ANNEX E

WATER POTENTIAL STUDY
IN TURKANA COUNTY

FINAL REPORT

THE PROJECT FOR ENHANCING COMMUNITY RESILIENCE AGAINST DROUGHT IN NORTHERN KENYA

ANNEX E WATER POTENTIAL STUDY IN TURKANA COUNTY

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CHAPTER E1. WATER RESOURCES IN TURKANA

E1.1 General

The investigation of water resources in Turkana County has been continued from 2012. The main objectives of the investigation are 1) to clarify the climatic, hydrological and hydro-geological condition in the study area, 2) to evaluate water resources such as the groundwater potential and surface water potential and 3) to identify the optimal water supply systems resilient to drought in order to facilitate access to water for emergency situations and for long term needs as a response to climate change.

To know the present condition of water resources, the previous report and existing data relating to water resources in Turkana County have been collected and analyzed in addition to community hearing survey.

E1.2 Existing Data Analysis and Previous Study

Data and reports collected are as follows:

- Topography: Shuttle Radar Topography Mission (SRTM) data
- Geology: Geological Map of Kenya (Ministry of Energy and Regional Development of Kenya, 1987)
- Meteorology: Kenya Meteorological Department (KMD)
- Water resources data:

  Turkana Water Sources Final Mapping Data (MWI-Oxfam, 2009)

  Water, School and Health Management Information System (MIS) (UNICEF, 2006)

  Borehole Data Base (MWI/WRMA, 2010)
- Previous Study:

  Advanced Survey of Groundwater Resources of Northern and Central Turkana County, Kenya, UNESCO (2013)

  The Project on the Development of the National Water Master Plan 2030 in the Republic of Kenya, JICA (2013)

The collected data has been analyzed and diagrams were drawn based on the analysis using spreadsheet and GIS software.

E1.3 Topography and Geology

E1.3.1 Topography

The topography of the Turkana County is shown in Figure BE1.3.1. Turkana is situated on the northwestern part of Kenya covering an area of 68,212 km^2, which is about 40% of the total area of Rift Valley Province. It shares international borders with Ethiopia to the North, South Sudan to the Northwest and Uganda to the West. Within Kenya, the county borders Marsabit to the East, Samburu to the South East, Baringo and West Pokot to the South. Much of the Eastern side of the county is on Lake Turkana, which stretches North-South for more than 200 km.

The area has several rivers with the major ones being Turkwel and Kerio, both originating in the highlands to the south. Most of them are seasonal rivers popularly known as *"laggas"*.

Figure BE1.3.1 is drawn based on SRTM data. SRTM is mounted on a Space Shuttle and obtains earth surface data by remote sensing technology utilizing synthetic aperture radar. Obtained data will be converted into height data called a Digital Elevation Model (DEM), and will be utilized to generate a more precise three-dimensional map of larger observation area of the earth than has ever been possible (JAXA, 1999). SRTM data including Turkana County has been downloaded and used for topographic analysis.

The Turkana area is subdivided into five main physiographic units:

- Uganda Escarpment
- The Mountain Ranges
- The Plains
- Lotikipi Swamp
- Lake Turkana Coastal Plain

Uganda Escarpment is found along the 900 m. It is located between Kenya and Uganda border. The summit of the escarpment in Uganda varies from an average elevation of about 1,800 m to above 2,400 m on peaks. Slopes of the escarpments are usually steep and average 20° from the horizontal.

The Mountain Ranges are aligned in the North-South direction and characterized by erosion and tilting; step-sided scarp slopes with contrasting gently inclined deep slopes, which coincide with the angle of slope. The altitude of the mountain ranges between 1,500 m and 1,800 m in the east reaching the peak at Loima which forms undulating hills for a stretch of some 65 km^2.

These are extensive **Plains** which occupy central parts of the area and regions between mountain ranges around Lodwar. These plains are covered with detrital material, red grey and brown soils, rock brash, gravels and pebble beds.

Lotikipi Swamp occupies an extensive basin in the core of broad open syncline pitching gently northwards. It is an alluvial flood plain in which even major rivers maintain their channels for only a few kilometers.

Lake Turkana Coastal Plain extends up to 25 km inlands from lakeshore to Labur-Lothidok Ranges, rising westwards to over 100 m above the lake level.

Uganda Escarpment and **The Mountain Ranges** are good grazing area for dry season.

E1.3.2 Geology

The geological map of the Turkana County is as represented by Figure BE1.3.2. This map is compiled on the basis of Geological Map of Kenya (1987).

The geology of Turkana is divided into eight major successive rock formations:

- Recent Superficial Deposits (Q2)
- Pleistocene to Recent Lake Beds (Q1v)
- Rhyolites, with intercalated andesites in the SouthWest
- Olivine Basalts
- Phonolites and nephelinites
- Augite and Analcime basalts
- Turkana Grits (JK)
- Basement Systems (σ, PD, γP, N)

(Rhyolites, Olivine Basalts, Phonolites and nephelinites, Augite and Analcime basalts: Tertiary volcanics (Mv, Pv))

Basement Systems consist of semi-granitized psammitic sediments, semi pellitic gneisses and crystalline limestones. They are well developed in the Lapur hills and in the west of the area especially along the Uganda Escarpment at Lorengippi, Oropoi and Lokiriama.

Turkana Grits unconformably overlie the Basement System rocks and are made up of a succession of sediments where locally exceed 150 m in thickness (Dodson 1969). The series is made up of conglomerates, quartzites, sandstones and minor shales where thin northwards and westwards from the lake region. Exposures of the Turkana grit are confined to the Eastern part of the areas such as Lapur Hills, Muruangapoi, Lothidok Hills and Lokitaung Gorge.

Most of the mountain ranges and groups of hills are composed of a series of lavas and intercalated pyroclastics erupted during a prolonged phase of Tertiary volcanicity where followed the early Miocene sedimentation. The lithological units in this category include the basaltic series of rocks, phonolites, nephelinites, rhyolites and andesites.

Augite and Analcime Basalts constitute augite and analcime minerals with little or no olivine; confined to the western parts of the County mostly near Labur, Lokitaung Gorge and west of Lodwar Town.

Olivine basalts are characterized by coarse pophyritic texture, medium to coarse textured, dark blue-grey or black in color with pheneocrysts of up to 0.5 cm (Mohr 1969). These outcrops occur at Lokitaung, Karamajoj hills.

Phonolites and nephenilites include phonolites, phonolitic agglomerates, nephelinites and olivine nephelinites (Dodson 1969). The lowermost lava seen in Muruangapoi Hills near Lodwar shows a dark grey color, buff fine-grained groundmass and conspicuous phenocrysts.

Pleistocene to Recent Lake Beds comprise a series of lucustrine deposits dating from Pleistocene and continuing into the recent period. These deposits are only developed near present lake Turkana shore and consist of a series of step-like deposition levels rising over 900 m above present lake level. The sediments along the lakeshore include sands and locally compact buff colored clays (Dodson 1969). They comprise of a series of sands and clays, generally rich in fossils.

Recent Superficial Deposits comprises of three formations, such as **Superficial Limestones**, **Sandy Soils**, **Recent lake deposits**.

Superficial Limestones consist of broad flat expanses of nodular pea-sized kunkar limestone of varying shades of white and pink admixture of soil and sand; in some localities they appear as pure limestone. Flank various localities such as along Lodwar-Lokitaung road.

Sandy Soils are derived from Basement System rocks and are generally buff to grey, occasionally light red, fine textured and powdery sandy soils derived mainly from lavas. These deposits are evenly distributed across Turkana County but they mostly flank river distributaries and channels such as river Turkwel.

Recent lake deposits are the youngest deposits in the area and are found around the lakeshore chiefly as sandy beaches with rare occasional pale yellow to bluff clay deposits. They contain remains of reptiles and fish. The deposits are liable to blow into dunes or to mask underlying Pleistocene deposits as at Eliye Springs where they form barchans and sand dunes.

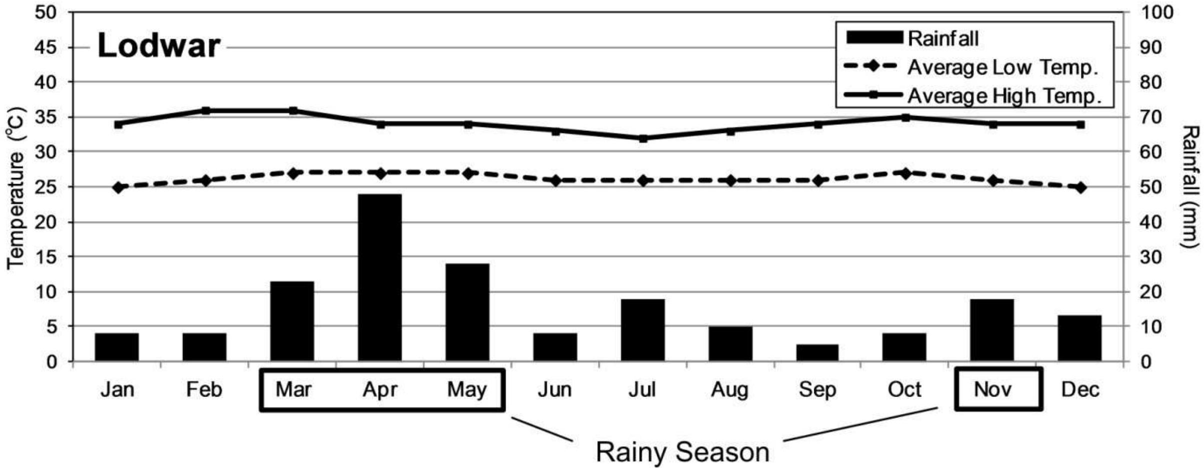
Water plays a critical role in weathering and consequent incorporation of weathered elements into groundwater systems.

E1.4 Climate and Meteorological Conditions

Turkana North, Central and South districts have both arid and semi arid lands. Figure BE1.4.1 is annual rainfall distribution map drawn using “WorldClim” 1951-2000 average annual rainfall data. Black circles are weather station in Turkana where data can be collected. The values with black character are annual rainfall in 1987 that have enough amounts of data and almost average rainfall in 50 years. Annual rainfall distributes concentrically and the center is the mouth of River Turkwel to Lake Turkana. Minimum rainfall area is downstream of River Turkwel where annual rainfall is below 200mm/yr. On the other hand, maximum rainfall area is mountain range around the border to Ethiopia where annual rainfall is more than 900mm/yr.

Mean annual temperature is almost the same distribution as rainfall shown in Figure BE1.4.2. High temperature area is downstream of River Turkwel and Lake Turkana coastal zone where the temperature is over 28 degree in Celsius and low temperature area is mountain range around the border to Uganda where the temperature is below 22 degree in Celsius. Rainfall and temperature show the same distribution trend as elevation. Rainfall distribution is proportional to elevation and temperature is inversely proportional to elevation.

Climate of Lodwar is shown in Figure AE1.4.1. The long rains usually fall between March and May, and short rains fall November. However, the pattern and duration of rainfall has been unreliable and erratic over the years. The annual average temperature ranges from 26.2ºC to 24.1ºC with a mean of about 30.2º C.



Source: JICA Project Team, Weatherbase

Figure AE1.4.1 Climate of Lodwar

To estimate the probability of occurrence (%), return period and annual precipitations of concern, the Hazen method was applied for the historical statistical data of 88 years at Lodwar. This method consisted in assembling the annual precipitations (mm) shown in the table in Figure BE1.4.3 with formula. Probability of occurrence 10% means the one-tenth rainy year, 90% means one-tenth droughty year and 50% means one-second average year. 1987 is plotted near probability of occurrence 50% and recent 3 years 2011-2013 are relatively rain-rich years at Lodwar.

E1.5 Natural Resources Distribution

E1.5.1 General

Turkana County lies in ASAL area having annual rainfall less than 500 mm. Most of the rivers called *Laggas* have seasonal water flow only during the rainy season, except the Turkwel River with perennial flow regulated by the Turkwel Dam located in the upstream river basin. Water resources for the pastoralist communities are therefore limited only to i) groundwater utilized from shallow wells and boreholes, ii) riverbed water in the seasonal rivers, and iii) small scale harvesting of surface water and rainwater, such as water pan, sand dam and rock catchment.

In these years, pastoralists in the county were seriously affected by chronic droughts especially from 2008 to 2011. During the drought period, water for the pastoralists could not be sufficiently reserved nor recharged and dried up, hence no longer in use during the drought for long time. Even at the deep wells, water level and discharge were observed to decrease and some of the wells dried up, which forced the pastoralists to access far distance to the water points and caused deterioration of the grazing area due to concentration of their livestock into the limited available water points during drought.

E1.5.2 Existing Water Points

In ASAL areas, water facilities to be used for livestock and domestic water supply in pastoralist communities are classified as shown in Table AE1.5.1, with reference to Rainwater Harvesting Handbook (African Development Bank, 2006).

Table AE1.5.1 Type of Water Points for Pastoralists

Type of water points	Water source	Water source facility
Water pan	Surface water and rainwater	Reservoir pond for harvesting rain water and surface water from relatively small catchment, generally excavated below ground level.
Rock catchment	Rain water	Rainwater harvesting facility with water tank, constructed on lower reaches of bare rock without fractures or cracks, where runoff losses to the soil, vegetation and structures is minimized.
Sand dam	Surface water	Storage dam build on and into the seasonal riverbed, effectively increasing volume of groundwater available for abstraction. Water is captured through a scope hole, hand-dug well or tube well.
Sub-surface dam	Riverbed water	Storage dam consists of a vertical, impermeable barrier through a cross section of a sand-filled seasonal river bed.
Shallow well	Groundwater and riverbed water	Wells drilled along seasonal rivers by machine or manpower. Water is abstracted by pump and manpower.
Borehole	Groundwater	Wells drilled by machine, from which water is abstracted with pump and flowed into trough for livestock though pipe.
Spring	Spring	Small inlet structure provided with concrete wall Water is generally abstracted through pipeline, or directly flowed into trough for livestock

Source: JICA Project Team

In 2009-2010, MWI and Oxfam (NGO) conducted mapping survey of the water points in Turkana County, in which 997 water points were surveyed in total, including 501 deep wells, 226 shallow wells, 148 reservoir dams and water pans, and 7 rock catchments. During the survey period of ECoRAD Project, data was obtained from DWO offices and updated the numbers of existing water points. The types of water facilities developed in Turkana County are shown in table below. Locations of these points referred to Turkana Water Sources Final Mapping Data, MWI-Oxfam are shown in Chapter E3.

Table AE1.5.2 Summary of Existing Water Points

District	Water pans	Rock catchment	Boreholes	Shallow wells	Springs
Turkana Central	6	2	42	45	4
Loima	4	-	36	32	3
Turkana North	18	-	82	15	5
Turkana West	35	3	13	87	3
Turkana South	3	-	36	24	3
Turkana East	10	-	25	18	2
Turkana County	76	5	234	221	20

Source: District Water Offices, June 2012

E1.5.3 Surface Water Resources

Surface water resources in Turkana County are shown in Figure BE1.5.1.

(1) Dams / Water Pans

Technically speaking, a dam has a structural wall can hold back the water. A pan is generally excavated below ground level. Although there is a technical difference between a dam and a pan, no distinction has been made between the two different types of structure in many reports. NMW-Oxfam data, 112 (76%) of dams / pans were found to be operational or partially operational.

United Nations Childern's Fund (UNICEF) (2006) point out that there are various problems reported in 3 cases. Siltation was the most common physical problem. The Other two problems are erosion of inlet and spillways. Many pans are under open access management and this condition is a feature of Turkana County. That provides a challenge in ensuring reliable access to water for livestock and domestic use, especially in the early dry season.

(2) Subsurface Dams

According to NMW-Oxfam data, there are 43 subsurface dams in Turkana and 29 of them are operational. These water sources have not been long in operation but there is potential to use them.

(3) Rock Catchments

The rock catchments are located in Lokichoggio, Lokitaung Kaaleng and Oropoi divisions. Many of them are in Songot area in the border of Lokichoggio and Oropoi divisions. 7 of the 8 are operational.

E1.5.4 Groundwater Resources

Groundwater resources in Turkana County are shown in Figure BE1.5.2.

(1) Boreholes

366 (72%) of 511 boreholes are operational or partially operational. 8 are permanently non-operational boreholes. 90 are non-operational and 45 are non-functional. They are non-operational or non-functional due to vandalism, insecurity, equipment problem, low yield and borehole collapse. UNICEF (2006) pointed out the non-operational or non-functional boreholes mean that they are "contingency" bore holes, lack fuel, low yield/dry, poor water quality, not fitted with equipment, insecurity or have non-functional equipment. Some of the other boreholes are awaiting equipping after drilling.

Most of the boreholes 252 (69%) mainly run on hand pumps. The boreholes managed by the institutions and management committees are mainly diesel and hand pump (manual) operated respectively.

(2) Wells

The majority of the wells are along seasonal rivers. 139 (62%) of the 226 wells were operational. The balance was under construction, abandoned and/or had broken hand pumps. Causes of wells being abandoned included low water level or no yield, dropped pump, collapse of the wells, vandalized, high salinity and contamination. Many of the wells are temporary wells, dug along the "laggas" during the dry season, then abandoned during the rainy season and re-dug in the next dry season.

Majority of the wells are managed by communities via management committees, WUA, communal and traditional systems of management. A few of them are owned and managed by individuals and other by institutions (UNICEF, 2006).

(3) Springs

There are 26 springs assessed during the exercise. 23 springs were operational, one was dry and 2 were abandoned due to insecurity. The springs are mainly in Kibish, Lomelo, Kerio, Kalokol and

Lokichogio divisions. Some of the springs need protection to ease water fetching and reduce contamination. Lomonakipi spring is a hotspring.

Majority of the springs are communally managed with a few under management committees (UNICEF, 2006).

E1.6 Present Condition of Water Resources by Hearing Survey

Hearing survey for communities and government agencies such as WRMA and DWO have been continued since 2012. The valuable information concerning water demand, water quality and recommendation for assistance and cooperation have been collected. The locations for the survey are shown in Figure AE1.6.1 and the information is summarized in Table BE1.6.1 with each district visited. The remarkable sites are explained in following section.

E1.6.1 Turkana North District

Hearing survey was conducted was executed to grasp the present condition of water facilities for four sub-locations: Lokolio, Milimatatu, Kangakipur, and Kanakurdio. The centre of this district is Lokitaung. Boreholes, wells, water pans and sand dams distribute along main *lagga*s and coastal plain of Lake Turkana. Springs are recognized 4 areas, such as north edge of Lorienetom Range, East edge of Moruarith hills, near Kakalae centre and West edge of Lokuwanamuru Range.

