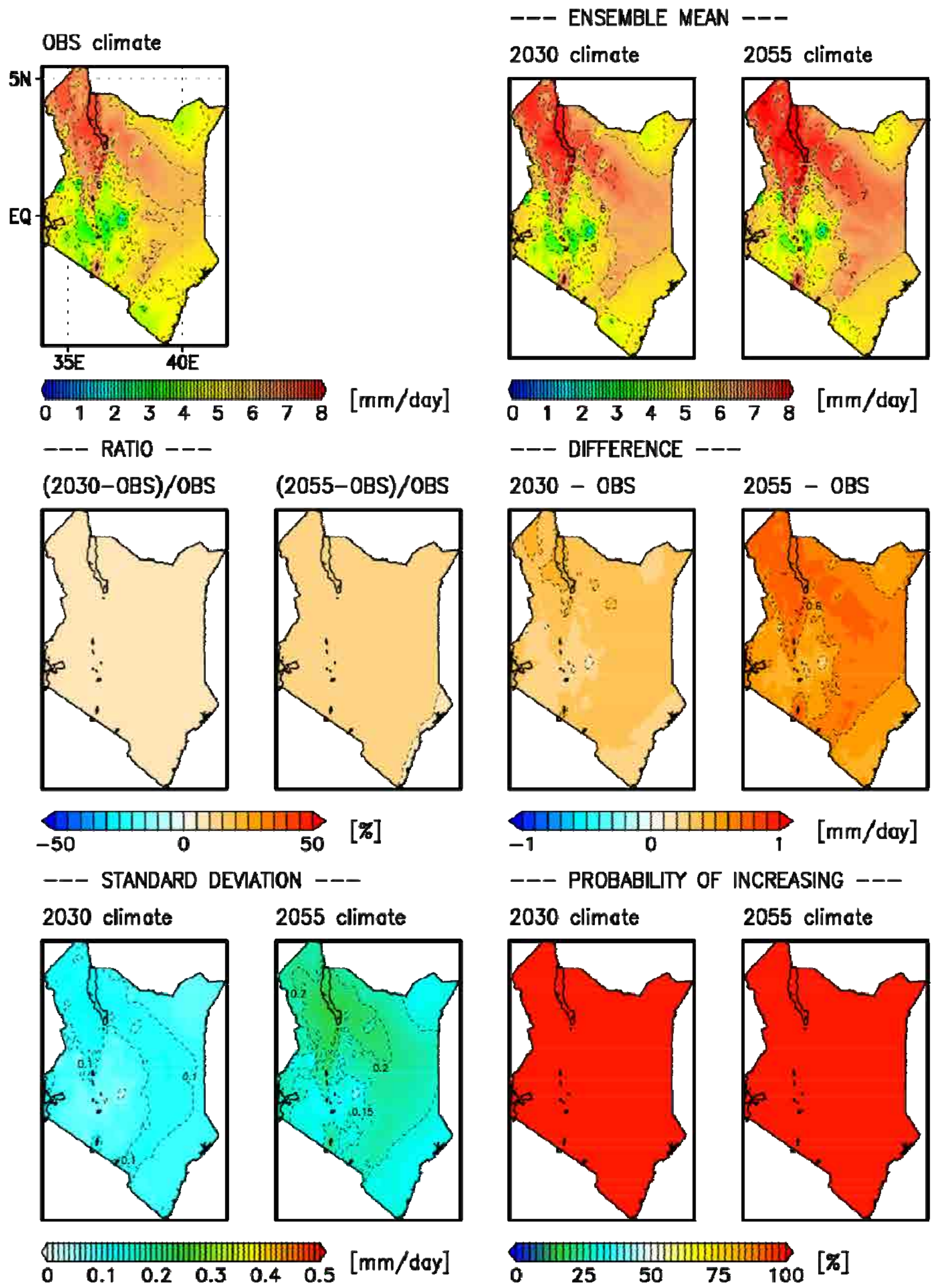
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.9.7** **Spatial Distribution of Mean Seasonal Potential Evapotranspiration (MAM, FAO Penman – Monteith Method)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



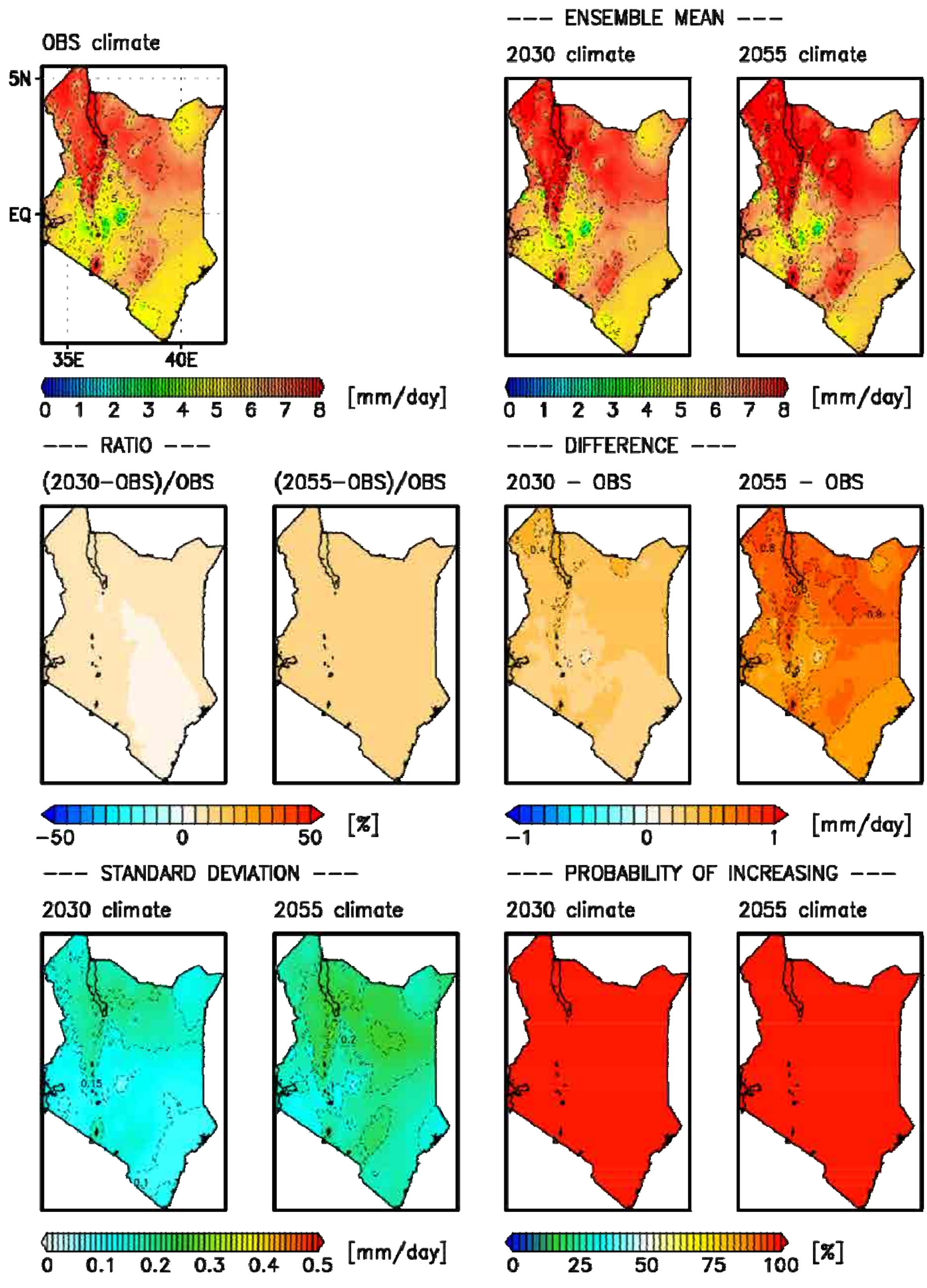
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.9.8 Spatial Distribution of Mean Seasonal Potential