(1) Lokolio sub-location

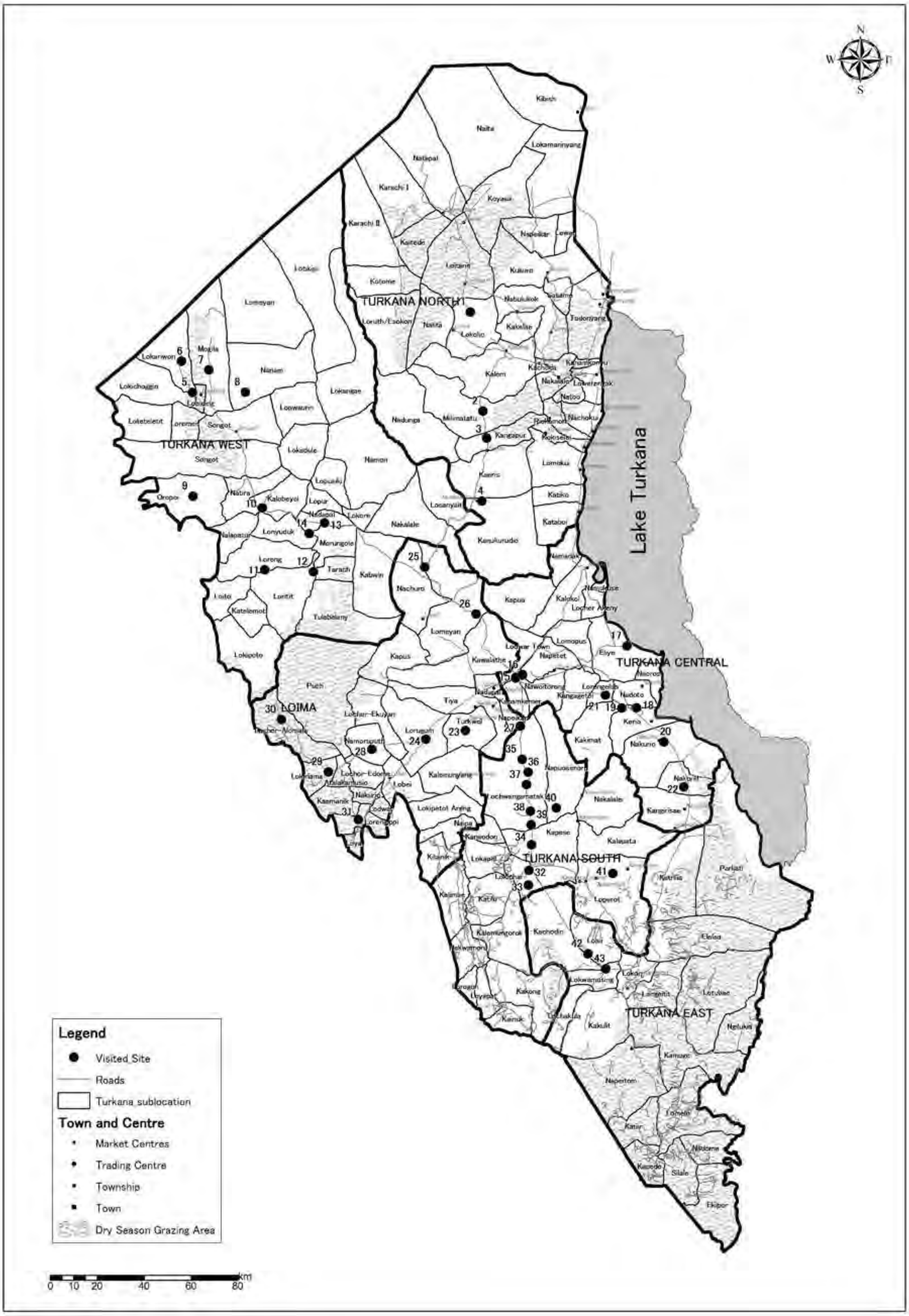
Lokolio sab-location has at least 12 boreholes and 6 are operational. Four of five water pans are operational. Kaikor (No.1, the number indicated in Figure AE1.6.1 and Table BE1.6.1), the centre of sub-location, is served by solar and genset powered borehole funded by Catholic Mission and Oxfam drilled in 1989. Water quality is generally good. Some other water points for livestock are scattered in the surrounding mountain range: Lokuwanamoru, Kadingetom, and Lokrienetom.

(2) Milimatatu sub-location

Milimatatu sub-location has six of seven operational boreholes and one shallow well. The borehole roughly 100m drilled by Ministry Water and Irrigation (MWI) serves near Milimatatu centre (No.2) with domestic water. Oxfam equipped pump initially with a genset and latter by solar panels as a backup alternative. Another hand pump well of 90m drilled in 1989 is sited along *lagga* adjacent to the solar-powered borehole. Its yield is low (1.2m^3/hr in 2005) and production is over whelmed by the high number of livestock and human. Gum packing of the borehole is faulty consequently hindering its pumping rate. Water quality of groundwater in Milimatatu sub-location shows 1.18mS/cm for Electrical Conductivity (EC) and 1,584ppm for Total Dissolved Solids (TDS).

(3) Kangakipur sub-location

Kangakipur sub-location has three of four operational boreholes. The Kangakipur borehole 100m in depth drilled by Oxfam in 2008 and equipped with solar-powered pump serves the entire Kangakipur centre (No.3). It’s sited along *lagga* and piped unplasticized polyvinyl chloride (uPVC) pipes from source to town centre. It has windmill that acts as a backup in case the solar exposure is insufficient. Water quality of the borehole shows 2.95mS/cm for EC and beyond detection limit for TDS.



Source: JICA Study Team

Figure AE1.6.1 Location Map of Field Survey

(4) Kanakurdio sub-location

Kanakurdiosub-location has three boreholes and two shallow wells. Two boreholes and one shallow well are operational. Kanakurdio Centre (No.4) is located along Gold-Lokitaung road. It is served by one solar powered borehole drilled by Oxfam. There was another non-functional borehole filled with sediments. Residents mentioned the water from borehole has slightly saline taste. Fresh water is derived from *lagga* Matakorio. It was also noted that Oxfam had planned to drill three additional boreholes in the area.

E1.6.2 Turkana West District

Hearing survey was conducted for nine sub-locations: Lokichoggio, Lokariwon, Mogila, Nanam, Oropoi, Kalobeiyei, Loreng, Loritit, and Nadapal. Out of these nine sub-locations, Lokichoggio, Oropoi, Kalobeyei, and Nadapal are situated along main road from Lodwar to Lokichoggio. Most of the water facilities in Turkana West District are located along this road and major *laggas*, i.e. Nanam River flowing near Lokichoggio centre and Tarach River flowing in Kakuma centre. Springs distribute only the east edge of Mogila Range (No.7) and Songot Hills.

(1) Lokichoggio sub-location

The Lokichoggio sub-location has the following water points. Boreholes are concentrated on the right bank of Nanam River near Lokichoggio centre (No.5). Two of main boreholes named Lokichoggio ICRC borehole and Lomesekin borehole serve water to the town. In addition, there are two water pans located along the road to Lodwar within Lokichoggio town mostly used by pastoralists for livestock. It was noted that these two pans recharged by rainfall were highly polluted. In most cases, Lokichoggio centre area has good quality ground water. However, the concentration of Fluoride was 1.59mg/L on the second chemical laboratory test in this project. This value is slightly beyond 1.50mg/L for the Kenyan standard (KEBS).

(2) Lokariwon sub-location

There are no water facilities in Lokariwon sub-location. The area called Nakeruman (No.6) is situated western side of Mogila Range and approximately 15km north from Lokichoggio centre. Government of Kenya constructed a water pan in 2012. It is well fenced but does not hold water due to inappropriate inlet design. Although Mogila Range is important area for dry season grazing activity, no water facility exists.

(4) Nanam sub-location

Nanam sub-location has 4 dry boreholes that were drilled by Oxfam. As a result there is no operational groundwater source near Nanam centre (No.8). Residents depend on water from scoop holes (shallow wells) along Nanam River. One of non operational borehole named Nanam borehole in centre is drilled in 1972 and equipped with hand pump by Turkana Water Project (TWP). The depth of this borehole was roughly 70m and the yield was $0.6m^3/hr$ (UNICEF, 2006).

(4) Oropoi sub-location

There are three water points in Oropoi sub-location and only one borehole is functional. The water pan located approximately 18km (beyond Oropoi border) from Oropoi centre (No.9) serves mainly for human, livestock, and minor irrigation systems. There is competition for water between livestock and humans. For this reason, community is forced to fetch water for consumption at night to avoid scrambling with livestock. Oropoi sub-location recorded high increase from 500 to 5,000 in population due to its good climatic condition favourable for pasture growth in this decade. Water quality in Oropoi area is good and favourable for consumption based on interview.

(5) Kalobeiyei sub-location

Kalobeiyei centre (No.10) is served by borehole named Nkilekipus (Kalobeiyei BH) equipped with pump using generator. The borehole is piped and efficiently serves the community. The area also has two functional shallow wells namely Nakwamunyen and Dikilkimat. In addition, there are three non-operational shallow wells located near community centre. Water quality in Kalobeiyei BH is enough for human consumption.

(6) Loreng sub-location

Loreng (No.11) has only dry borehole. The approximate depth of the borehole was estimated to be about 140m. There is a hand dug well that was initially productive but later dried up. The area has a population of about 3,000. The water quality is generally poor based on interview.

(7) Nadapal sub-location (Kakuma)

Kakuma centre (No.13) is located Nadapal sub-location. Kakuma has hosted the Kakuma Refugee Camp since 1992. In Nadapal, there are many wells along Tarach River to serve over 70,000 refugees who fled wars in neighboring countries. However, the water demand is still high. *Laggas* and shallow wells available in the area dry up during dry season although they are recharged during rainy season. Komdei is a new UNESCO drilling site for host community. Ground was found at 57m below ground level and amount of water was $5m^3$/hr. The water quality in Kakuma area is changeable by location because of a complex pattern of aquifers from surface (alluvial) to the weathered basement. The example of chemical test in the laboratory for Natir 1 BH in this area is shown in Table BE1.6.2 and Table BE1.6.3 as No.21.

Rift Valley Water Services Board (RVWSB) has 10 construction plans for subsurface dams along Tarach River to lead the formation of villages that will minimize the movement the communities make while searching for water.

E1.6.3 Turkana Central District

Hearing survey was conducted for five sub-locations: Lodwar Town, Napetet, Eliye, Kerio, and Nakurio. Most of boreholes and shallow wells in Turkana Central District are concentrated near Lodwar Town and the outlet of Turkwel River to Lake Turkana. Water pans, rock catchments and sand dams are very few in this district. Springs distribute at the coastal area of Lake Turkana and near Kerio River.

(1) Lodwar Town and Napetet sub-location (Lodwar Town location)

Lodwar town sub-location's water demand is high. The location within Lodwar area has water scarcity. There are many communities around Lodwar Town who have no water sources and potable water is supplied to the area by water tankers from Lodwar Town Centre (No.15). The water demand in Napetet sub-location is also high. People living in suburbs including Napetet centre (No.16) have to walk long distances in search of water. Some locations in this area have very saline water consequently dangerous.

UNESCO drilled three boreholes of different depths (47m, 60m, and 128m) in Nawoitorong on April 2013. Drilling was succeesful and groundwater found in each borehole. Although water yields were good ($1.83m^3$/hr, $62.4m^3$/hr, and $27.3m^3$/hr), water quality is poor for human consumption.

(2) Eliye sub-location

Eliye Springs (No.17) has eight boreholes and five shallow wells in the area. Two boreholes and three wells are functional while the others are faulty and non-operational. Water from Eliye Springs has been harnessed and channelled to Eliye Springs Centre. In other area in the neighbouring villages, residents walk up to 10km for water. TWP and Diocese of Lodwar drilled new borehole at Etiriwae in May 2013 and equipped it with a hand pump.

Groundwater has high Fluoride and TDS concentration. The concentrations of Fluoride in spring water at Eliye Springs and Lobolo Springs, about 12.5km northwest from Eliye Springs, are 1.75mg/L and 1.85mg/L respectively. Both values are higher than Kenyan Standard. The locals as a result have dental fluorosis.

(3) Kerio sub-location

Locals in Kerio Centre (No.18) derive their water from nearby *lagga* Lomuyenkupurat River because of groundwater quality problem. Although Kerio sub-location has three boreholes and eight shallow wells, only one operational borehole and one operational shallow well are more than 10km upstream of Lomuyenkupurat River. There are not any other operational water facilities near Kerio Centre. Water for the secondary school is supplied from Lodwar Town via water tankers. Most of the groundwater resources in Kerio sub-location are excessively saline. Deep boreholes drilled in the area turned saline last year while several shallow waters drilled in the neighborhood have all turned saline.

E1.6.4 Loima District

Hearing survey was conducted for eight sub-locations: Turkwel, Lorugum, Lomeyan, Napeikar, Namorupth, Lokiriama, Lochar-Abmala, and Lorengippi. Most of the boreholes and shallow wells in Loima District are situated along river Turkwel and "lagas" near the community centre. There are some water pans along "*laggas*" in whole district. There are many sand dams constructed at the upstream of Nakaton River. Only 1 spring is reported at Atalatamisio sub-location.

(1) Turkwel sub-location

Turkwel sub-location has at least 17 boreholes and six shallow well. And total 10 boreholes and shallow well are functional. Three of the boreholes are equipped with pump using generator and seven boreholes and wells are equipped with hand pumps. Water quality of Turkwel centre (No.23) is generally good (slightly saline). The groundwater is within Kenyan drinking standard except iron concentration of 0.86mg/L (KEBS 0.3mg/L) for the first analysis in laboratory on August 2012. The livestock uses water in the daytime the domestic use is limited only in the night time.

(2) Lokiriama sub-location

In Lokiriama sub-location, two of three boreholes and one of six shallow wells are operational. The borehole in Lokiriama Centre (No.29) is installed with a solar-powered pump. There are four sand dams in the mountain area. In addition, Lokiriama sub-location depends on river water. Insecurity is the major issue in the area.

(3) Lorengippi sub-location

Lorengippi sub-location has four boreholes and four shallow wells. Two boreholes and three shallow wells are operational. One of the operating boreholes installed with a solar-powered pump near Lorengippi Centre (No.31) doesn't supply enough water to the locals because of constant solar panels vandalism and operational failure. The surrounding areas are experiencing drought, consequently pastoralist move into Lorengippi Centre in search for better grazing ground.

Insecurity is a major issue in the area but a peace initiative is underway to bring the warring communities together. The area hosts tribes from Turkana, Tepesi and Pokot. Groundwater at Lorengippi Centre is saline and alkaline based on the physical test conducted on site. Cases of diarrhoea were also reported as results of consumption of the borehole water.

(4) Namoruputh sub-location

Namoruputh (No.28) is the locational headquarter with a high population. The Pastoral community accesses water from Kospir River approximately 30km away from residential area. Factors of population increase should be taken into consideration during planning for water resources. All of five boreholes and one of four shallow wells are operational. One borehole is equipped with windmill and another borehole is equipped with solar-powered pump. Windmill borehole is fresh water but solar powered borehole is salty.

E1.6.5 Turkana South District

A hearing survey was conducted for five sub-locations: Lokichar, Kapese, Lochwaangikamatak, Napuosimoru, and Loperot. Most of boreholes and shallow wells in Turkana South District are concentrated near Lokichar Centre and along Turkwel River. At least three water pans and two sand dams are situated along main road from Lodwar to Lokichar. There are six water pans near Kaakong centre in Kaakong sub-location. Two springs are reported at Lochwaangikamatak sub-location.

(1) Lokichar sub-location

Lokichar (No.32) area has high water demand. It was noted that the area has an approximate population of 500,000. Lokichar Water Service Corporation (LOKIWASCO) highlighted the several challenges faced with when providing water to the community. Such an example is the shortage of generator diesel for pumping the area's boreholes. Borehole depth within Lokichar area lies between 50-70m below ground level.

(2) Lochwaangikamatak sub-location

Lochwaangikamatak sub-location has 15 boreholes and three shallow wells. 10 boreholes are operational but none of shallow well is operational. 1 community borehole and 1 shallow well owned by the Catholic Mission Church are installed at Lochwaangikamatak Centre (No.38). The source of energy for the borehole is solar while the shallow well is equipped with a hand pump. There is competition for water by the locals and livestock especially during drought. Two of new boreholes were drilled and equipped with hand pump in 2011.

E1.6.6 Turkana East District

Hearing survey was conducted for two sub-locations: Lopii and Lokwamosing. Most of boreholes and shallow wells in Turkana East District are concentrated near Lokori centre. Six water pans are situated along the road from Lokichar to the south via Lopii and Lokwamosing. There are no functional rock catchment and sand dam in this district. 11 springs are situated in Lokwamosing sub-location and surrounding area.

(1) Lopii sub-location

Lopii sub-location has three boreholes and five shallow wells. However only 1 borehole is operational, the borehole is 16 km NNW away from Lopii Centre (No.42). In 2012, Korean contractor drilled borehole 120m in depth, situated 1km south west of the centre, but there was no water. There are two functional water pans for livestock. One of them is adjacent to Lopii centre constructed Government of Kenya in 2011. There is a Lopii Spring located approximately 10km ENE from the centre, but it is too saline to be applicable to human consumption. Problem of Lopii Centre is no water for domestic use. The residents get water form Lokichar by water trucks.

(2) Lokwamosing sub-location

Lokwamosing (No.43) has 2 operational boreholes and 2 shallow wells. 1 borehole equipped solar-powered pump serves residents with water for domestic use in Lokwamosing centre. All shallow wells are not operational. There are 7 springs used by human and livestock in this sub-location. Water quality is generally good (see No.10 in Table BE1.6.2 and Table BE1.6.3).

E1.7 Review of Previous Groundwater Potential Survey

E1.7.1 Advanced Survey of Groundwater Resources of Northern and Central Turkana County, Kenya, UNESCO (2013)

Radar Technologies International (RTI) has been contracted by UNESCO to provide highly technical services of developing a database of hydro-geological information derived from advanced remote-sensing information of the Kakuma Valley of the Turkana District in Kenya. JICA Study Team provided following datasets for this study: meteorological (rainfall and air temperature) data, well data, simultaneous survey data, continuous water level data, and water quality data.

RTI has processed a significant quantity of raw datasets in order to produce a consolidated, integrated data pool that is specific to the survey area. The "processing" of data entails applying the proprietary methods and techniques of the WATEX System™, which aims to achieve a fully developed collection of data material for use and analysis. Finally, UNESCO has accomplished three maps of Northern and Central Turkana County, i.e. Groundwater Potential Map, Recharge Map and Soil Potential Map. This Groundwater Potential Map is used as a base-map for the location map for proposed drilling site in Figure BE1.7.1.

To confirm the potential of groundwater, UNESCO had test borings at three sites, such as Kakuma, Lodwar, and Lotikipi Basin (near Lokichoggio). Since UNESCO could find aquifers at all site, they were not satisfied with their result because the amount of water was below their prediction and water quality may be poor. For example, Lotikipi BH yield they predicted was more than 70m^3/hr but actual yield is only 11m^3/hr. And EC is 7.0mS/cm measured during pumping test. It is too salty to drink and generally unfit for dairy cattle and young cattle. In Lodwar BH, the concentrations of Sodium, Total Alkalinity, Chloride and Fluoride are exceeding Kenyan Standard (KEBS).

Although the UNESCO Groundwater Potential Maps are very useful to evaluate groundwater potential, those maps do not cover the whole of Turkana County. And the information of water quality and water balance cannot be acquired from the Groundwater Potential Map.

Almost all areas in Turkana County have water quality problem, such as saline water unsuitable for human consumption and high concentration of Fluoride in drinking water-the cause of dental fluorosis.

The amount of rainfall in Turkana County is very small especially in the plains which occupy central parts. It means that the recharge in this area is quite limited and groundwater flow velocity may be very slow. That is, even if people are successful for drilling to get groundwater, the groundwater might be impossible to use due to water quality.

Groundwater level was evaluated based on the UNESCO maps. Groundwater level evaluation in other area was conducted with Landsat satellite image analysis referred to UNESCO Maps, result of boreholes and shallow wells distribution survey, collected geological and hydro-geological aspects, hearing survey results, and other information.

E1.7.2 The Project on the Development of the National Water Master Plan 2030 in the Republic of Kenya, JICA (2013)

The groundwater analysis using groundwater flow model MODFLOW was carried out in this study to understand the occurrence, distribution and movement of groundwater in the whole of Kenya. Major outputs of groundwater analysis include evaluation of sustainable yield of groundwater by watersheds and preparation of the groundwater potential map showing the evaluation results. This report points out the considerations related to groundwater analysis in the arid region in the recomendation for further study.

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.

The evapo-transpiration directly affects the groundwater recharge amount. Groundwater evapotranspiration (or riparian evapotranspiration) is an important component of water budget especially in arid and semi-arid regions.

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.

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.

The groundwater analysis in this study was carried out for the entire country and the groundwater resources were estimated roughly. 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.

CHAPTER E2. SURFACE WATER POTENTIAL IN TURKANA

E2.1 Introduction

Potential of surface water development for pastoralists in arid and semi-arid lands in northern Kenya mainly consists of construction of 1) water pan, 2) rock catchment, and 3) sand dam. Potential sites for the rock catchments and sand dams are fully dependent on local topographic and geological conditions, and hence potential map in Turkana for rock catchments and sand dams covering entire Turkana County can hardly be prepared without a detailed field survey. Therefore in this study, only water pan potential is discussed.

The water pan development also depends on local conditions such as topographic, surface geological, and meteorological conditions of micro catchment area of small Laggas. Thus the potential map is preliminary, as it is evaluated based on the available data and information.

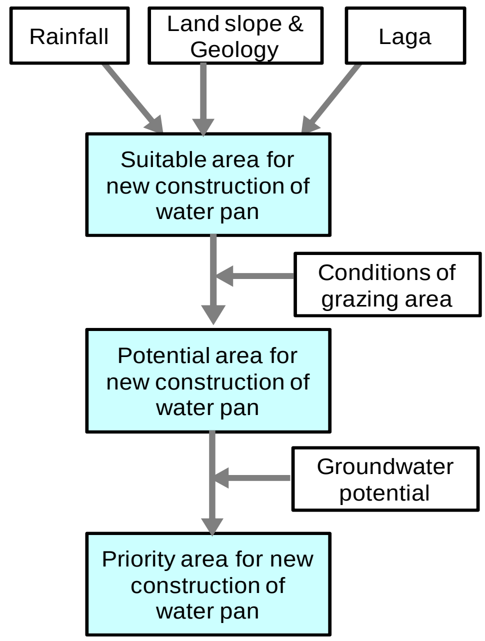
Conditions of suitable areas for water pan construction is set up based on locations of the existing water pans, which have been planned and developed based on detailed investigation of the local conditions.

E2.2 Water Pan Development Potential Mapping

(1) Procedure of potential evaluation

Suitable areas for water pan construction were studied with the following procedure, as illustrated in Figure E2.2.1

1) Suitable area for water pan construction is evaluated in terms of fundamental conditions of 1) rainfall, 2) land slope, 3) geological map, and 4) Lagga.
2) The potential area is also evaluated, taking conditions of grazing area into consideration. It should be selected in grazing areas where pasture is rich particularly during the dry season.
3) The priority area for new construction of a water pan is evaluated with reference to the potential of groundwater development with installation of hand pump. If the area has high potential both for water pan and groundwater development, the priority is given to groundwater because of 1) perennial availability and 2) less construction cost.



Source: JICA Project Team

Figure AE2.2.1 Procedure of Potential Evaluation

(2) Available data and information

For the evaluation process in the study mentioned above, the following existing data and information was used.

1) Annual isohyetal map using data obtained from World Clim Website
2) Land slope map based on Shuttle Radar Topography Mission (SRTM) data
3) Geological Map of Kenya (Ministry of Energy and Regional Development of Kenya, 1987)
4) Lagga map referred to UNESCO GIS data
5) Location map of existing water pans referred to UNICEF MIS (2006) and MWI-Oxfam (2009).
6) Wet and dry grazing areas based on the UNICEF MIS, reviewed and modified by the Project through field surveys and interviews with the pastoralists

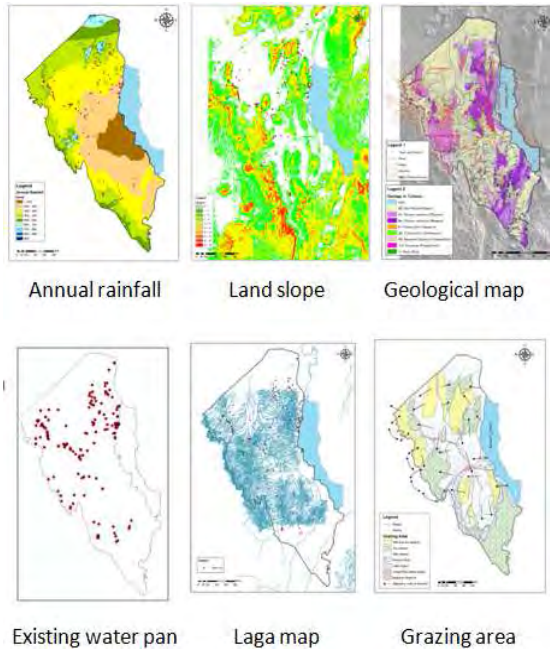
(3) Suitable area for water pan construction in terms of annual rainfall

Based on the classification of distribution of the existing water pans, they are mostly concentrated in the area of which annual rainfall was estimated at more than 200 mm/year, as shown in Figure BE2.2.1. Table AE2.2.1 and Figure AE2.2.3 show the result that 99% of the existing water pans are located in these areas.

Table AE2.2.1 Existing Pans in terms of Annual Rainfall

Rainfall	Nos. of sites
less than 200 mm/year	2 sites (1%)
200 - 300 mm/year	38 sites (27%)
300 - 400 mm/year	62 sites (44%)
more than 400 mm/year	39 sites (28%)

Source: JICA Project Team



Source: JICA Project Team

Figure AE2.2.2 Data Used for the Water Pan Potential Study

(4) Suitable area for water pan construction in terms of land slope

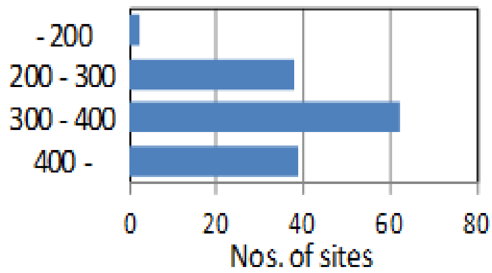
The area with steep land slope is mostly rocky as shown in land slope and geological maps (Figure BE2.2.2).

Disadvantage of the areas with steep slope for pan construction are explained as below:

1) Construction cost is dependent on land slope, because: i) more excavation is additionally required above designed water level (effective water storage volume), and ii) base rock may appear, and rock excavation requires high construction costs, as illustrated in Figure AE2.2.4.

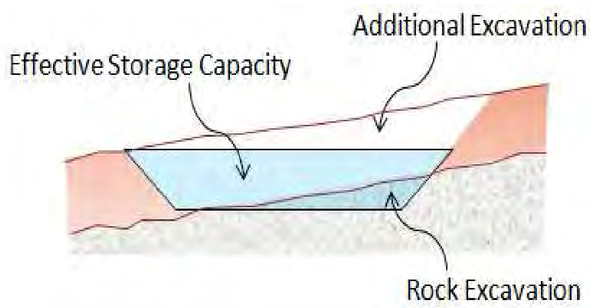
2) Gradient of source river / stream is steep and river flow flushed quickly within a short duration, and it is difficult to harness sufficient runoff. A fast flow also leads to more sedimentation in the pan due to suspended load in the water

Based on the classification of the distribution of the existing water pans, the pans are mostly concentrated in the areas whose land slope is less than 3%, as shown in Table AE2.2.2 and Figure AE2.2.5, which show the result that 98% of the existing water pans are located in these areas.



Source: JICA Project Team

Figure AE2.2.3 Distribution of Existing Pans in terms of Annual Rainfall



Source: JICA Project Team

Figure AE2.2.4 Disadvantage of Water Pan Construction on Slope

(5) Existing water pan and Laggas

With reference to the Lagga map showing location of the existing pans in Figure BE2.2.3, the followings was observed:

1) Existing water pans are located along the small seasonal rivers (Laggas), mostly within 100 m from the Laggas, and all Laggas including seasonal streams with small catchment area can be considered as water sources for water pan.

2) Meanwhile, the major rivers, such as main branches of the Turkwel, Tarach, Kerio Rivers and so on, are not suitable water sources for water pans.

3) There are is available detailed information of Laggas in the northern and southeastern areas.

(6) Suitable area for water pan construction in terms of annual rainfall, land slope, geology and Laggas

Applying the clarification mentioned above, the suitable areas for water pan construction that satisfy all of the above conditions of rainfall, land slope, geology and Lagga are shown in Figure AE2.2.6. The figure shows:

1) The suitable areas are spread in most of the sub-counties, but Turkana Central Sub-county has limited suitable areas, due to less rainfall.

2) In the other sub-counties, there are many suitable areas in low flat lands.

E2.3 Water Pan Potential in Priority Grazing Area

(1) Grazing area in which rich pasture is available during the dry season

Figure BD1.4.6 shows grazing area, and the grazing areas are divided into three categories.

1) Dry season grazing area

These areas are currently utilized during the dry season and both water and pasture are available.

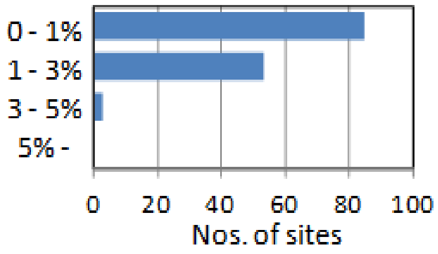
2) Wet / dry seasons grazing area.

These areas are currently utilized only during wet season because water is not available while pasture is available during the dry season. When water source will be developed, the area can be used during dry season

Table AE2.2.2 Existing Pans in terms of Land Slope

Land Slope	Nos. of sites
0 - 1%	85 sites (60%)
1 - 3%	53 sites (38%)
3 - 5%	3 sites (2%)
more than 5%	0 site (0%)

Source: JICA Project Team



Source: JICA Project Team

Figure AE2.2.5 Distribution of Existing Pans in terms of Land Slope

Source: JICA Project Team

Figure AE2.2.6 Suitable Area for Water Pan Construction

3) Wet season grazing area

These areas are currently utilized during only wet season. Water and pasture are not available during dry season.

(2) High potential area for new constriction of water pan

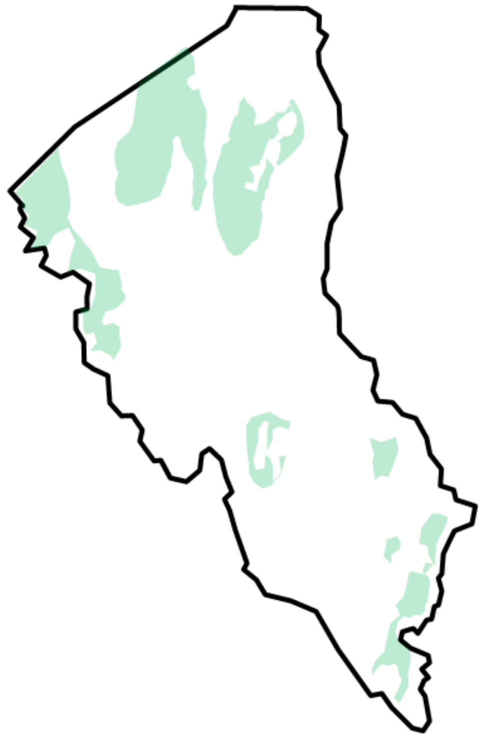
Taking the above conditions of grazing areas, the suitable area for the water pan construction is to be in and around good grazing areas during the dry season. The suitable area of water pan construction shown in the map in Figure AE2.2.6 and the map of grazing area in Figure BD1.4.6 were combined to indicate high potential areas for new constriction of water pan. As a result, the Figure AE2.3.1 shows suitable areas, which satisfy the above conditions and fall in the dry and wet/dry grazing areas. The areas with high development potential are located in Turkana North and West Sub-counties, and scattered in the other sub-counties.

(3) Water resource development belt

In the ECoRAD Project, a concept of water resource development belt was proposed for effective use of rangeland, taking migratory routes to rich grazing areas into consideration, as shown in Figure BE2.3.1. Water source development (including groundwater) was proposed in the dry season and wet/dry season grazing area, especially in the development belts.

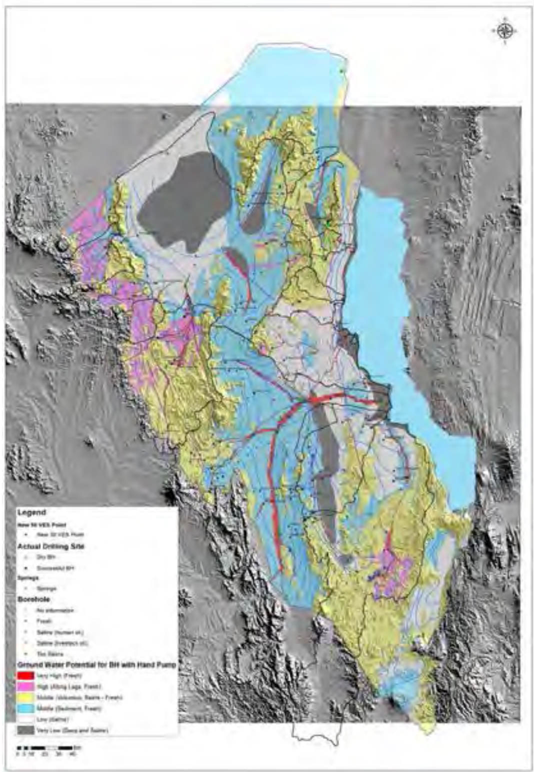
(4) Priority potential area for new construction of water pan

The groundwater potential in Turkana County is discussed in detail in the previous section E1, in which the potential of groundwater development for drilling borehole with hand pump is shown in Figure AE2.3.2. In this map, if both potentials are high for boreholes and water pans, the higher priority would be given to the groundwater development, because of the fact that it is a stable perennial water source and requires less construction costs. As shown in the map, the largest area with less potential for groundwater development is Lotikipi Plain, because of i) high potential for water pan construction in dry/wet grazing area, and ii) less potential for groundwater development, as shown in Figure AE2.3.3.



Source: JICA Project Team

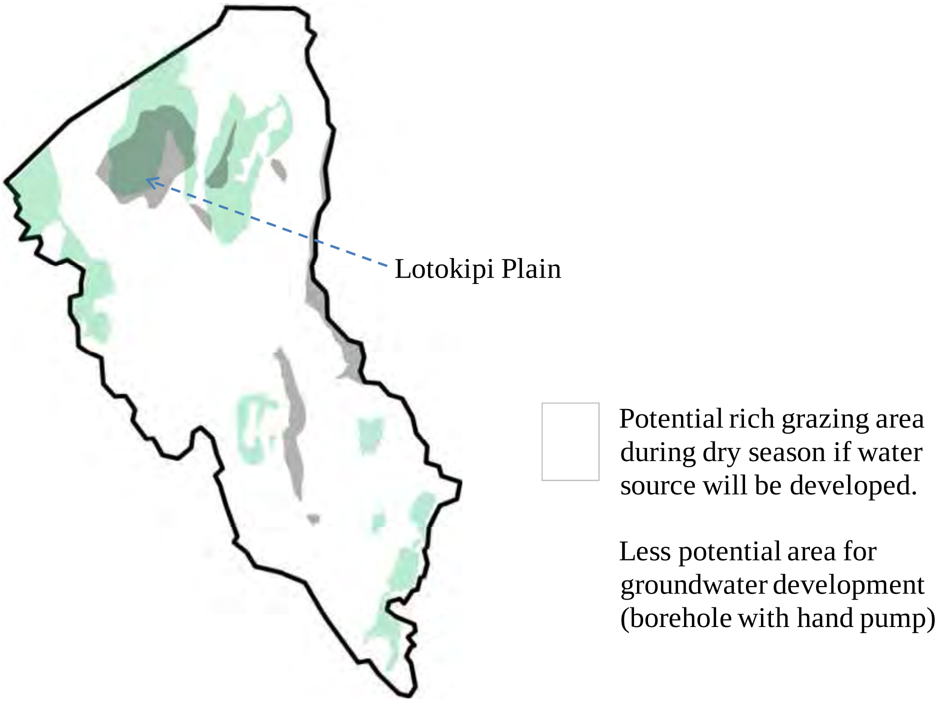
Figure AE2.3.1 High Potential Area for New Construction of Water Pan



(Details refer to previous Section E1).