Evapotranspiration (JJA, FAO Penman – Monteith Method)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



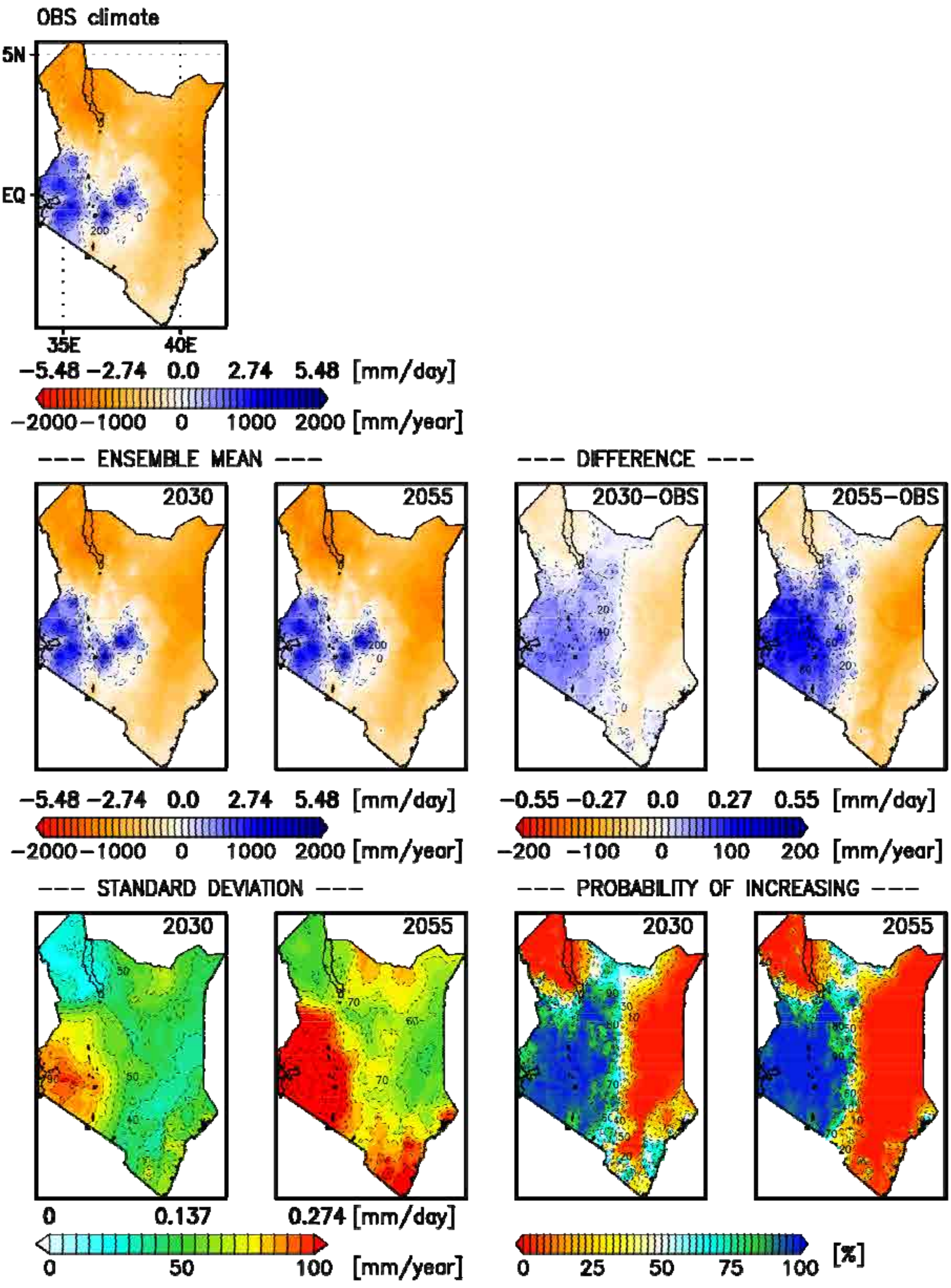
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.9.9 Spatial Distribution of Mean Seasonal Potential Evapotranspiration (SON, FAO Penman – Monteith Method)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



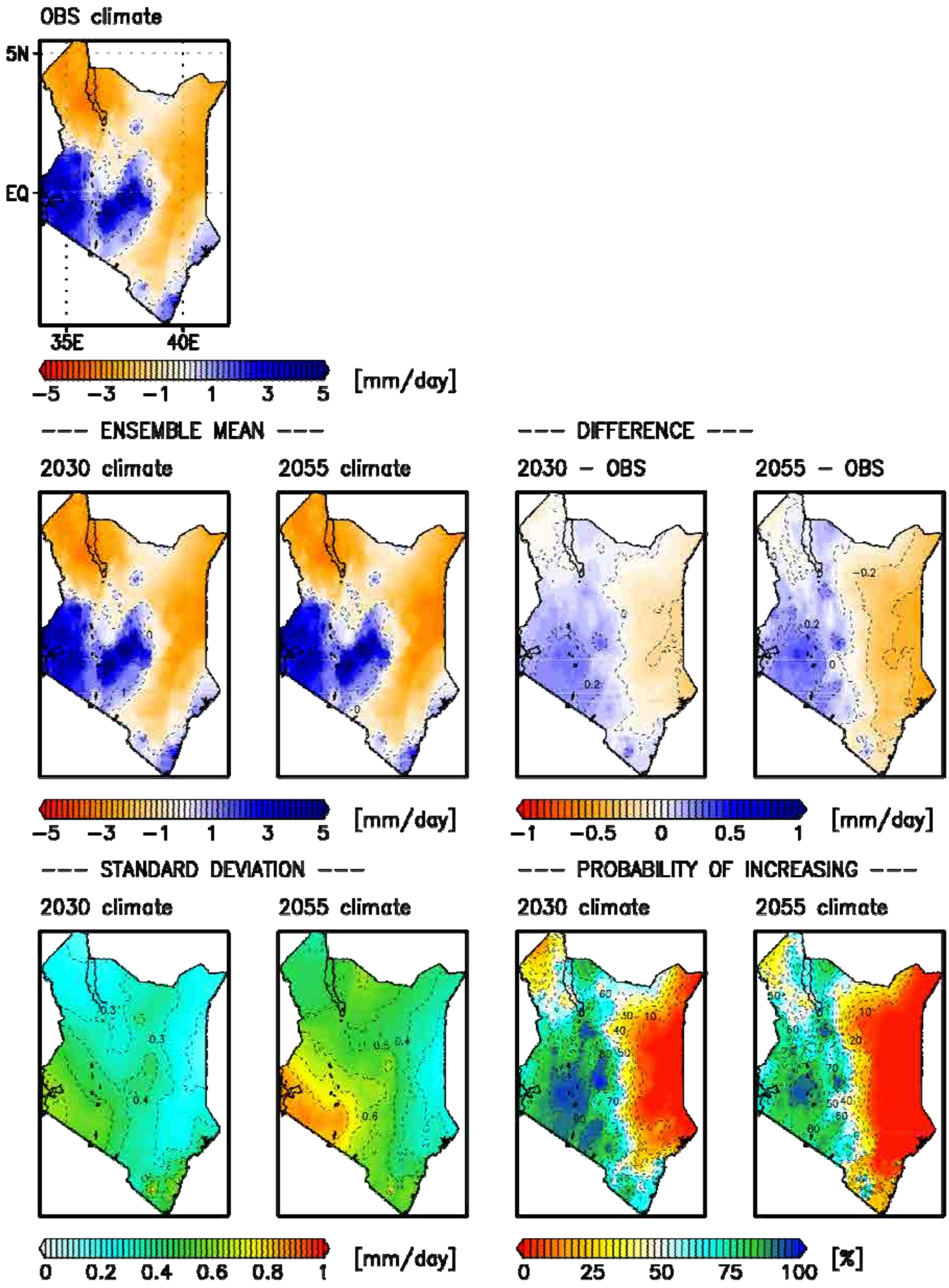