Source: JICA Project Team

Figure AE2.3.2 Potential of Groundwater Development



Source: JICA Project Team

Figure AE2.3.3 Priority Potential Area for New Construction of Water Pan

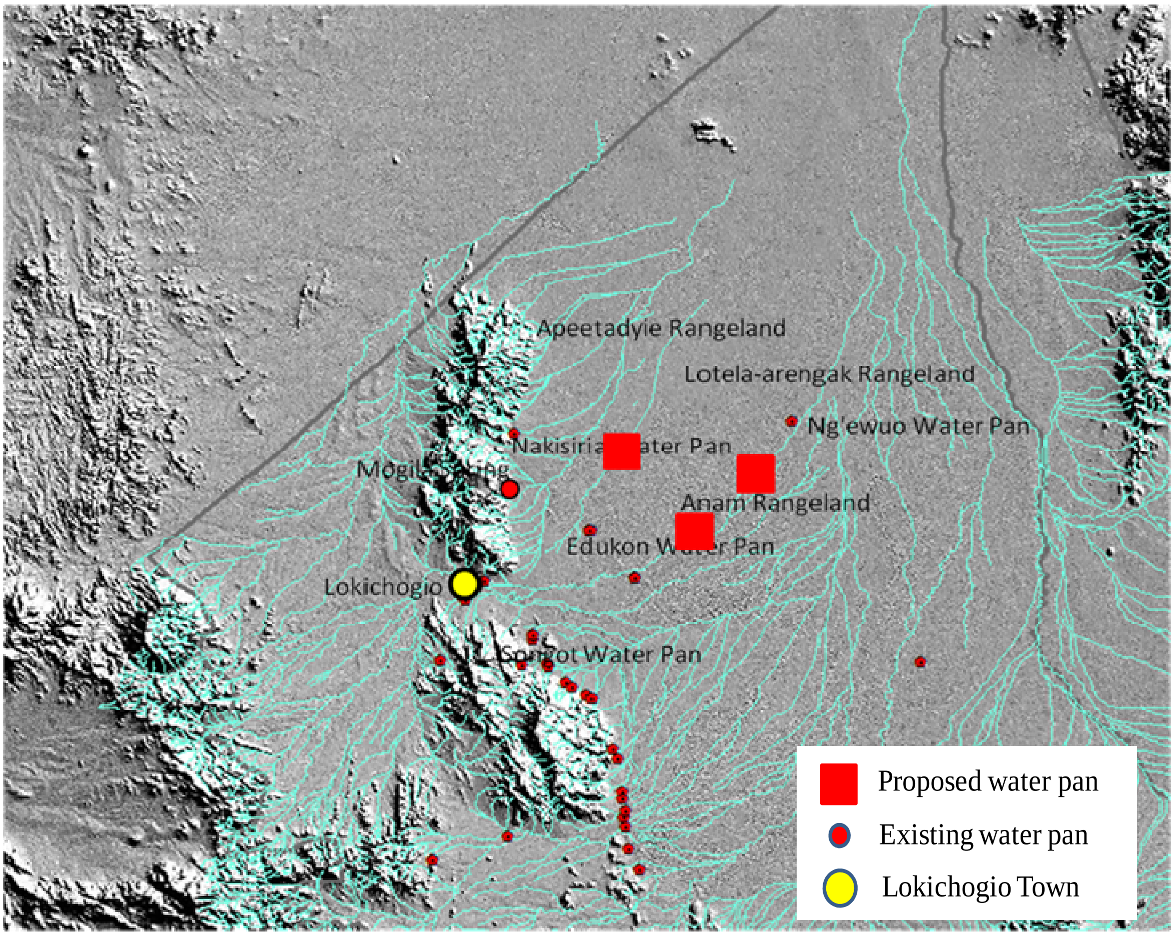
E2.4 Proposed Development of Water Pan in Lotikipi Plain

(1) Existing water pan and rangeland in Lotikipi plain

In Lotikipi Plain, pasture is found rich both in wet and dry seasons as shown in Figure BD1.4.6, and if water points will be developed it will become good grazing area during early dry season. However, existing water pans are limited and only one pan was found functional in the field survey, which is called Ng'ewuo Water Pan. While some pans are located in the south western side of the plain and near Mogila region including two pans of Edukon and Nakisiria Pans which were included in ECoRAD, as shown in Figure AE2.3.4.

(2) Proposed Water Pan in Lotikipi Plain

Based on the location of existing pan and available Laggas, it is proposed to develop the water pans, taking into consideration i) pastoralist' migratory routes, ii) grazing distances and iii) watering cycle. In this study, the following three pans are proposed as shown in Figure AE2.3.4.



Source: JICA Project Team

Figure AE2.3.4 Existing and Proposed Water Pans in Lotikipi Plain

CHAPTER E3. GROUNDWATER POTENTIAL

E3.1 Hydrological Environment in Turkana

E3.1.1 Rainfall and Temperature

Turkana County lies in the arid and semi-arid regions of kenya. The aridity is characterized by the climate in Turkana mainly rainfall and temperature that accelerate evaporation and transpiration.

Annual rainfall distribution has already been described in Chapter E1. Annual rainfall distributes concentrically and the center is the mouth of River Turkwel to Lake Turkana. The area of Minimum rainfall is downstream River Turkwel having below 200mm/yr and maximum rainfall area is the mountain range around the border to Ethiopia having more than 900mm/yr.

The Mean annual temperature distribution is also described in Chapter E1. Rainfall and temperature show the same distribution trend as elevation. That is, rainfall distribution is proportional to elevation and temperature is inversely proportional to elevation. The High temperature area is downstream of River Turkwel and Lake Turkana coastal zone and low temperature area is mountain range around the border to Uganda.

E3.1.2 Evapotranspiration

Potential evapotranspiration (ET) in arid and semi-arid regions is composed of 2 elements: “Soil ET” and “Groundwater ET”, and both of them are a function of temperature (Figure BE3.1.1).

The Project on the Development of the National Water Master Plan 2030 in the Republic of Kenya, JICA (2013) evaluated potential soil ET using FAO Penman-Monteith equation. Calculation result shows the potential ET from soil was more than 2,000mm/yr. This value corresponds 2 to 10 times of rainfall in Turkana and it means if rainwater is stored in surface soil, most of it returns to the air as ET from the soil.

In addition, trees and gasses directly absorb groundwater and vapour it into the atmosphere as transpiration in riparian area such as riversides. This phenomenon combined with evaporation from the ground surface is known as “groundwater ET”. The groundwater ET is an important component of water balance as a sink especially in arid and semi-arid regions. Potential groundwater ET is more than 1,500mm/yr which corresponds to 1.5 to 8 times of rainfall in Turkana. Thus, most of the rain water and groundwater at shallow depth returns to the air by two kind of ET. ET is one of the most important factors to evaluate sustainable yield.

E3.1.3 Drought and Standardized Precipitation Index

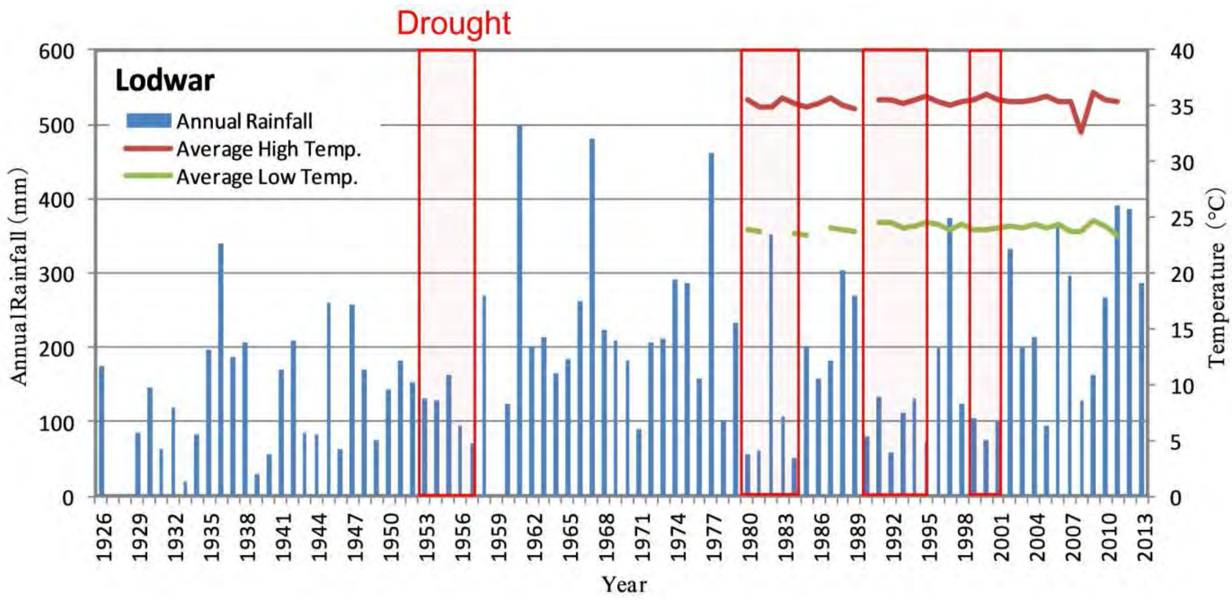
(1) Drought at Lodwar

Climate data confirms pastoral livelihoods are at risk from rising surface temperatures, more intense rainfall and more frequent droughts. The frequency and severity of droughts have increased in recent decades at Lodwar, with episodes of moderate to severe drought occurring more frequently since the 1980s.

These droughts are occurring at the same time as rainfall has become erratic and sometimes torrential. The net effect has been to reduce the vegetative cover that feeds livestock and protects soils against erosion. And conflict is increasing due to competition over scarce water and pastures.

Figure BE3.1.2 is illustrating the progression of drought, and the relationship between meteorological, agricultural, and hydrological drought. Economic, social and environmental impacts are shown at the bottom of the chart, independent of the time scale, indicating that such impacts can occur at any stage during a drought.

Figure AE3.1.1 is time series of annual rainfall with average high temperature and low Temperature variation. Red square is the duration reported as severe drought year. Lodwar has been encountered 4 times drought in about 90 years.



Source: JICA Project Team

Figure AE3.1.1 Time Series of 48 Months SPI Variation at Lodwar

(2) Standardized Precipitation Index

A variety of drought indices shown in Table AE3.1.1 have been developed to quantify whether or not a region is experiencing a drought and to categorize the seriousness of the drought. Drought indices are useful for mapping regional water supply trends, both temporal and spatial.

Standardized precipitation is defined as the difference from the mean for a specified time period divided by the standard deviation, where the mean and standard deviation are determined from past records (McKee et al. 1993). Standardized Precipitation Index (SPI) values are calculated for various time scales. The long-term precipitation data are fitted to a probability distribution, which are transformed to a normal distribution so the mean SPI for the location and time period is zero. Drought occurs when the SPI continuously reaches an intensity of –1.0 or less (Table AE3.1.2) and ends when the SPI becomes positive. Large minus value of SPI means more severe drought has been occurred. The SPI is the most widely used drought index and has the advantage that it is based only on precipitation and, thus, has a lesser data requirement than the other drought indices.

Table AE3.1.1 Estimated Pumping Rate by the Data Sets

Index	Method	Parameter
Percentage of Normal Precipitation	Statistical	Precipitation (actual precipitation / local normal precipitation x 100%)
Palmer Drought Severity Index (PDSI)	Moisture balance	Precipitation, Evapotranspiration, soil available moisture capacity
Standardized Precipitation Index (SPI)	Statistical	Precipitation (mean / standard deviation)

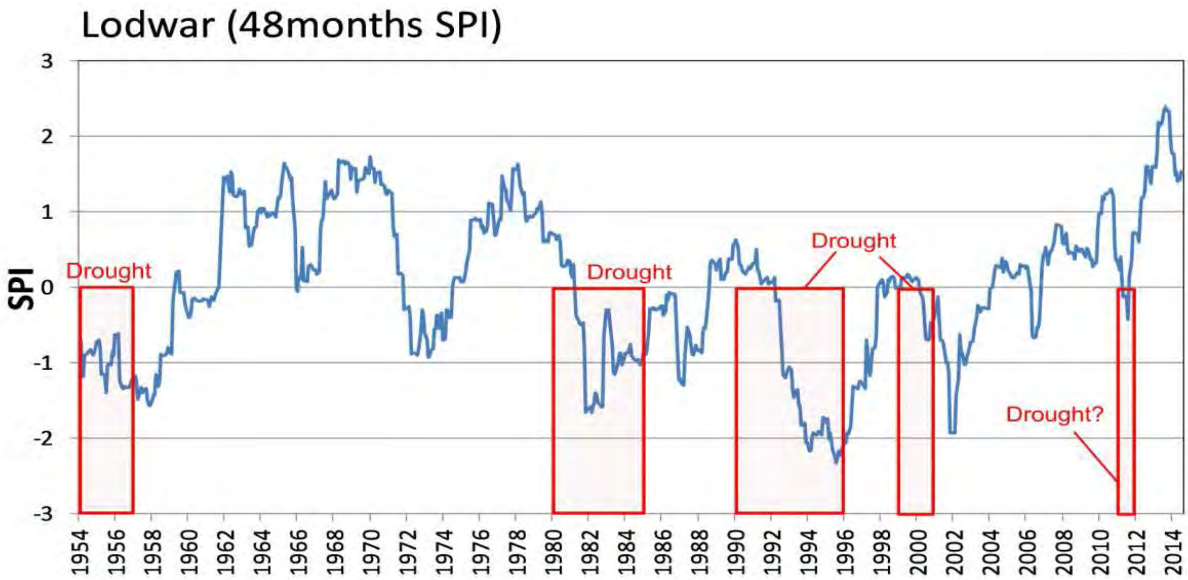
Source: JICA Project Team

Table AE3.1.2 Drought Categories from SPI

SPI	Drought Category	Time in Category
0 to -0.99	Mid drought	～24%
-1.00 to -1.49	Moderate drought	9.2%
-1.5 to -1.99	Statistical	4.4%
-2.00 or less	Extreme drought	2.3%

Source: McKee et al.(1993)

Lodwar meteorological station observes rainfall for a long time since 1926. JICA Project Team tried to apply SPI for the data and verify that past severe drought can be detected by SPI. Downloadable SPI program "SPI_SL_6.exe" by National Drought Mitigation Centre (http://drought.unl.edu/MonitoringTools/DownloadableSPIProgram.aspx) in University of Nebraska was used to calculate SPI. Figure AE3.1.2 shows that the time series of 48 months SPI variation with severe drought duration at Lodwar are able to detect severe drought clearly.



Source: JICA Project Team

Figure AE3.1.2 Time Series of 48 Months SPI Variation at Lodwar

E3.2 Groundwater in Turkana

E3.2.1 Groundwater Use

Groundwater is one of the most important water resources in Turkana. It is very important for the people who live in Turkana to identify the high groundwater potential area from the point of view of water quantity and water quality.

Collected borehole data from UNICEF(2006) and MWI and Oxfam(2010) were used to estimate present maximum pumping rate. All borehole locations from the data sets are plotted in Figure BE3.2.1 with water quality classification: fresh, saline (human OK), saline (animal OK), too saline, and no information. Although some boreholes in the 2 data sets are same, a lot of different boreholes are included in each data set because the two data sets have gaps in four years, and many boreholes have been drilled and abandoned in the meanwhile. Hence, two data sets were combined into one data base as shown in Table AE3.2.1. Present maximum pumping rate is 6.7MCM/yr estimated from the data base.

Table AE3.2.1 Estimated Pumping Rate by the Data Sets

Data Set	Borehole		
	Total Number	Operational	Pumping rate (MCM/yr)
UNICEF(2006)	282	214	4.0
MWI-Oxfam(2010)	511	332	6.1
Combined	605	366	6.7

Source: JICA Project Team

E3.2.2 Water Quality of Groundwater and Recommended Drilling Depth

(1) Water Quality of Groundwater

The geology of Turkana is divided into eight major successive rock formations according to Geological Map of Kenya (1987). In this study, geological units were simplified into 4 units to import groundwater model; Basement Rocks, Volcanics, Sediments and Others (Turkana Grits) shown in Figure BE3.2.2.

Geology and groundwater quality in Turkana County have very close relationship because most of the groundwater presents in rock fractures and a large amount of dissolved substances exist in the groundwater having long retention time. Fortunately, substance such as arsenic which causes health hazards to humans and livestock with the exception of fluoride is hardly included in the groundwater. Therefore, main problem of the water quality is salinity.

Relationship between water quality and geology was already explained in Annex D6. According to water quality information from compiled data set shown in TableAE3.2.2, about 90% of water from existing boreholes can use for livestock. One of the objectives in this project is to enhance resilience against pastoralist with livestock through groundwater development. Therefore, if newly drilled borehole is able to get enough groundwater, it means groundwater development will be about 90% successful because there is high potential which the water can be used at least for livestock.

Table AE3.2.2 Water Quality of Existing Boreholes

Data Set	Flesh	Saline			No Data
		Human OK	Animal OK	Too Saline	
UNICEF (2006)	182	62	4	14	20
MWI-Oxfam (2010)	294	148	8	45	16

Source: JICA Project Team

(2) Stiff Diagram and Piper Diagram

Stiff diagram is a graphical representation of chemical analyses. A polygonal shape is created from four parallel horizontal axes extending on either side of a vertical zero axis. Cations are plotted in milliequivalents per litre on the left side of the zero axis, one to each horizontal axis, and anions are plotted on the right side. Stiff patterns are useful in making a rapid visual comparison between water from different sources. The size of the diagram indicates ion concentration. Ion rich water recognized saline water here.

Figure BE3.2.3 shows water quality distribution of newly drilled boreholes by Stiff Diagram with simplified geology. Saline water can be found in deep boreholes: Lotikipi and Napuu3 drilled by UNESCO and Turkwel downstream and Lake Turkana coastal area boreholes: Losagam and Kangirisae. Water quality in other boreholes is fresh except for Kaituko (Kanakurudio) and Kaidir (Namoruputh) having unique water qualities.

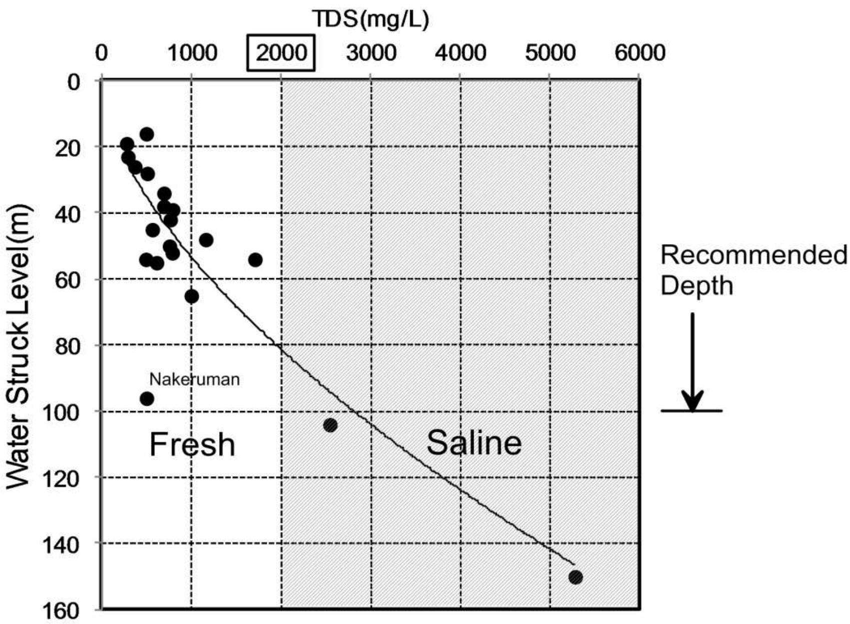
Piper diagram is also a way of visualizing the chemistry of water sample. It is comprised of three pieces: a ternary diagram in the lower left representing the cations, a ternary diagram in the lower right representing the anions, and a diamond plot in the middle representing a combination of the two.

Figure BE3.2.4 shows water quality of newly drilled boreholes on Piper Diagram. Most of boreholes are plotted in zone II in the diagram where indicates deep and old (long retention time) groundwater. On the other hand, Lotikipi borehole is plotted near border of zone IV where sea water is included in.

(3) Recommended Drilling Depth

Figure AE3.2.1 shows the plots with fitting curve which is excluded singular points such as plots in deep basin area and Lake Turkana coastal area. Fitting curve and TDS 2,000mg/L line intersect at about 80m of water struck level. It means that if groundwater is struck below 80m, TDS may be more than 2,000mg/L and the water may not be suitable for human consumption. On the other hand, Nakeruman is plotted in fresh water zone around 100m in depth with TDS 500mg/L. The reason is because Nakeruman is situated on fracture near mountain range where fresh groundwater is always recharging. Considering comprehensively, recommended drilling depth of borehole from water quality is around 100m shown in Figure AE3.2.1.

General water quality in Turkana is already explained in Annex D6.



Source: JICA Project Team

Figure AE3.2.1 Recommended Drilling Depth Based on Relationship between Water Struck Level and TDS

E3.2.3 Recharge Mechanism

In the mountain ranges, infiltration goes down deeply through fractures even though the hydraulic conductivity of the ground itself is low. This deep recharge is called “mountain block recharge”. On the other hand, the recharge phenomenon at the border of rock and sediment is called “mountain front recharge” There are a lot of faults around mountain range in Turkana County. Because the faults disturb the horizontal movements of groundwater in some places, groundwater flow becomes complex. Schematic diagram of these two recharge mechanism is shown in Figure BE3.2.5.

In plains area, when rain comes, water flows in seasonal river called *laggas* only for few a hours or few days. Most part of this flood water flow away into Lake Turkana or marsh directly, and remaining rainwater is kept in bed of *laggas* temporarily. Groundwater ET occurs through the bed of *laggas* as shown in Figure BE3.2.6. Therefore, the amount of local groundwater seepage from the bed of *laggas* should be little.

Estimation of groundwater recharge in Turkana is very difficult. Table AE3.2.3 is summary of various estimation study results for renewable groundwater recharge in arid and semi arid lands. Recharge values show a wide range between 0.7 and 18% of rainfall in the table. In Kenya, previous surveys and studies show value between 4 and 22% of rainfall and common case is 7% of rainfall. In 2013, JICA Master Plan 2030 Team estimated the recharge as 5% of rainfall as the average in Kenya using numerical analysis.

Table AE3.2.3 Estimated Recharge Rates from Some Arid and Semiarid Region Studies

Location Name	Mean annual precipitation (mm)	Mean annual recharge (mm)	Recharge/ precipitation	Method	References
Wadi Yalamlam, Saudi Arabia	231	22.8	10%	CMB*1	Subyani and Sen (2006)
Southern High Plains Aquifer, USA	485	11±2	2%	CMB	Wood and Sanford (1995)
South and Central New Mexico	230	8.4-9.4 1.5-2.5	3.7-4.1% 0.7-1.1%	Tritium CMB	Phillips et al. (1988)
Interior Southwestern US (7 Basins)	106-303	0.9-4.4	0.7-1.8%	BCM*2 modeling	Flint and Flint (2007)
Upper Virgin Basin, SW Utah	303	17.3	5.7%	BCM modeling	Flint and Flint (2007)
Wadi Tharad, Saudi Arabia	57.5	6.1	11%	CMB	Subyani (2004)
Wadi Wajj, Saudi Arabia	268	11.5	4.8%	CMB	Al-Shaibani (2008)
Wadi, Marwani, KSA	60	10.9	18%	CMB	Al-ahmadi and El-fiky (2009)
Nyamandhlovu aquifer, Zimbabwe	555	15-20	2.7-3.6%	CMB, WTF*3, flow net, dating, modeling	Sibanda et al. (2009)
Amargosa Basin, Southern Nevada and California	180	2.9	1.6%	Hydrologic models	Osterkamp et al. (1994)

*1: Chloride Mass Balance method
*2: Basin Characterization Model
*3: Water Table Fluctuation

Source: Maliva and Missimer (2012)

E3.3 Groundwater Flow Model

E3.3.1 Conceptual Model and Numerical Model

(1) Conceptual Model

The conceptual hydrogeologic model is the most important step in groundwater model process and it forms the basis for developing the numerical model. An increased level of effort in creating the conceptual model reduces the effort calibrating the numerical model.

Figure BE3.3.1 shows the conceptualized groundwater flow in arid and semi-arid regions. Precipitation percolates to underground and recharges groundwater, and reappears on the ground following three paths: local flow, intermediate flow, and interbed flow. Finally, groundwater discharges to the surface or return to the air by everpotranspiration. Groundwater ET is the uptake of groundwater, which is once recharged to the aquifer, through trees and vegetation.

Aquifer system in Turkana County can be classified into the following 3 types:

- Basement Rocks: Water in fracture
- Volcanics: Water in fracture
- Sediments: Local aquifer near River Turkwel and deep aquifer governed by basin structures

And the conceptual model of Turkana groundwater flow is as follows:

- Recharge occurs at mountain ranges in Turkana County and water infiltrates down into fractures deeply or flows in shallow depth along *laggas*.
- Most of groundwater along *laggas* is lost by groundwater ET.

- Therefore, regional groundwater flow dominates sustainable yield.

(2) Numerical Model

To evaluate sustainable yield and clarify regional groundwater flow, groundwater flow model using MODFLOW was introduced. MODFLOW is a 3-dimensional, steady-state or transient, finite-difference, numerical groundwater flow model developed by the US Geological Survey (USGS) in 1983. MODFLOW is one of the popular groundwater models used worldwide.

MODFLOW is a 3-dimensional, steady-state/transient, finite-difference, numerical groundwater flow model developed by the USGS (McDonald & Harbaugh, 1983). It calculates hydraulic head at each grid block center, and flow from cell-to-cell, by solving the following equation:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+W=S_s\frac{\partial h}{\partial t}$$

h: hydraulic head

x,y,z: direction

W: source and sink

Ss: specific storage

E3.3.2 Simulation Setting

(1) Model Grid

SRTM (Shuttle Radar Topographic Mission) data was imported for surface elevation on the process of model development with basin structure mentioned above. Three hydrogeological units (Figure BE3.3.2) were classified in the basic model: basement rocks, volcanics and sediments. Local features of hydrogeology were taken into consideration through the adjustment works of hydraulic constants in the calibration process.

In 2013, UNESCO discovered 7 deep basin structures which store large amount of water; Nanam-Nalira Deep Aquifer, Tarachi-Nakale Deep Aquifer, South Lotikipi Basin, Gatome Basin, Kachoda Basin, Nakalale Basin and Lodwar-Lokichar Basin as shown in Figure BE3.3.3. These basin structures were digitized and imported into groundwater flow model explained below.

The whole Turkana County was divided by meshes of 2km grid in MODFLOW. This grid size is considered to be small enough to express regional groundwater flow. Bottom of the model set -1,000m to avoid affecting groundwater flow (Figure BE3.3.4 (a)).

(2) Boundary Condition

320m of water level was assigned at Lake Turkana cells as constant head boundary. Because River Turkwel serves as a source and sink for groundwater, river boundary condition was assigned to the cells. Part of model margin is open for surrounded groundwater system and groundwater can flow to and from outside the model area. To express such kind of boundary, flux boundary condition was introduced to Northern side and South-Western side of model margin (Figure BE3.3.4 (b)).

Groundwater ET (Drain) boundary was set to model surface. 5% of rainfall from “Worldclim” rainfall distribution was calculated and assigned to appropriate area as renewable groundwater recharge in the groundwater model.

(3) Recharge and Pumping Rate

5% of rainfall was adopted as renewable groundwater recharge in this study and assigned the values to recharge area such as rock exposure area in developed groundwater model (FigureBE3.3.4 (c)).

Estimated pumping rates were also imported in the model at exact well positions.

(4) Calibration Target and Simulation Method

Calibration target was set at static water levels for newly drilled 20 boreholes and 4 UNESCO's boreholes scattering in whole Turkana County shown in Figure BE3.3.5.

Transient simulation was repeated to reach a steady state condition expressing present groundwater flow and water balance. Hydraulic constants for each hydrogeological unit were adjusted to fit static water level in 24 wells and fixed finally.

E3.3.3 Simulation Result

(1) Hydraulic constants and Model Caribration

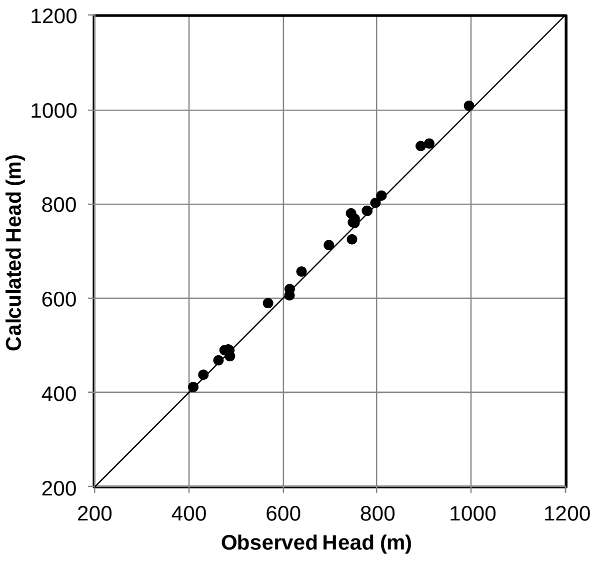
Fixed hydraulic constants and calibration result were shown in TableAE3.3.1 and Figure AE3.3.1. The values in the table are for surface layer and the values for deep layer and very deep layer were multiplied by 0.1 and 0.01 respectively. These hydraulic constants are reasonable compared with general value. Calculated heads from groundwater model and observed heads match well enough. It means Turkana groundwater flow condition can be represented by groundwater model.

Table AE3.3.1 Fixed Hydraulic Constants after Calibration

Hydraulic Conductivity	Kx, Ky (cm/s)	Kz (cm/s)	Sy	Ss(1/m)
Sediments and Sedimentary Rocks	1.5×10^{-5} - 1×10^{-4}	1.5×10^{-6} - 1×10^{-5}	0.2	1×10^{-5}
Volcanic Rocks*	1 - 2.5×10^{-5}	1 - 2.5×10^{-5}	0.05	1×10^{-5}
Basement System Rocks*	2×10^{-6}	2×10^{-6}	0.05	1×10^{-5}

*deep layer = (Kx, Ky, Kz) x 0.1, very deep layer = (Kx, Ky, Kz) x 0.01

Source: JICA Project Team

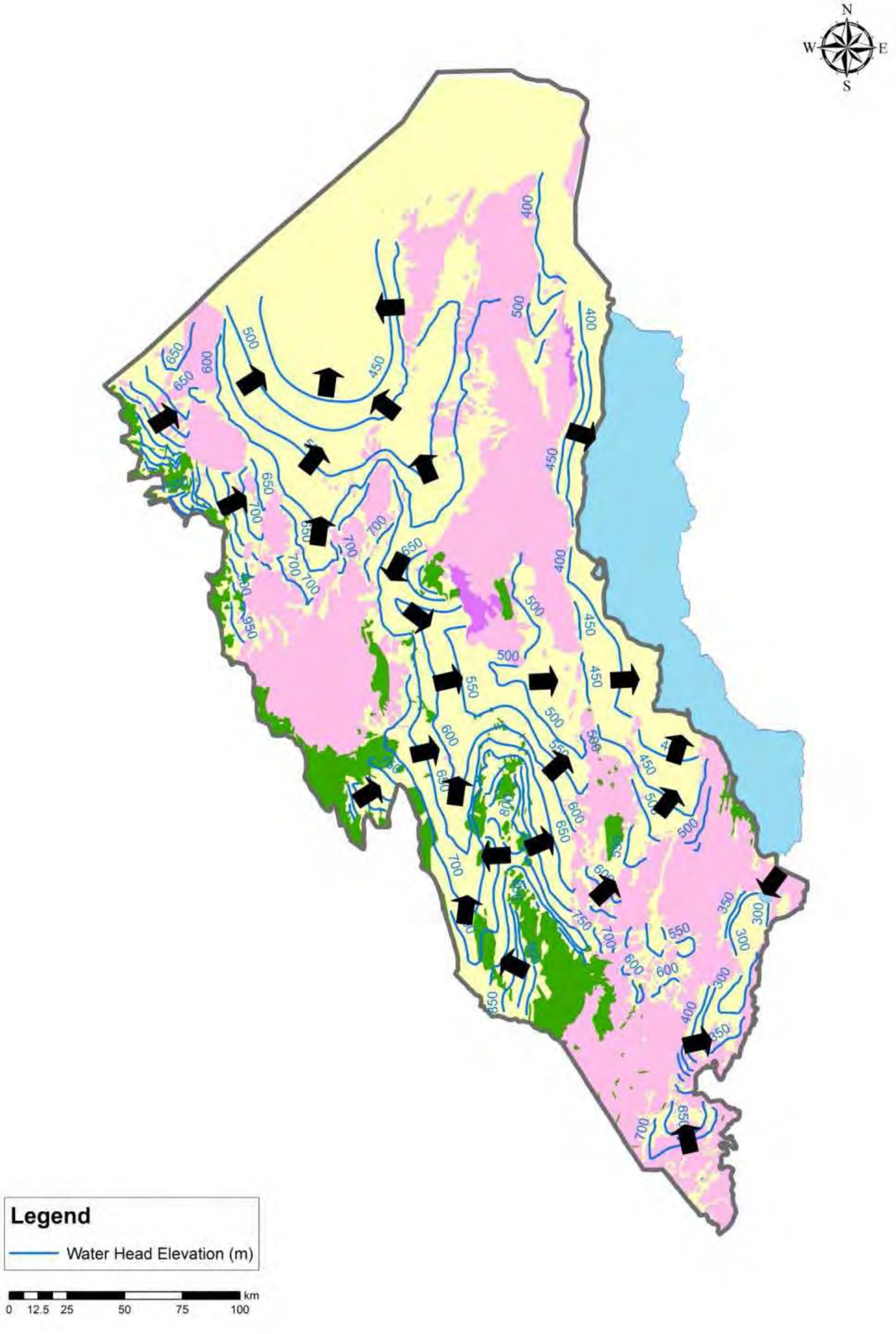


Source: JICA Project Team

Figure AE3.3.1 Calibration Result of Groundwater Flow Simulation

(2) Regional ground water flow

Calibrated groundwater flow model provides a lot of information: e.g. regional groundwater flow direction, travel time, and water budget. Figure AE3.3.2 shows hydraulic head elevation contours in plain areas and groundwater flow direction. Groundwater recharged at mountain range flows to lower plain area very slowly. For example groundwater near Lokichoggo reaches UNESCO Lotikipi borehole site after 6,000 years or more according to the model. Water quality of groundwater should get worse to the downstream.



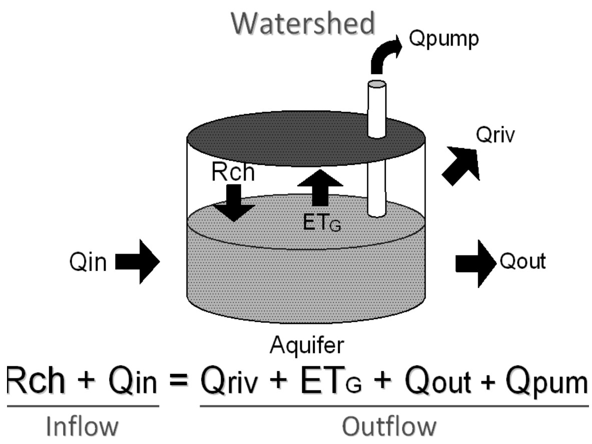
Source: JICA Project Team

Figure AE3.3.2 Hydraulic Head Elevation Contours in Plain Areas and Groundwater Flow Direction

E3.4 Sustainable Yield in Turkana County

In a broad sense, "Sustainable Yield is defined by stored groundwater amount in the basin that can be used without consuming". However, groundwater storage is always changing due to external factors such as climate change and human activities. This is the reason that it is quite difficult to estimate the sustainable yield of groundwater. Schematic diagram of sustainable yield is shown in following Figure AE3.4.1.

In 2008, Ponce in USGS proposed that sustainable yield may reasonably be around 10% of renewal groundwater recharge taking into consideration the aspects of hydrology, socio-economy, culture, etc. Based on the definition, water balance in groundwater was calculated and summarized into Table AE3.4.1. Average rainfall in Turkana County is 361mm/yr (24,790MCM/yr). Renewable groundwater recharge assigned to the groundwater model is 8.0mm/yr (547MCM/yr). Therefore, Sustainable yield is 10% of renewable groundwater recharge which is 0.8mm/yr (55MCM/yr). Assuming the present maximum pumping rate is about 7MCM/yr, renewable groundwater recharge is 2.2%, sustainable yield is 0.2% of rainfall and present maximum pumping rate becomes 12.1% of sustainable yield.