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.9.10** **Spatial Distribution of Mean Seasonal Potentia Evapotranspiration (DJF, FAO Penman – Monteith Method)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



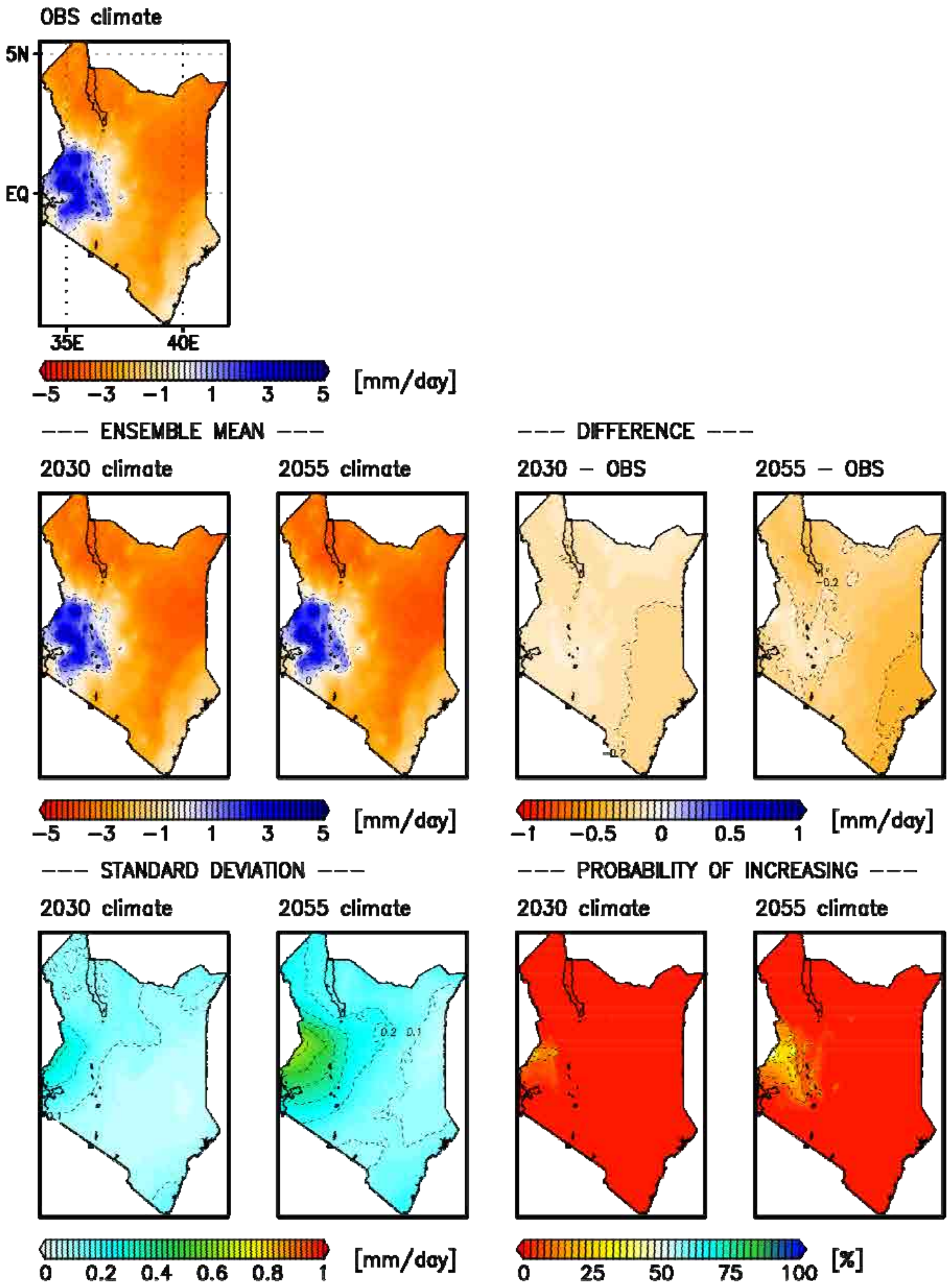
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.9.11 Spatial Distribution of Mean Annual P-PET (Hamon Method)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