Source: JICA Project Team

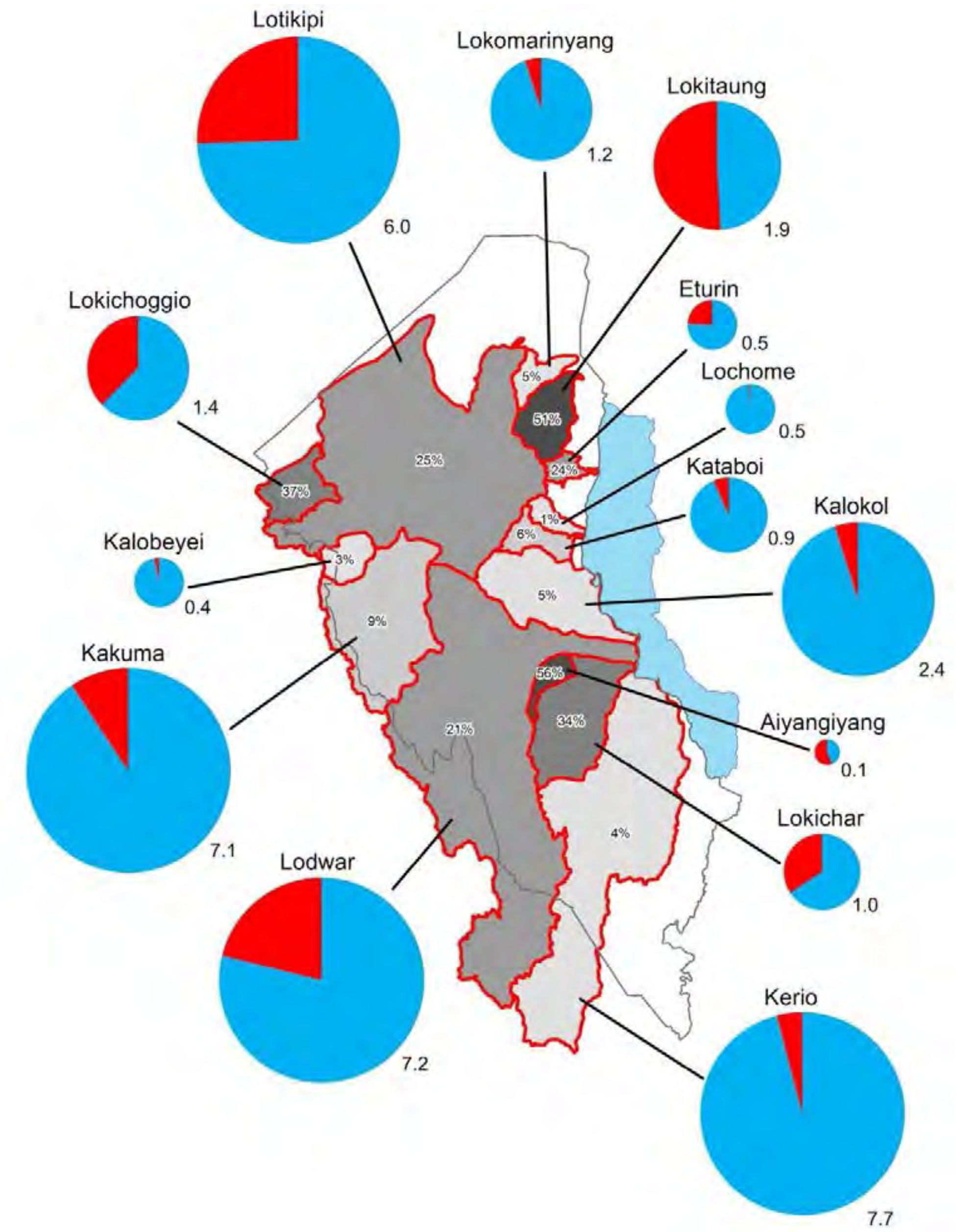
Figure AE3.4.1 Schematic Diagram of Sustainable Yield

Table AE3.4.1 Sustainable Yield in Turkana

Water Budget in Groundwater	Area 68,671km^2		
	mm/yr	m^3/d	MCM/yr
(a) Average Rainfall	361	67,918,000	24,790
(b) Renewable Groundwater Recharge	8.0	1,497,900	547
(c) Sustainable Yield	0.8	149,800	55
(d) Present Maximum Pumping Rate	0.1	18,100	7
(b) / (a)	2.2%		
(c) / (a)	0.2%		
(d) / (c)	12.1%		

Source: JICA Project Team

Figure AE3.4.2 is pumping rate occupied in sustainable yield for each watershed using groundwater simulation results. Lokitaung watershed pumping rate exceeds 50% of sustainable yield because the watershed is small and groundwater recharge is also low. Although Lokichoggio watershed, Lodwar watershed and Lokichar watershed are below 50% of groundwater use for sustainable yield, the condition that wells are concentrated in town may affect sustainable yield value in near the future.



Source: JICA Project Team

Figure AE3.4.2 Pumping Rate Occupied in Sustainable Yield for Each Watershed

E3.5 Turkana Groundwater Development Potential Map

E3.5.1 Concept of the Map

Turkana groundwater potential study by JICA Project Team has continued since beginning of the project. The result of the study based on the actual groundwater development works and groundwater model analysis were compiled as Turkana Groundwater Development Potential Map (TGDP Map). The concept of TGDP map is as follows;

> When groundwater development plan is developed, the planner should want to know the area possibility groundwater comes out with high possibility, the recommended depth to be drilled and the water quality risk for human and livestock. TGDP Map is one of the map provides such kind of information visually.

Target of TGDP Map is boreholes for groundwater development. Boreholes are one of the most important water resources and can be used sustainably under the appropriate maintenance and management in Turkana County. TGDP Map includes supposed hydraulic head elevation in watershed, sustainable yield and water quality information. The study should be also valuable for future political measures in the water sector of Kenyan Government. The part of the results was introduced in Turkana water resources seminar held on 21st November 2014 at St. Teresa in Lodwar.

E3.5.2 Target of TGDP Map

Target of TGDP Map is boreholes which is most important water resources in Turkana County. Borehole can use sustainably under the appropriate maintenance and management and the water quality is stable.

When drilling point is determined, at first select area or community should be selected by regional level groundwater development information such as existing borehole distribution, geology and topography, and condition of *laggas*. And after that, just point for drilling should be decided by vertical electrical sounding with local level information. TGDP Map is intended to provide information of drilling point in regional level.

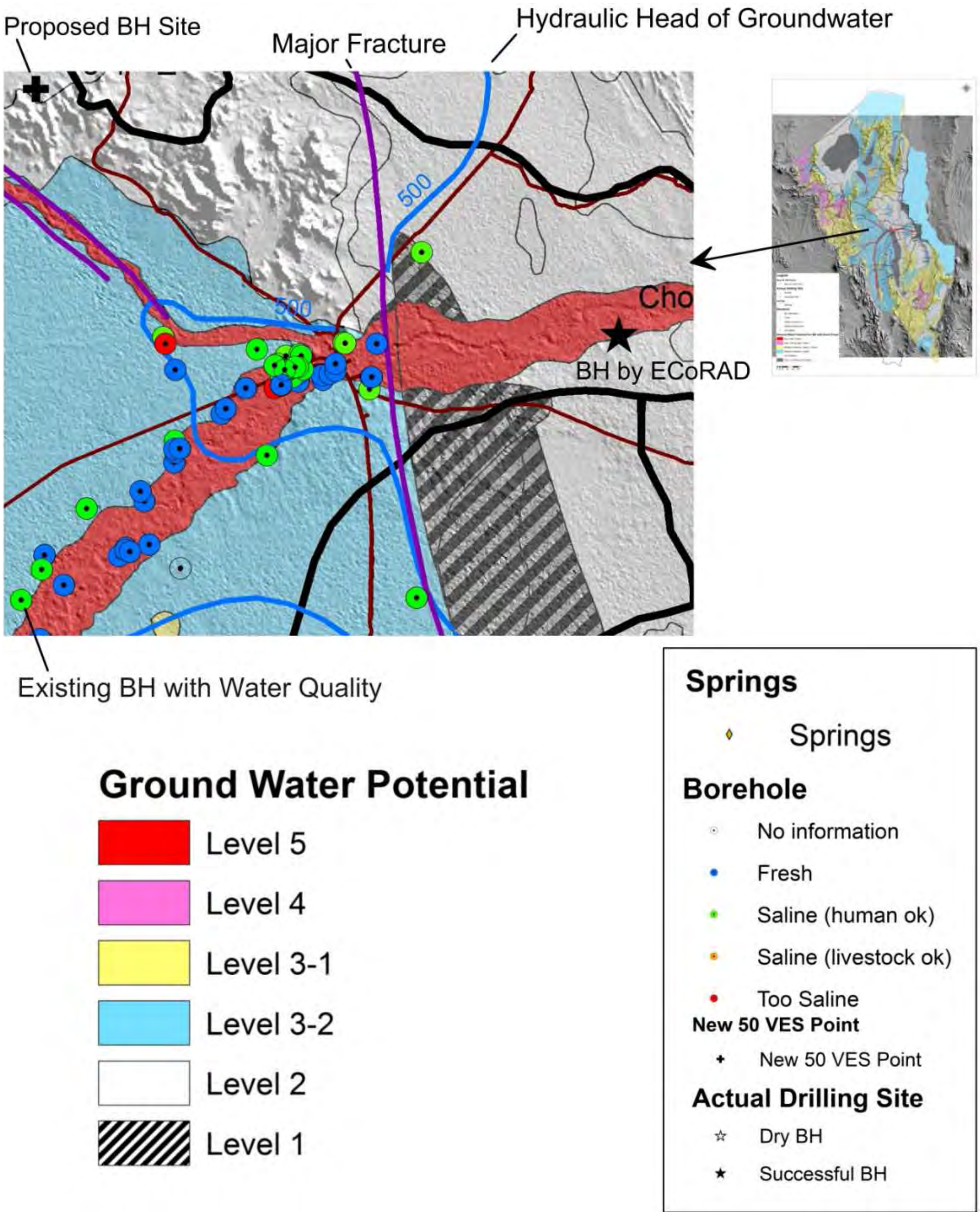
E3.5.3 Usage of TGDP Map

Two and a half years experience in the Project and groundwater simulation results were summarized as TGDP Map. TGDP Map is on the process of editing and a sample of the map is shown in Figure AE3.5.1. TGDP Map will include a lot of information about groundwater. Base map will be SRTM topographic imaging and UNESCO groundwater potential map already released will be referred. In addition, field survey results and groundwater simulation output will be reflected on this map including springs as exposure of groundwater and water quality information. Map will be composed of 6 coloured zones indicating groundwater development potential level from high potential (Level 5) to low potential (Level 1) shown in Table AE3.5.1. TGDP Map should be able to be used in the area screening process. The Project Team will release 1st edition of the Map with final report and expect that the map is constantly updated using newest data.

Table AE3.5.1 TGDP Map Level Classification

Level	Area	Description
5	River and Major Laggas Area	Potential is high. Water struck level may be shallow and yield may be high. The water should be fresh.
4	Surround Area of Level 5	Potential is relatively high. Recommended site is along laggas. Fresh water is expected.
3-1	Volcanics and Basement Rocks Area	Potential is medium. Groundwater struck level is less than100m. Recommended site is along laggas. The water quality may be mildly saline in Volcanics.
3-2	Sediments Area	Potential is medium. Development target is limited along laggas. The water is fresh-saline.
2	Surround Area of Level 1	Potential is relatively low. Groundwater struck level may be more than 100m. The water may be saline.
1	Basin and Lake Turkana Coastal Area	Potential for hand pump is low. Groundwater struck level in Basin Area is more than 100m and hydraulic head may be low for hand pump. The water quality could be saline. Groundwater could be struck at shallow depth in Lake Turkana Coastal Area. However, the water could be saline.

Source: JICA Project Team



Source: JICA Project Team

Figure AE3.5.1 Sample of TGDP Map

E3.6 Natural Resource Development Belts and Proposed 50 Borehole Sites

(1) Prioritized Areas for Drought Resilience

Based on TGDP map and condition of pastures and migratory routes, the Project prioritized the areas to be developed in order to alleviate damage of drought and improve drought resilience. At first the distribution condition of grazing areas in Turkana was classified as shown in Figure BE3.6.1 with the following classifications in the table below.

Table AE3.6.1 Classification of Seasonal Grazing Areas

	Wet season		Dry Season	
	Pasture	Water	Pasture	Water
Wet Season GA	Available	Available	No Available	No Available
Wet/Dry Season GA	Available	Available	Available	No Available
Dry Season GA	Available	Available	Available	Available

Source: JICA Project Team

Then the Project mainly targeted to develop "Wet/Dry season grazing area" with high priority, then proposed natural resource development belts as shown in Figure BE3.6.2

(2) Proposed Borehole Sites

The Project team also executed and evaluated hydro-geological electrical survey for 50 boreholes, and proposed its potentials in order to provide tangible guideline for groundwater development derived from the TGDP map.

Detailed data and its locations of those 50 boreholes are shown in Table BE3.6.1 and Figure BE3.6.2 respectively.

According to the regulation of procedures for drilling boreholes, any project executing agency should study and prepare geological investigation reports in order to obtain permission for drilling from Water Resource Management Authority (WRMA) at every borehole. Thus, in order to facilitate and accelerate such approval process, the Project team compiled the geological report at all the 50 proposed sites which comply with requirements for WRMA's approval for drilling. Then the Project submitted those reports to the county ministry of water and the Ministry of Devolution and Planning for their reference. Thus any organization that plans to develop borehole can obtain those geological reports from the above mentioned offices, and submit an application for a permission of drilling borehole without any additional cost for making the geological investigation reports.

Tables

Table BE1.6.1 Locations for Hearing Survey in Turkana County

No.	District	Site Name	Sublocation	Location	Area(km²)*2	Population*2	Density*2	Coordinate Northing	Coordinate Easting	Water facility*1 BH/SW	WP	SD/RC	SP	Borehole / Spring WL(GL-m)	Depth(m)	Yield(m³/hr)	Water Demand	Water Quality pH	EC(mS/cm)	F(mg/L)	Interview
1	North	Kaikor	Lokolio	Kaikor	484.5	6,859	14	4° 31 07.7"	35° 25 16.3"	6(12)	4(5)	2(2)/0(1)	0(0)	19	42	9	Fair	8.8	1.03	2.21	Not good (alkaline)
2		Milmatatu	Milimatatu	Yapukuno	835.1	4,622	6	4° 8 21.3"	35° 28 09.8"	6(7)/1(1)	3(4)	0(0)/0(0)	0(0)	-	80-100	1.2	High	6.2	2.17	(1.5)	Not good
3		Kangakipur	Kangakipur	Kaeris	344.1	2,407	7	4° 2 05.5"	35° 29 01.3"	3(4)/0(0)	0(0)	0(3)/0(0)	2(2)	-	85-105	4	High	7.4	2.95	(1.0)	Unknown
4		Kanukurdio	Kanakurdio	Kaaling	1,113.5	4,991	4	3° 47 36.2"	35° 27 53.9"	2(3)/1(2)	0(1)	0(0)/0(0)	0(0)	-	<80	-	High	-	-	-	Not good
5	West	Lokichoggio	Lokichoggio	Lokichoggio	503.9	10,980	22	4° 12 34.8"	34° 21 19.0"	22(27)/1(1)	3(3)	0(0)/0(0)	0(0)	64.0	9.7	2.1	High	8.2	0.88	1.42	Generally good (Pollution by human activities)
6		Nakeruman	Lokariwon		520.0	10,980	21	4° 19 47.6"	34° 18 50.2"	0(0)/0(0)	0(1)	0(0)/0(0)	0(0)	-	-	-	Very High	-	-	-	Unknown
7		Mogila	Mogila	Mogila	597.7	14,547	24	4° 17 48.9"	34° 25 04.8"	4(6)/1(1)	1(1)	0(0)/0(0)	2(4)	0(SP)	-	45-80L/s	High	-	-	-	Not good (Pollution by livestock)
8		Nanam	Nanam	Nanam	781.0	5,603	7	4° 12 39.6"	34° 33 32.0"	0(4)/5(6)	1(2)	0(0)/0(0)	0(0)	7	70	-	High	-	-	-	Unknown
9		Oropoi	Oropoi	Kalobeyei	559.1	4,827	9	3° 48 43.1"	34° 21 27.9"	3(6)/1(1)	0(3)	0(0)/0(0)	0(0)	-	<80	-	High	-	-	-	Good
10		Kalobeyei	Kalobeyei		267.9	3,010	11	3° 46 02.9"	34° 37 24.0"	1(3)/2(5)	0(0)	0(0)/0(0)	0(0)	15	100	16	High	8.8	0.8	0.62	Good
11		Loreng	Loreng	Loreng	308.5	3,210	10	3° 31 48.0"	34° 37 59.5"	1(2)/2(2)	0(0)	0(0)/0(0)	0(0)	-	<80	-	Very High	-	-	-	Not good
12		Loritit	Loritit	Letea	646.1	577	1	3° 31 21.8"	34° 49 08.6"	1(4)/7(7)	0(0)	0(0)/0(0)	0(0)	-	<80	-	High	-	-	-	Good
13		Kakuma	Nadapal	Kakuma	41.5	15,870	382	3° 42 33.0"	34° 51 45.0"	12(16)/1(4)	3(7)	1(1)/0(0)	0(0)	8.1	110	6	High	8.3	1.04	5.64	Natir 1 Quite different among wells
14		Nakoros						3° 40 06.9"	34° 48 14.3"					-	<80	-	High	-	-	-	Grondwater polution by human activities
15	Central	Lodwar	Lodwar Town	Lodwar Town	304.2	24,351	80	3° 6 57.8"	35° 35 42.7"	21(27)/1(2)	1(1)	0(0)/0(0)	0(0)	5.1-1.6	21-24	4-96	High	7.8-8.9	0.19-0.35	0.68-0.81	Good
16		Napetet	Napetet		240.2	11,155	46	3° 7 38.1"	35° 37 14.0"	2(3)/12(13)	0(0)	0(0)/0(0)	0(0)	6.2	20.5	1.2	High	8.0	-	0.96	Good
17		Eliye Springs	Eliye	Kangatothe	493.7	4,792	10	3° 14 14.8"	36° 1 19.8"	2(8)/3(5)	0(0)	0(0)/0(0)	3(3)	0(SP)	51(BH)	20-100L/s (SP)	High	7.1-9.0 (Spring) 8.2 (BH)	0.57-0.79 (Spring) 0.48 (BH)	1.75-1.85 (Spring) (0.6) (BH)	Groundwater, Springs (High F and TDS Concentration)
18		Kerio	Kerio	Kerio	266.0	4,254	16	3° 0 07.9"	36° 3 31.7"	1(3)/1(8)	0(0)	0(0)	0(0)	5-49	1-90	0.8-3.8	Very High	7.9-8.4	3.33-7.00	-	Fiar (lagga) Saline (groundwater)
19		Nanyangakipi						3° 0 02.0"	36° 0 06.3"					<5	-	-	High	-	-	-	Generally good （Slightly saline）
20		Nakurio	Nakurio		769.3	7,754	10	2° 52 17.8"	36° 9 49.1"	0(0)/2(4)	0(0)	0(0)/0(0)	5(5)	0(SP) <5(BH)	-	50-80L/s	High	-	-	-	Good （Underflow water form Kerio river）
21		Lorengelup	Lorengelup	Lorengelup	112.1	2,173	19	3° 3 02.7"	35° 56 19.6"	3(3)/0(0)	0(0)	0(0)/0(0)	0(0)	23	36	4	High	8.4	1.13	3.9	Not good (Saline and Alkaline)
22		Nakoret	Nakoret	Kangirisae	225.6	4,198	19	2° 41 54.1"	36° 14 23.4"	1(2)/0(0)	0(0)	0(0)/0(0)	0(0)	<5	-	-	High	-	-	-	Good（Underflow water form Kerio river）
23	Loima	Turkwel	Turkwel	Lorugum	333.3	8,139	24	2° 54 56.0"	35° 24 07.0"	10(17)/3(6)	0(0)	0(0)/0(0)	0(0)	1.5-9.0	20-50	6-6.9	High	9.5	0.3	0.77	Good (slightely saline)
24		Lorugum	Lorugum		582.6	4,737	8	2° 52 54.4"	35° 15 01.7"	6(10)/3(5)	1(1)	0(1)/0(0)	0(0)	1.7-8.2	20-50	2.6-3.8	High	10.0	0.9	1.64	Not good in centre (saline) Other area is good
25		Lolupe	Lomeyan	Lomeyan	883.0	10,093	11	3° 32 25.7"	35° 14 47.2"	9(12)/0(0)	1(1)	2(2)/0(0)	0(0)	-	6-80	2	High	-	-	-	Not good (saline)
26		Nasiger						3° 21 34.9"	35° 26 34.5"					-	<80	-	Very High	-	-	-	Not good
27		Loturerei	Napeikar	Nadapal	276.4	4,526	16	2° 55 55.2"	35° 36 45.3"	3(3)/0(1)	0(0)	0(0)/0(0)	0(0)	-	<80	-	High	-	-	-	Not good
28		Namoruputh	Namoruputh	Loima	243.3	4,478	18	2° 50 33.1"	35° 2 35.0"	5(5)/1(4)	0(1)	5(5)/0(0)	0(0)	-	60-200	-	Fair	-	-	-	Good (windmil well) Saline (solar-powered well)
29		Lokiriama	Lokiriama	Lokiriama	163.7	3,315	20	2° 45 23.4"	34° 52 35.7"	3(3)/1(6)	1(2)	4(4)/0(0)	0(0)	-	24	-	Very High	-	-	-	Not good
30		Urum	Locher-Alomala		428.2	5,389	13	2° 57 24.8"	34° 41 49.4"	0(2)/0(0)	0(1)	1(1)/0(0)	0(0)	-	<80	-	Very High	-	-	-	Unknown
31		Lorengipi	Lorengipi	Lorengipi	209.4	2,459	12	2° 34 22.2"	34° 59 30.5"	2(4)/3(4)	0(2)	0(0)/0(0)	0(0)	8.4	50	4.8	Very High	9.8	0.62	1.67	Moderately saline and alkaline
32	South	Lokichar	Lokichar	Lokichar	187.8	10,820	58	2° 22 40.7"	35° 38 44.3"	10/(14)	0(0)	0(0)/0(0)	0(0)	4.7-22.3	36-76	4.5-7	High	9.7	1.53	1.03-4.65	Not good - good (Change among locations)
33		Kalali						2° 19 18.8"	35° 38 38.0"												
34		Kasuroi	Kapese		690.2	12,632	18	2° 28' 35.6"	35° 39' 19.9"	2(3)/1(1)	0(0)	0(0)/0(0)	0(0)	-	<80	-	High	-	-	-	generally good
35		Kimabur	Lochwangamatak	Lochwangamatak	1,071.6	14,561	14	2° 48 16.9"	35° 37 10.2"	10(15)/0(3)	0(2)	1(1)/0(0)	2(2)	48.7	80	3.8	High	9.2	1.2	1.65	Not good
36		Locheremoit						2° 45 18.1"	35° 38 36.5"					19.8	70-80	1-3	High	9.55	1.32	5.07	Not good
37		Nagetei						2° 42 27.1"	35° 38 11.1"					-	<80	-	High	7.9	2.1	(0.8-1.5)	Slightly high salinity
38		Lochwangamatak						2° 36 20.1"	35° 39 05.2"					19	50	5	High	7.6(SP)	2.14	(0.8-1.5)	Unknown
39		Karoge						2° 33 11.8"	35° 39 16.8"					-	<80	-	High	-	-	-	Good (On borehole drilled in 2012 is saline)
40		Nagimamki	Napuosimoru		602.8	6,220	10	2° 37 03.0"	35° 45 03.0"	1(3)/0(2)	0(0)	0(0)/0(0)	0(0)	-	<80	-	High	-	-	-	Unknown
41		Lomeleku	Loperot	Klapata	898.6	7,384	8	2° 21' 58.8"	35° 58' 04.5"	8(10)/2(5)	0(0)	0(0)/0(0)	0(0)	6	48	2.4	High	9.15	1.2	1.1	Generally good
42	East	Lopii	Lopii	Kichodin	323.5	2,810	9	2° 03' 30.4"	35° 52' 20.7"	1(3)/0(5)	2(3)	0(0)	1(1)	-	<80	-	High	7.3("*lagga*")	0.16("*lagga*")	(0.0)	BH no good（saline）
43		Lokwamosing	Lokwamsing	Lochakula	154.8	2,919	19	2° 00' 00.2"	35° 56' 25.3"	2(2)/0(2)	0(1)	0(0)	3(7)	6.7(BH) 0(SP)	25	7.2(BH)	Fiair	9.8(BH) 7.1(SP)	1.31(BH) 1.21(SP)	1.7	Generally good (Slightly salaine)

*1: BH/SW - Bohehole/Shallow Well, WP - Water Pan, SD/RC - Sand Dam/Rock Catchment, SP - Spring
*2: Kenya - 2009 Kenya Population and Housing Census, Population and Housing Census

Source: JICA Project Team

Table BE1.6.2 Results of Laboratory Tests for Turkana County (1)

No.	SAMPLING SITE NAME	CHEMICAL TEST (ANIONS)													
		PHENOLPHTHALEIN ALKALINITY (Mg/L CO_3)		TOTAL ALKALINITY (Mg/L CO_3)		CHLORIDE (Mg/L Cl)		FLUORIDE (Mg/L F)		SULPHATE (Mg/L SO_4)		NITRATE (Mg/L NO_3)		NITRITE (Mg/L NO_2)	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
1	Chinese BH	ND	ND	120	100	3	4	**3.45**	0.97	4	6	1.9	1.9	0.004	0.003
2	Kaikor Community BH	ND	ND	300	357	4	6	0.71	0.84	20	20	2.8	1.1	0.003	0.003
3	Kalemunyang Water Project	ND	ND	340	410	**300**	**320**	**8.22**	**9.19**	224	250	3.8	4.2	0.009	0.008
4	Kalobeyei	ND	ND	315	220	31	28	0.22	1.01	34	30	10.0	1.1	0.000	0.003
5	Katilu WP	ND	ND	100	115	**400**	**412**	**2.54**	**4.29**	203	215	4.2	4.6	0.121	0.014
6	Lodwar BH 1C	ND	ND	55	50	3	2	0.63	0.72	3	2	1.2	1.6	0.002	0.001
7	Lodwar BH 2B	ND	ND	95	102	4	3	0.56	1.05	6	8	1.3	1.9	0.005	0.005
8	Lokichoggio BH	ND	ND	130	120	14	10	1.25	**1.59**	20	20	1.0	0.9	0.004	0.003
9	Lokori Community BH	ND	ND	190	200	4	6	**1.93**	**2.89**	32	37	3.3	2.7	0.005	0.003
10	Lokwamusing BH	ND	ND	210	200	12	10	1.50	**1.90**	32	35	3.3	1.9	0.003	0.003
11	Lokwii Community BH	ND	ND	40	63	5	8	0.72	0.65	4	4	1.9	0.7	0.005	0.003
12	Loperot BH	ND	ND	90	124	8	15	0.90	1.32	6	30	3.3	3.7	0.040	0.009
13	Lorengelop	ND	ND	210	230	10	15	**2.56**	**5.24**	34	43	3.2	3.0	0.009	0.006
14	Lorengippi BH	ND	ND	130	150	10	10	**1.70**	**1.63**	12	20	2.1	1.9	0.006	0.004
15	Lorugum	ND	ND	140	120	31	30	**1.80**	1.49	28	29	1.9	2.2	0.004	0.004
16	Lwarengak Genset	ND	ND	50	64	8	10	0.72	0.52	12	15	3.0	2.8	0.005	0.005
17	Lwarengak Solar	ND	ND	140	130	95	90	1.28	1.50	203	194	1.9	1.6	0.004	0.003
18	Morulem Water Project	ND	ND	90	110	5	6	1.13	1.04	8	6	2.1	2.0	0.003	0.002
19	Nalemsekon	ND	ND	520	510	100	6	**3.79**	**5.52**	278	30	4.0	3.8	0.009	0.006
20	Napasinyang' BH	ND	ND	30	35	10	10	0.38	0.11	8	8	3.4	3.8	0.004	0.005
21	Natir 1 BH	ND	ND	30	316	21	64	**2.26**	**9.02**	22	64	0.9	2.7	0.004	0.004
22	Kan'galita Shallow well	ND	ND	250	270	6	10	0.68	0.80	6	8	3.8	2.7	0.004	0.005
23	Kimabur Shallow well	ND	ND	230	275	10	15	**1.62**	**1.68**	28	26	3.3	3.2	0.008	0.007
24	Locheromoit Shallow well	ND	ND	480	510	2	6	**4.20**	**5.95**	24	20	3.2	2.7	0.008	0.003
25	Lokichar BH 3	ND	ND	250	270	3	6	1.05	1.01	8	10	2.7	1.6	0.005	0.003
26	Lokitaung Shallow well	ND	ND	140	100	**270**	250	1.06	0.98	28	30	3.0	2.7	0.006	0.004
27	Nareng'ewoi Shallow well	ND	ND	35	86	22	40	0.68	1.49	10	26	1.2	2.3	0.005	0.008
28	Nariokotome Parish BH	ND	ND	310	280	4	6	1.46	1.38	22	20	2.6	1.9	0.004	0.003
29	River Turkwell	ND	ND	15	12	7	10	ND	ND	2	2	1.0	1.8	0.006	0.004
30	Kwatisa Farm BH	ND	ND	40	97	10	20	0.91	0.63	2	10	3.3	1.2	0.004	0.003
RECOMMENDED STANDARDS (KEBS)		-		-		250		1.5		400		50		3	
WHO Standards		-		< 500		< 250		< 15		< 400		< 10		< 0.01	
European Union Standards		-		-		25		1.5		250		50		0.1	

No.	SAMPLING SITE NAME	CHEMICAL TEST (CATIONS)															
		SODIUM (Mg/L Na)		POTASSIUM (Mg/L K)		CALCIUM (Mg/L Ca)		MAGNESIUM (Mg/L Mg)		IRON (Mg/L Fe)		MANGANANESE (Mg/L Mn)		COPPER (Mg/L Cu)		ZINC (Mg/L Zn)	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
1	Chinese BH	22.5	24.3	7.4	8.6	15.31	13.11	10.4	9.78	0.07	0.05	0.1	ND	0.02	ND	0.09	0.06
2	Kaikor Community BH	87.9	77.8	15.3	14.6	52.18	50.34	36.84	34.5	0.05	0.07	0.2	0.2	0.04	0.08	0.09	0.09
3	Kalemunyang Water Project	**357**	**372**	46	44	2.67	10.79	2.04	7.46	0.04	0.04	0.2	0.1	0.04	0.07	0.25	0.31
4	Kalobeyei	68.5	4.17	13.7	1.63	16.91	25.38	12.66	17.77	0.05	0.04	0.2	0.1	0.03	0.05	0.03	0.31
5	Katilu WP	113	149.2	29	38.2	62.71	66.71	41.11	45.09	0.07	0.02	ND	0.1	0.47	0.56	0.01	0.07
6	Lodwar BH 1C	5.05	5.13	1.41	1.4	6.73	6.09	2.44	2.11	0.04	0.01	0.1	0.1	0.02	0.02	0.08	0.04
7	Lodwar BH 2B	5.53	6.89	1.63	2.74	4.21	4.11	3.81	3.76	0.04	0.06	ND	ND	ND	0.04	0.02	0.48
8	Lokichoggio BH	53.5	66.8	12.4	13.7	26.72	24.37	19.18	18.87	0.13	0.1	0.1	0.1	0.01	0.02	0.03	0.03
9	Lokori Community BH	85.5	95.9	14.4	17.7	8.81	9.81	3.03	2.96	ND	ND	0.1	ND	0.03	0.02	0.11	0.15
10	Lokwamusing BH	93.1	99.5	27.4	30.2	6.84	6.55	6.29	5.96	0.07	0.02	0.1	ND	0.06	0.03	0.09	0.07
11	Lokwii Community BH	9.38	11.75	3.1	6.8	6.07	6.19	2.33	2.48	0.05	0.03	0.2	0.1	0.01	ND	0.06	0.01
12	Loperot BH	34.5	74.1	8.1	15.8	8.97	25.97	7.22	16.84	0.04	0.06	0.2	0.1	0.03	0.10	0.05	0.11
13	Lorengelop	115.9	119.1	7.9	8.7	4.71	4.81	2.18	2.74	0.1	0.11	0.1	0.1	0.05	0.06	0.05	0.06
14	Lorengippi BH	20.1	23.7	4.7	6.8	45.97	46.21	19.94	21.19	0.05	0.08	0.1	0.1	0.02	0.06	0.07	0.10
15	Lorugum	93.1	91.6	14.2	12.6	2.39	2.31	1.77	1.64	0.02	0.01	0.1	0.1	0.04	0.08	0.07	0.06
16	Lwarengak Genset	34.6	37.1	7.7	8.6	16.12	17.49	8.94	9.41	0.1	0.06	0.2	0.1	0.05	0.07	0.02	0.08
17	Lwarengak Solar	**269**	**258**	36.4	30.3	7.61	7.38	5.33	4.111	0.04	0.02	ND	ND	0.01	0.03	0.02	0.06
18	Morulem Water Project	21.1	25.8	2.74	3.7	4.79	4.66	2.93	2.86	0.05	0.03	0.1	0.1	0.07	0.03	0.03	0.08
19	Nalemsekon	**242**	**266**	33.7	40.6	77.81	51.19	56.08	35.28	0.07	0.03	ND	ND	0.02	0.02	0.01	0.15
20	Napasinyang' BH	24.7	31.3	9.3	10.6	8.64	9.78	2.33	4.76	0.1	0.11	0.2	0.1	0.02	0.04	0.12	0.11
21	Natir 1 BH	59	133	10.7	29.6	20.34	75.674	9.14	22.98	**1.18**	0.06	0.4	0.2	0.07	0.07	0.55	0.12
22	Kan'galita Shallow well	36.8	34.8	7.7	6.9	27.04	28.6	19.78	20.9	0.05	0.08	0.3	0.2	0.02	0.06	0.04	0.02
23	Kimabur Shallow well	87.5	85.3	29.3	26.4	7.21	6.83	6.83	6.34	**0.36**	0.3	0.1	0.2	0.03	0.04	0.02	0.06
24	Locheromoit Shallow well	149.6	154.5	27.8	30.6	4.37	4.21	7.83	7.76	0.22	0.3	0.1	0.1	0.01	0.06	0.12	0.10
25	Lokichar BH 3	63.2	68.2	12.6	14.3	26.65	28.38	25.74	22.26	0.05	0.02	0.1	ND	ND	0.01	0.15	0.13
26	Lokitaung Shallow well	76.4	71.8	12.8	11.3	69.45	65.58	12.37	13.21	0.06	0.03	0.2	0.2	0.08	0.04	0.08	0.03
27	Naren'gewoi Shallow well	29	87.1	11.3	20.6	9.75	20.9	4.56	11.34	0.1	0.2	ND	0.1	0.06	0.04	0.01	0.07
28	Nariokotome Parish BH	90.6	76	13.3	12.8	9.84	2.48	2.27	1.78	0.11	0.08	0.1	0.1	0.05	0.01	0.04	0.03
29	River Turkwell	3.98	5.25	1.11	1.74	7.43	4.09	1.57	2.11	**0.78**	**0.69**	0.2	0.2	0.17	0.11	0.01	0.04
30	Kwatisa Farm BH	13.65	18.07	6.3	6.41	11.47	5.27	8.73	4.09	**0.86**	0.09	0.3	0.07	ND	0.10	0.03	0.03
RECOMMENDED STANDARDS (KEBS)		200		50		150		100		0.3		0.5		1		5	
WHO Standards		< 200		-		75		150		< 0.3		< 0.1		< 1		< 5	
European Union Standards		175		12		100		50		0.2		0.05		0.1		-	

WHO Standards Source: Appendix 2.10, Ewaso Ng'iro North Catchment Area June, 2008

European Union Standards source : Based on Table 6.1, in Twort, Law & Crowley, 1985

Source: JICA Project Team

Table BE1.6.3 Results of Laboratory Tests for Turkana County (2)