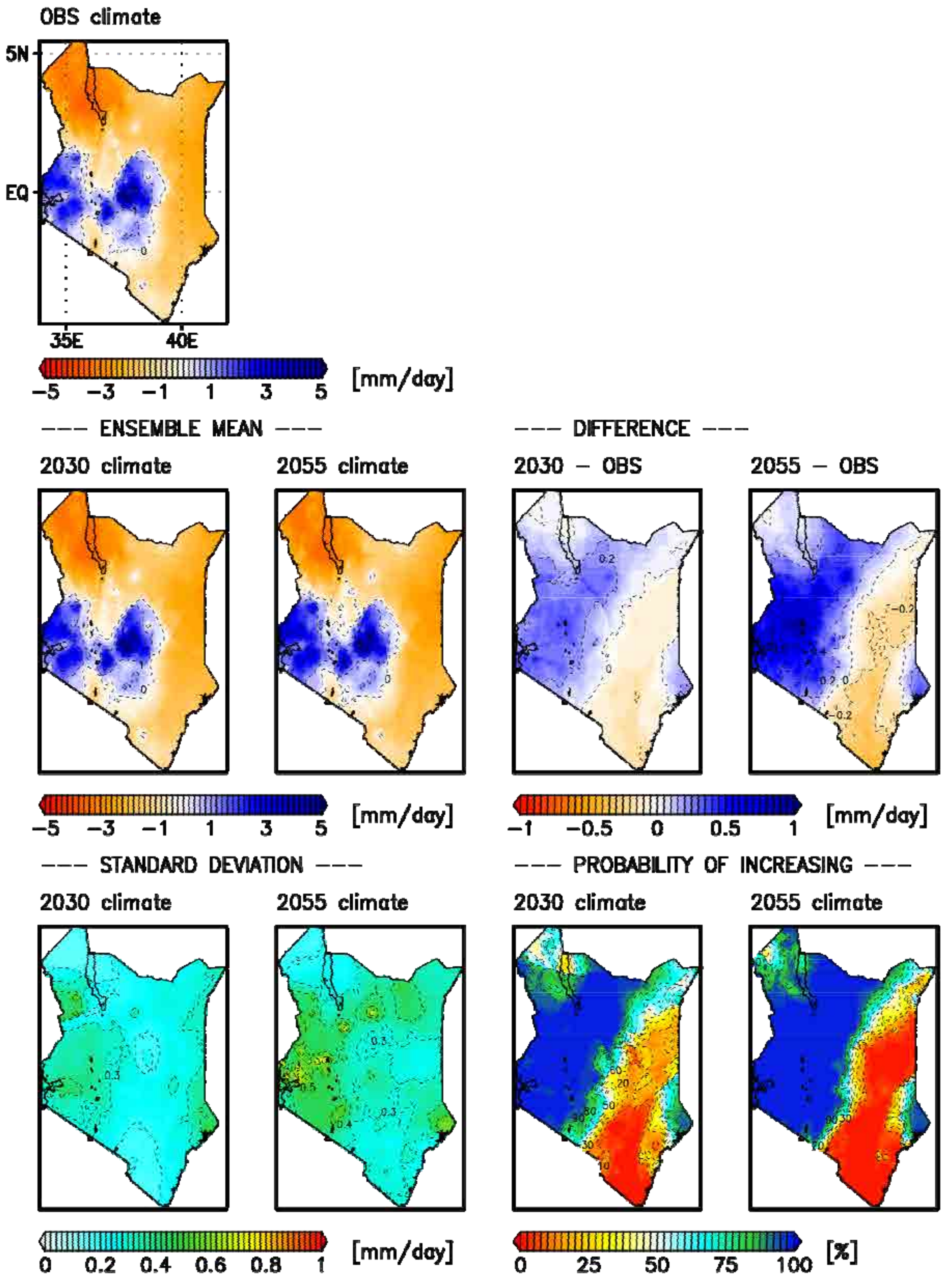
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.9.12 Spatial Distribution of Mean Seasonal P-E (MAM, Hamon Method)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



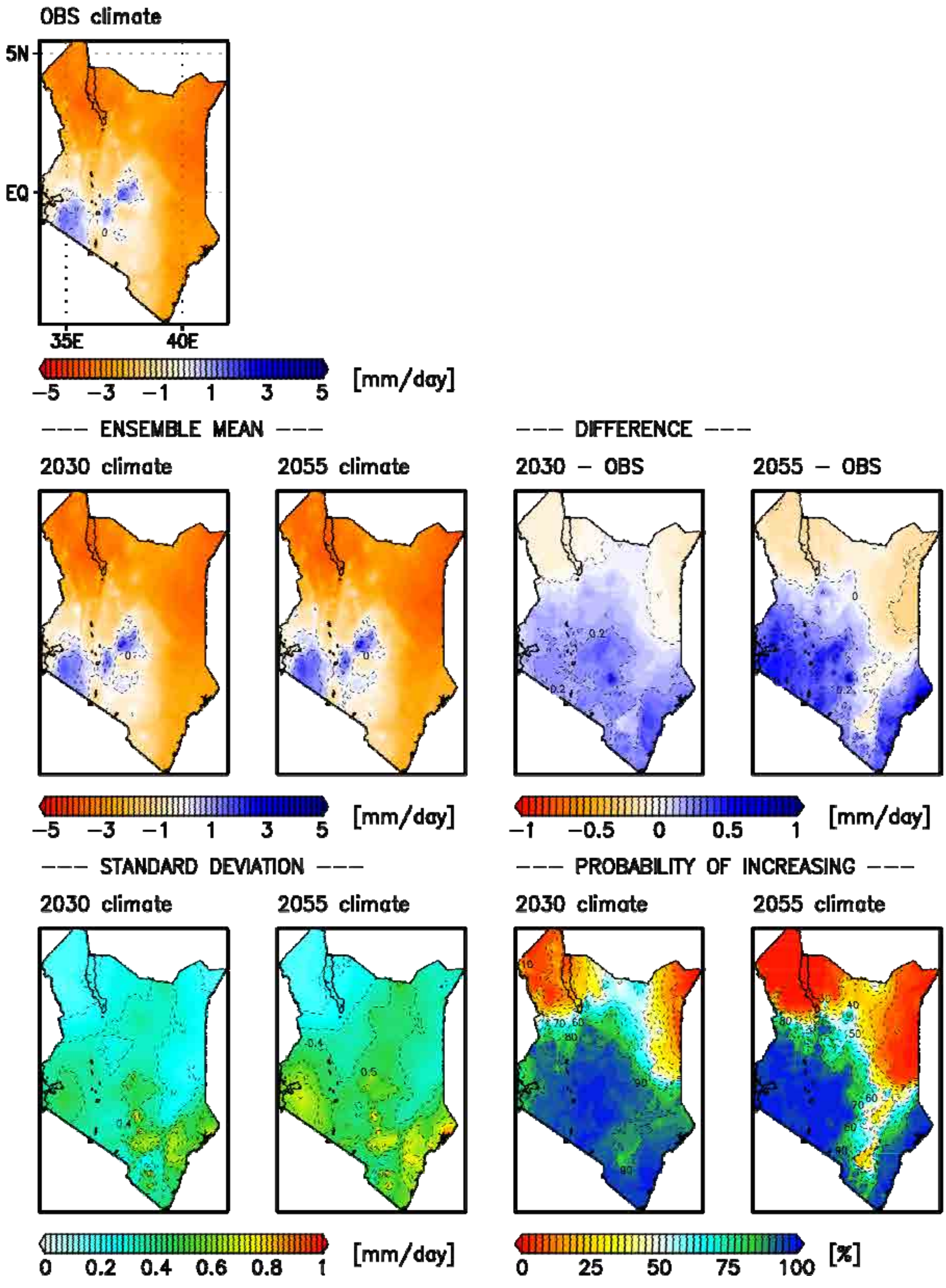
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.9.13 Spatial Distribution of Mean Seasonal P-E (JJA, Hamon Method)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



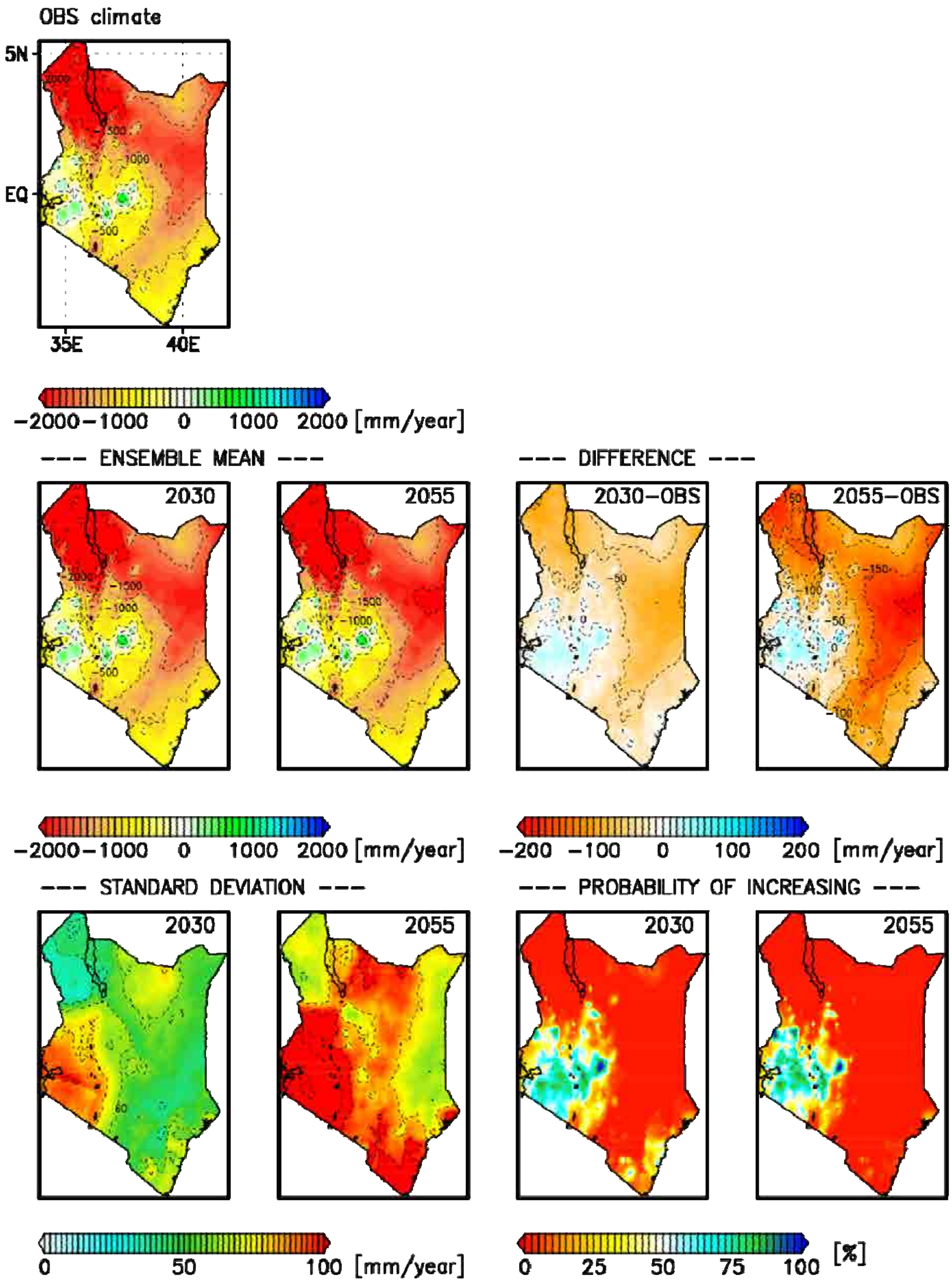
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.9.14 Spatial Distribution of Mean Seasonal P-PET (SON, Hamon Method)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



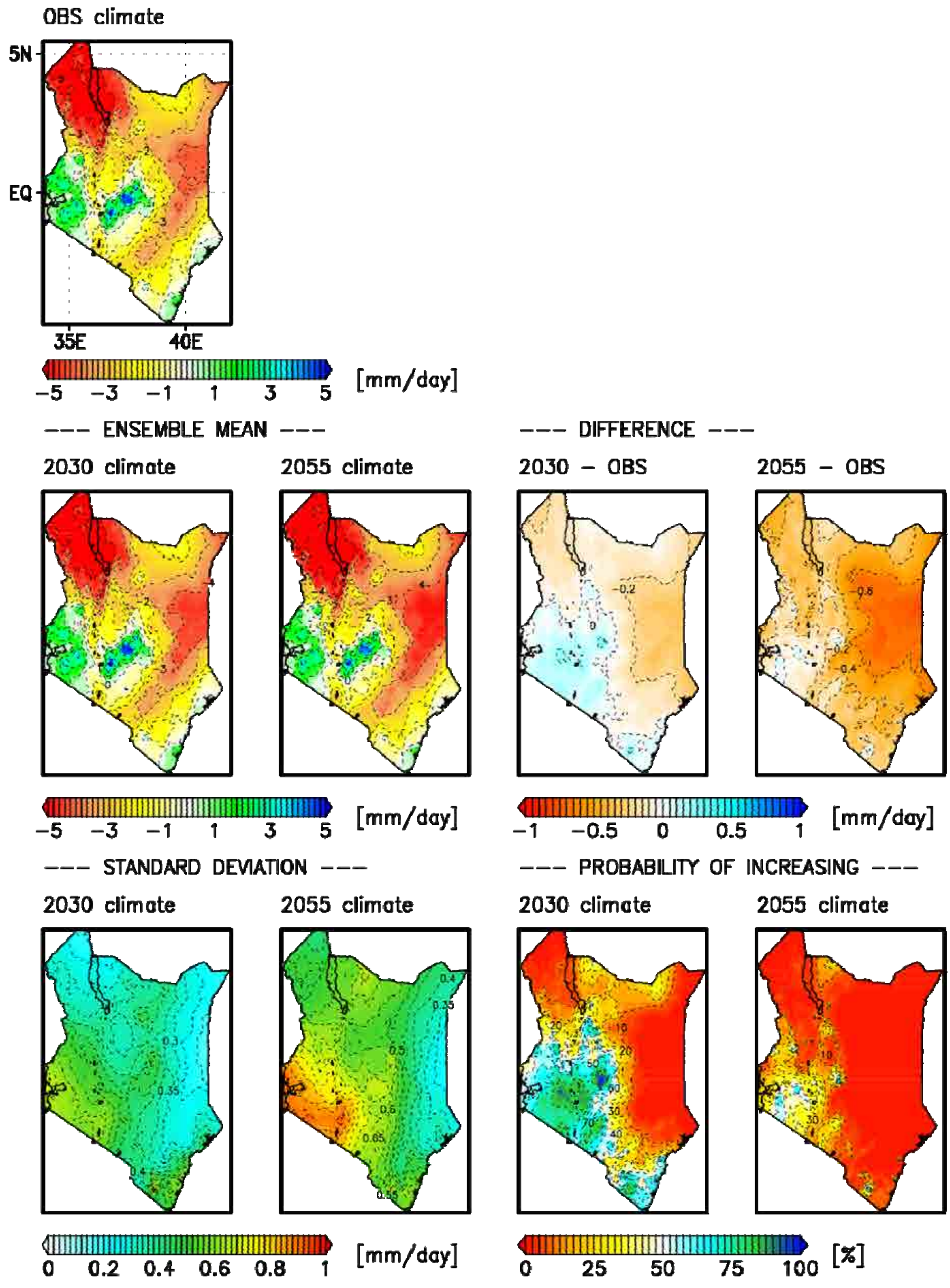
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.9.15 Spatial Distribution of Mean Seasonal P-PET (DJF, Hamon Method)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



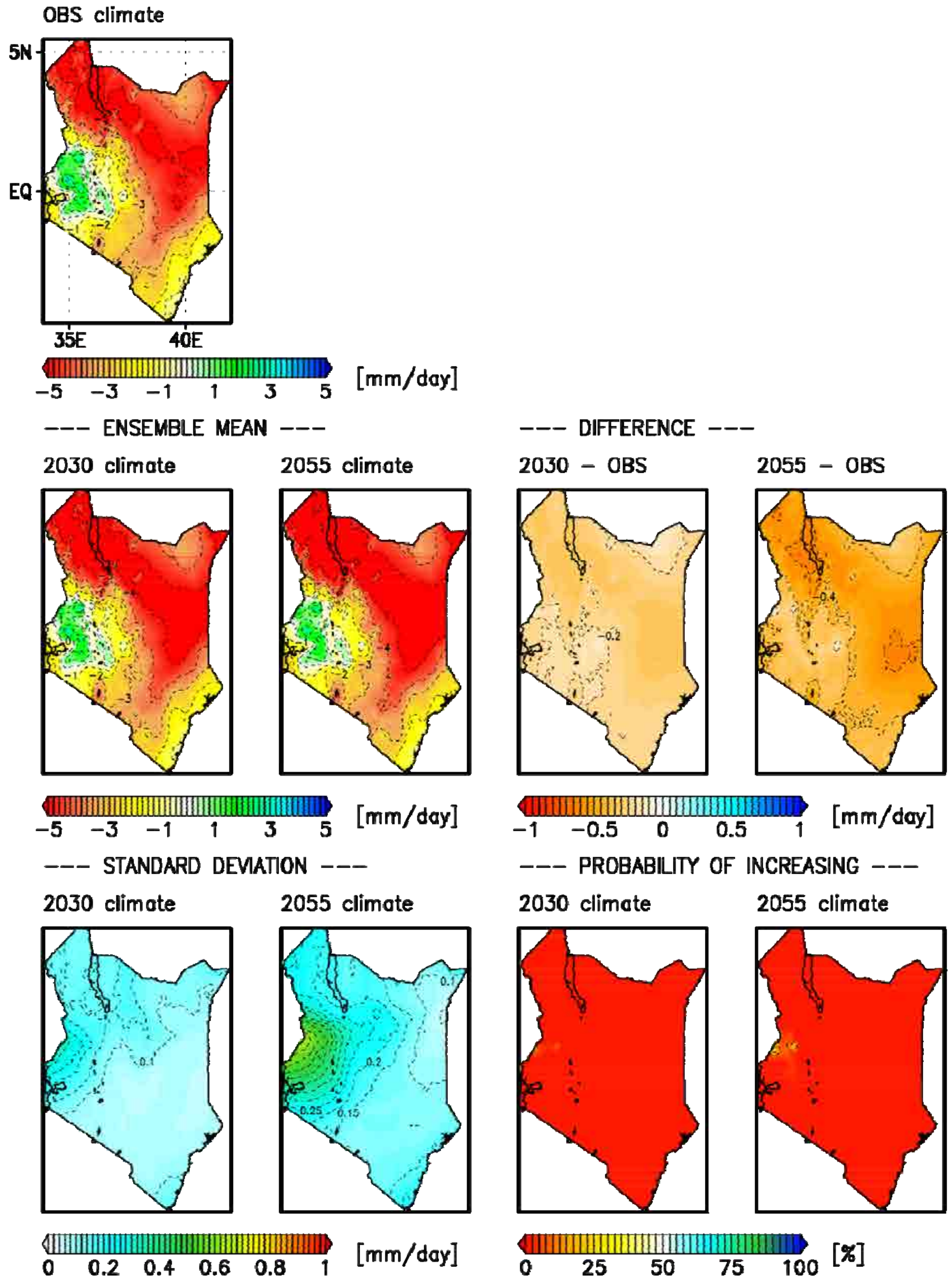
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.9.16 Spatial Distribution of Mean Annual P-PET (FAO Penman – Monteith Method)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



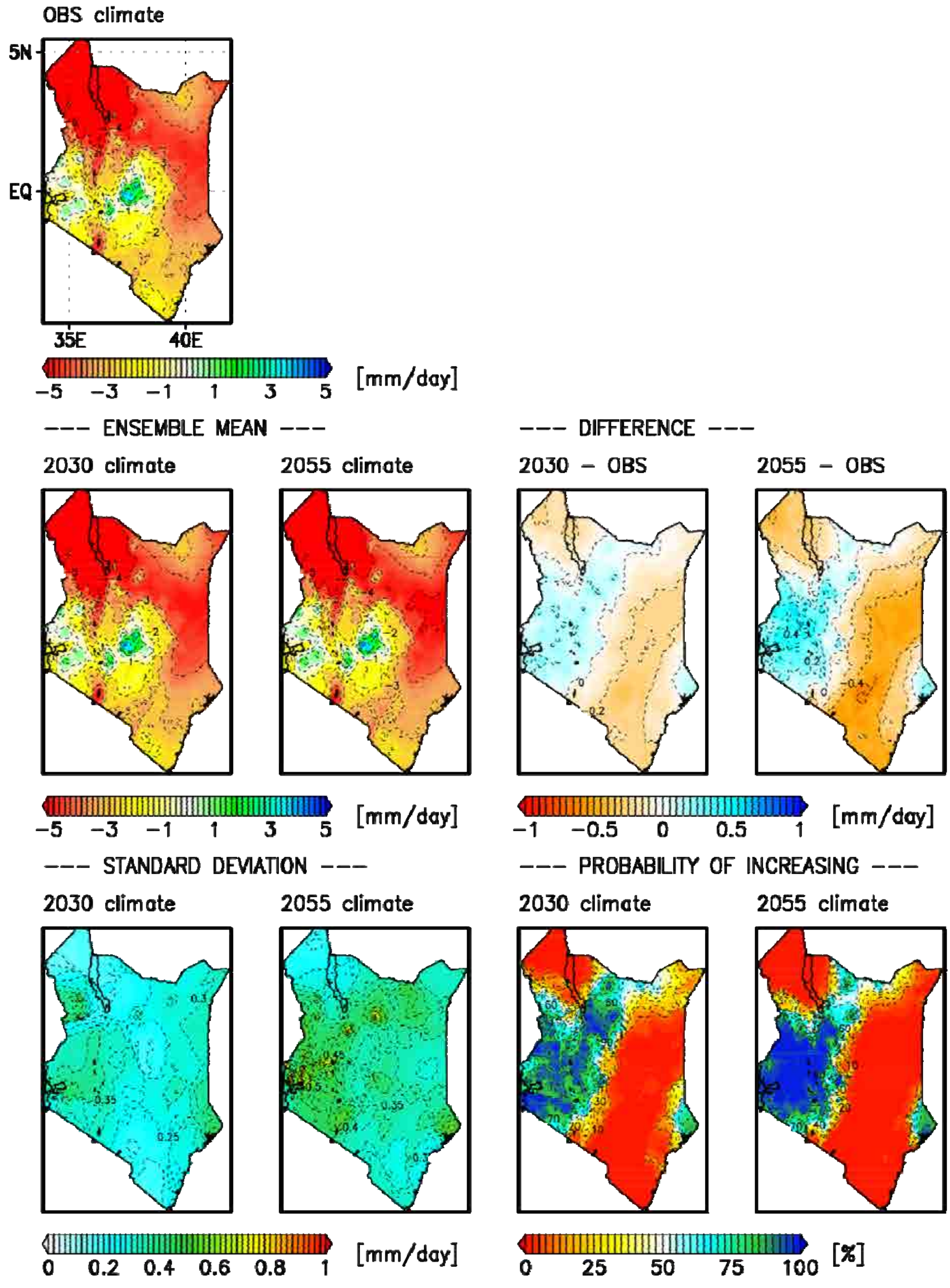
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030 JAPAN INTERNATIONAL COOPERATION AGENCY	**Figure 4.9.17** **Spatial Distribution of Mean Seasonal P-PET (MAM, FAO Penman – Monteith Method)**



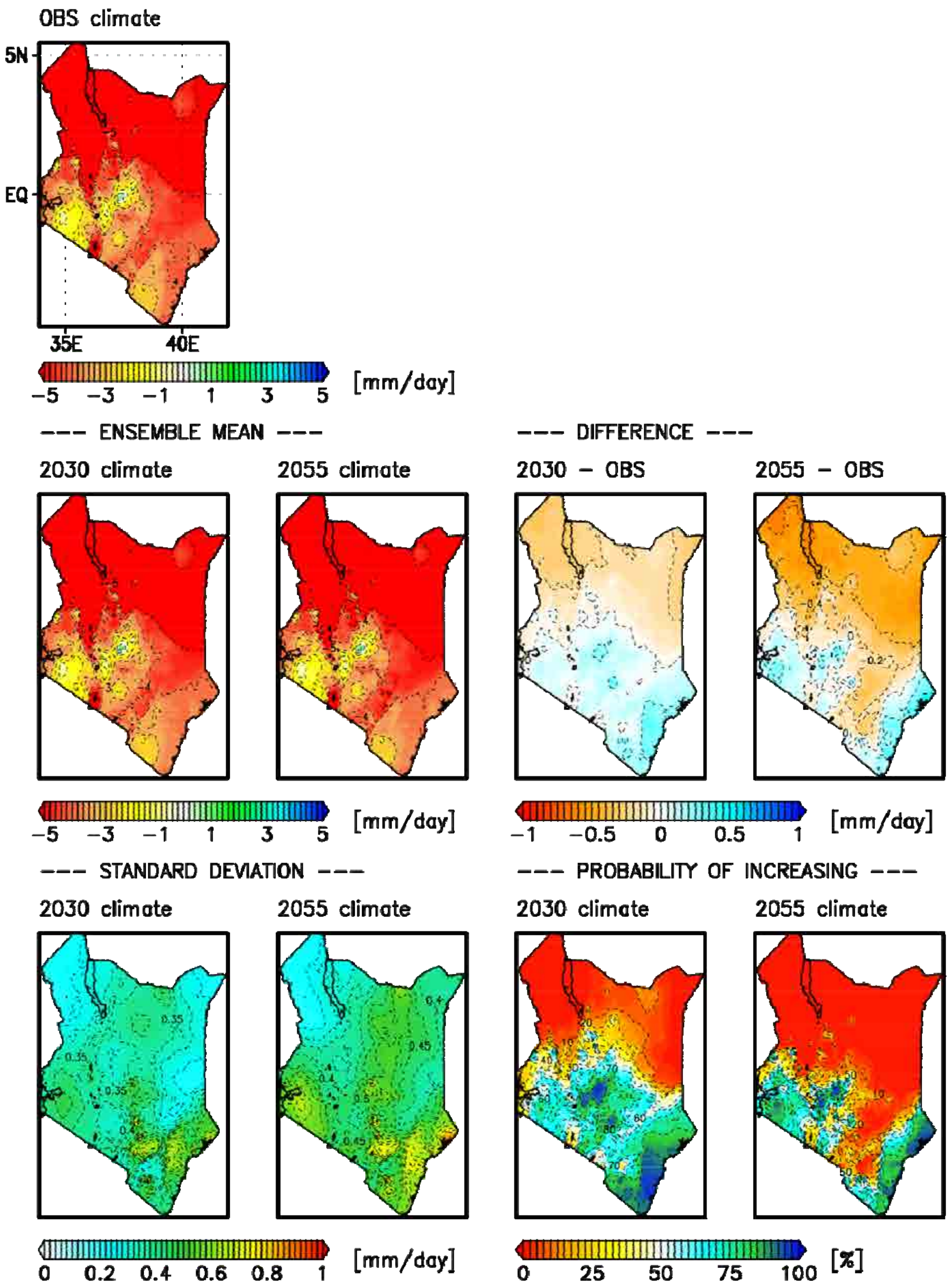
Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.9.18** **Spatial Distribution of Mean Seasonal P-PET (JJA, FAO Penman – Monteith Method)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.9.19 Spatial Distribution of Mean Seasonal P-PET (SON, FAO Penman – Monteith Method)**
JAPAN INTERNATIONAL COOPERATION AGENCY	



Source: Kenya Meteorological Department, The Data Integration and Analysis System (DIAS) dataset, and The Phase 3 of Coupled Model Intercomparison Project (CMIP3) multi-model dataset.

THE DEVELOPMENT OF THE NATIONAL WATER MASTER PLAN 2030	**Figure 4.9.20 Spatial Distribution of Mean Seasonal P-PET (DJF, FAO Penman – Monteith Method)**
JAPAN INTERNATIONAL COOPERATION AGENCY	