No.	SAMPLING SITE NAME	PHYSICAL TESTS						OTHER PARAMETERS					
		TURBIDITY (NTU)		COLOUR (Pt. Co APHA)		TDS (Mg/L)		TOTAL HARDNESS (Mg/LCaCO$_3$)		SILICA (Mg/L SiO$_2$)		OXYGEN ABSORBED (Mg/L O$_2$)	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
1	Chinese BH	0.35	0.43	8	3	238	232	76	70	47.9	69.3	5.3	4.47
2	Kaikor Community BH	0.84	0.55	15	2	514	498	225	200	66.6	68.7	4.96	4.56
3	Kalemunyang Water Project	0.39	0.48	5	2	**1932**	**1948**	20	60	98.3	97.4	5.73	4.88
4	Kalobeyei	0.29	0.42	2	6	401	376	120	100	74.6	70.6	4.66	6.08
5	Katilu WP	0.49	0.5	8	3	**1130**	**1159**	250	300	89.3	97.1	4.95	5.14
6	Lodwar BH1C	0.58	0.5	10	2	95.9	89.5	24	20	36.1	34.8	4.86	5.14
7	Lodwar BH2B	1.61	2.29	14	15	114.6	110.5	37	35	43.4	40.7	5.27	3.72
8	Lokichoggio BH	0.3	0.37	13	ND	456	433	210	180	63.6	62.7	6.08	4.06
9	Lokori Community BH	1.98	0.51	5	4	558	480	25	20	77.2	74.8	4.8	4.89
10	Lokwamusing BH	0.37	0.44	4	2	535	527	40	35	81.9	88.9	6.08	4.07
11	Lokwii Community BH	0.4	0.38	2	ND	116	107	20	20	38.1	39.2	5.79	5.19
12	Loperot BH	0.31	0.45	5	4	364	965	55	100	68.1	74.8	5.53	3.56
13	Lorengelop	1.58	0.58	11	4	509	512	20	20	84.3	94.6	5.95	4.79
14	Lorengippi BH	0.42	0.45	15	ND	302	324	155	180	47.7	64.8	5.21	4.06
15	Lorugum	0.63	0.46	5	3	482	475	25	20	73.2	60.4	5.52	4.46
16	Lwarengak Genset	0.1	0.5	7	3	370	368	70	70	67.3	70.3	5.46	4.25
17	Lwarengak Solar	1.58	0.54	ND	4	**1332**	**1295**	45	35	98.7	87.6	5.31	4.17
18	Morulem Water Project	0.32	1.81	6	8	239	231	20	20	54.3	64.7	4.71	4.49
19	Nalemsekon	0.42	0.56	8	4	**1789**	**1684**	270	200	46.4	89.6	5.73	5.13
20	Napasinyang' BH	1.13	**7.36**	7	**24**	173.7	192.2	30	40	37.4	40.3	4.86	4.78
21	Natir 1 BH	**20.3**	1.2	**119**	9	364	801	90	220	40.7	87.3	4.69	4.06
22	Kan'galita Shallow well	0.32	0.6	11	4	322	323	115	120	34.3	38.7	5.68	4.54
23	Kimabur Shallow well	1.19	0.98	7	8	601	569	45	40	79.4	76.8	5.01	3.69
24	Locheromoit Shallow well	0.73	0.46	3	ND	781	752	55	50	69.6	70.3	4.56	4.15
25	Lokichar BH3	0.26	0.75	2	6	475	462	200	180	73.2	69.4	5.53	5.28
26	Lokitaung Shallow well	0.33	0.6	6	3	674	653	215	200	77.5	64.6	5.78	3.97
27	Naren'gewoi Shallow well	1.09	3.5	3	12	223	447	40	80	30.7	64.8	5.32	4.5
28	Nariokotome Parish BH	1.36	2.08	3	13	442	361	30	20	46.7	38.7	5.68	4.2
29	River Turkwell	**85.6**	**358**	**1978**	**2077**	91.8	84.4	25	12	32.3	24.9	4.17	4.3
30	Kwatisa Farm BH	2.32	**5.38**	**55**	**27**	163.4	190.8	70	0.1	28.6	45.6	5.64	3.69
RECOMMENDED STANDARDS (KEBS)		< 5		15 TCU		1000 MAX		300		-		-	
WHO Standards		< 5		5		1000		< 500		-		> 4	
European Union Standards		< 4		20		1500		-		-		-	

No.	SAMPLING SITE NAME	HEAVY METALS											
		ARSENIC (Mg/L As)		LEAD (Mg/L Pb)		SELENIUM (Mg/L Se)		MERCURY (Mg/L Hg)		CYANIDE (Mg/L CN)		CADMIUM (Mg/L Cd)	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
1	Chinese BH	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2	Kaikor Community BH	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3	Kalemunyang Water Project	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4	Kalobeyei	ND	0.01	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
5	Katilu WP	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6	Lodwar BH1C	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7	Lodwar BH2B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8	Lokichoggio BH	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
9	Lokori Community BH	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10	Lokwamusing BH	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
11	Lokwii Community BH	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
12	Loperot BH	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
13	Lorengelop	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14	Lorengippi BH	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15	Lorugum	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16	Lwarengak Genset	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
17	Lwarengak Solar	0.01	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
18	Morulem Water Project	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
19	Nalemsekon	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
20	Napasinyang' BH	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
21	Natir 1 BH	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
22	Kan'galita Shallow well	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
23	Kimabur Shallow well	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
24	Locheromoit Shallow well	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
25	Lokichar BH3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
26	Lokitaung Shallow well	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
27	Naren'gewoi Shallow well	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
28	Nariokotome Parish BH	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
29	River Turkwell	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
30	Kwatisa Farm BH	0.01	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
RECOMMENDED STANDARDS (KEBS)		0.01		0.01		0.01		0.001		0.07		0.003	
WHO Standards		< 0.05		< 0.05		< 0.01		< 0.001		< 0.01		< 0.005	
European Union Standards		0.05		0.05		0.01		0.001		0.05		0.005	

WHO Standards Source: Appendix 2.10, Ewaso Ng'iro North Catchment Area June, 2008

European Union Standards source : Based on Table 6.1, in Twort, Law & Crowley, 1985

Source: JICA Project Team

Table BE3.6.1 Proposed 50 Borehole Sites (1/2)

Site No.	Sub-county	Site Name	Locality	Viilage	Sub-location	Location	Division	Eastings	Northings	Rec. depth (m)	Alt. (m)	Ground Water potential	Aquifer Type	Drilling Method	Remarks/ Priority	Expected Yield (cu.m/h)
1	South	Lotonguna	Lochwaa	Lotonguna	Lochwaa	Lochwaa	Lochwaa	35^0 30'14.5″E	02^{0}28'21.0″N	100	760	medium	basement	DC	pasture land/high	1.2
2		Kaichupaluk		Kaichupaluk	Lochwaa	Lochwaa	Lochwaa	35^0 34'46.9″E	02^{0}32'07.9″N	100	812	medium	basement	DC	pasture land/high	1.2
3		Kalokoda	Katilu	Kalokoda	Lokapel	Katilu	Katilu	35^0 30'23.7″E	02^{0}23'52.1″N	130	746	medium	basement	DC	pasture land/high	1.2
4		Kagete		Kagete	Katilu	Katilu	Katilu	35^0 29'23.7″E	02^{0}17'35.9″N	130	743	medium	basement	Dc	pasture land/ high	1.2
5		Kachila		Kachila	Katilu	Katilu	Katilu	35^0 29'58.6″E	02^{0}13'05.1″N	150	763	medium	sediments	Mud/Dc	pasture land/ high	1.2
6	Central	Kalokol	Kalokol	Nakuamomua	Kalakol	Kalakol	Kalakol	35^0 50'58.9″E	03^{0}32'39.8″N	30	377	high	sediments	Mud/Dc	Town/high	1.38-18.0
7	South	Kaapoo	Lokichar	Kaapoo	Nalemskon	Lokichar	Lokichar	35^0 38'11.6″E	02^{0}29'29.6″N	140	781	medium	basement	Dc	Pastures/high	1.2
8		Kalodicha		Kalodicha	Lokichar	Lokichar	Lokichar	35^0 36'03.1″E	02^{0}22'23.5″N	130	799	medium	basement	DC	Pastures/high	5.0
9		Kamarese		Kamarese	Kapese	Lokichar	Lokichar	35^0 35'44.0″E	02^{0}20'09.0″N	100	833	Low	Basement	DC	Pasture/ Low	5.0
10	Loima	Nachuro	Nachuro	Nachuro	Nachuro	Lomaiyan	Turkwel	35^0 08'54.0″E	03^{0}18'29.7″N	100	624	High	sediments	Dc	pasture / high	4.5 – 6.0
11	Central	Kakimat	Kerio	Kakimat	Kakimat	Lorengelup	Kerio	35^0 58'21.0″E	02^{0}56'55.7″N	120	425	high	sediments	Mud/Dc	pasture / high	12.0
12		Nanyangakipi		Nanyangikipi	Nanyangikipi	Lorengelup	Kerio	35^0 59'20.8″E	03^{0}00'14.4″N	80	405	high	sediments	Mud/Dc	pasture / high	12.0
13		Akudet		Akudet	Nanyangikipi	Lorengelup	Kerio	35^0 50'16.9″E	02^{0}58'35.6″N	130	469	high	sediments	Mud/Dc	pasture / high	12.0
14	Loima	Tapayik	Urum	Tapayik	Urum	Urum	Loima	34^0 39'54.9″E	02^{0}53'56.5″N	100	1086	high	basement	Mud/Dc	pasture/ high	0.9 – 4.8
15		Lochorenkalalio	Lokiriama	Lochorenkalalio	Lochorenkalalio	Lokiriama	Lokiriama	34^0 50'51.7″E	02^{0}42'51.0″N	150	943	high	Basement	Dc	Pasture/high	0.9 – 4.8
16		Kang'ipei		Kang' ipei	Atakalomsio	Lokiriama	Lokiriama	34^0 56'24.8″E	02^{0}43'26.2″N	140	848	medium	Basement	Dc	Pasture/high	0.9 – 4.8
17		Loya	Lorengipi	Loya	Loya	Lorengipi	Lokiriama	34^0 58'18.0″E	02^{0}31'10.8″N	100	931	High	sediments	Dc	Pasture/high	0.9 – 4.8
18	Central	Kanyuda	Kang'irisae	Kanyuda	Kang'irisae	Kang'irisae	Kerio	36^0 10'37.9″E	02^{0}39'23.6″N	130	454	Medium	sediments	Mud	Pasture	12.0
19	Central	Kairiama	Nakurio	Kairiama	Kerio	Kerio	Kerio	36^0 06'55.7″E	02^{0}51'53.1″N	100	387	medium	sediments	mud	pasture	3.8
20	Loima	Kaapus	Turkwel	Kaapus	Kaapus	Lomaiyan	Turkwel	35^0 15'50.2″E	03^0 09'52.1″N	150	600	high	basement	DC	pasture/high	0.9 – 4.5
21	North	Lokaliban	Mlima Tatu	Lokaliban	Mlima Tatu	Kaaleng	Kaaleng	35^0 26'20.1″E	04^0 08'38.9″N	100	641	high	volcanics	DC	pasture/high	0.5 – 7.1
22	North	Lotorob	Kaikor	Lotorob	Lotorob	Kaikor	Kaikor	35^0 33'33.4″E	04^0 40'39.7″N	150	532	high	volcanics	DC	pasture/high	9.0
23	North	Karearegae		Karearegae	Lotorob	Kaikor	Kaikor	35^0 28'54.2″E	04^0 37'09.7″N	150	588	high	volcanics	DC	pasture/high	9.0
24	Kibish	Napeimong	Lowasa	Lowasa	Kotome	Lorus	Kaikor	35^0 13'08.9″E	04^0 23'44.9″N	150	547	high	volcanics	Dc	pasture/high	9.0
25	Kibish	Nayanae Amoni	Kotome	Nayanae Amoni	Kotome	Lorus	Kaikor	35^0 14'53.1″E	04^0 27'47.8″N	150	560	high	volcanics	Dc	Pasture/high	9.0

Table BE3.6.1 Proposed 50 Borehole Sites (2/2)

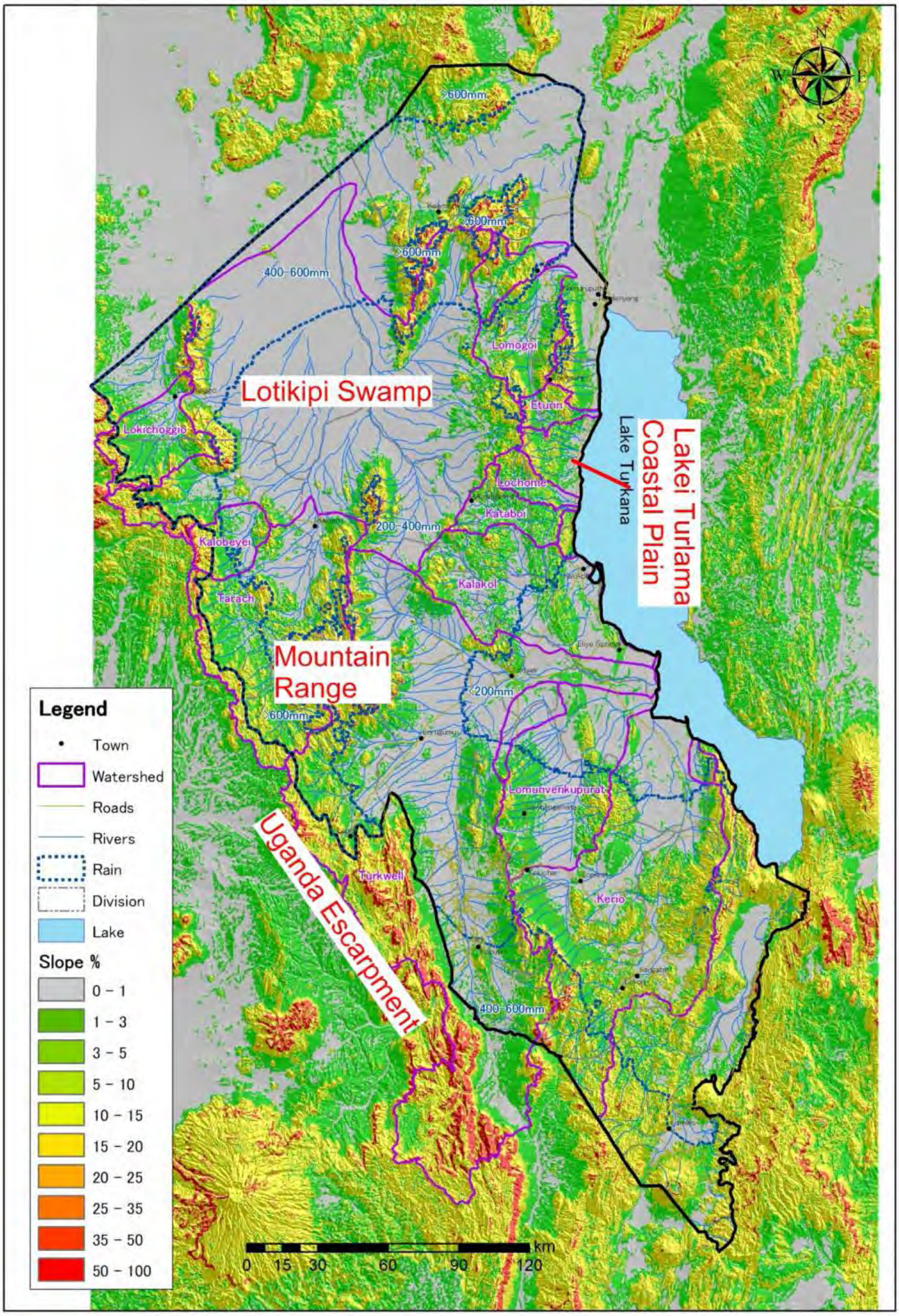
Site No.	Sub-county	Site Name	Locality	Viilage	Sub-location	Location	Division	Eastings	Northings	Rec. depth (m)	Alt. (m)	Ground Water potential	Aquifer Type	Drilling Method	Remarks/ Priority	Expected Yield (cu.m/h)
26	North	Kalonyang' Kori	Lokitang'	Kalonyang' Kori	Nakalale	Lokitang'	Lokitang'	35° 44'18.5"E	04° 18'08.0"N	130	747	high	volcanics	DC	pasture	2.0
27	North	Natukobenyo		Natukobenyo	Nakalale	Lokitang'	Lokitang'	35° 44'18.5"E	04° 17'23.0"N	150	780	medium	volcanics	Dc	pasture/medium	2.0
28	Central	Kalimapus	Kalokol	Kalimapus	Namadak	Kalokol	Central	35° 47'53.0"E	03° 36'35.6"N	180	445	medium-high	Volcanics	Dc/ Mud	pasture/ Medium	0.84- 18.0
29	Loima	Kang'ataruk	Nachuro	Kang'ataruk	Nachuro	Nachuro	Nachuro	35° 05'54.0"E	03° 18'40.1"N	140	638	High	Volcanics	Dc	Pasture	4.5 - 6.0
30	Loima	Nameiyan		Nameiyan	Nasiger	Nachuro	Nachuro	35° 04'34.1"E	03° 21'58.2"N	150	634	High	Volcanics	DC	Pasture	4.5 - 6.0
31	Loima	Kaemanik	Kaemanik	Kaemanik	Kaemanik	Kaemanik	Kaemanik	34° 59'10.5"E	02° 40'07.5"N	100	840	medium-high	basement	Dc	pasture/ high	0.9 - 4.8
32	Loima	Alabalab	Kotaruk	Alabalab	Naipa	Kotaruk	Turkwel	35° 19'26.4"E	02° 26'35.4"N	150	670	High	volcanics	DC	pasture/ high	0.9 - 4.8
33	Loima	Ulukuse		Ulukuse	Naipa	Kotaruk	Turkwel	35°18'11.1"E	02° 31'28.1"N	130	667	High	volcanics	Dc	Pasture/ high	0.9 - 4.9
34	Loima	Kasiolipus	Nasiger	Kasiolipus	Nasiger	Napelilim	Lolgum	35° 27'21.5"E	03° 23'01.0"N	180	564	High	Volcanics	Dc	Pasture/ high	2.7 - 6.0
35	West	Nakalale	Naduat	Nakalale	Nakalale	Nakalale	Kakuma	35° 12'32.0"E	03° 38'14.2"N	130	633	Medium-high	volcanics	Dc	Pasture/ high	2.88 - 11.0
36	West	Lokeng	Lokore	Lokeng	Nakalale	Nakalale	Kakuma	35° 08'21.4"E	03° 42'28.7"N	130	645	medium	volcanics	Dc	Pasture	2.88 - 11.0
37	West	Lorus	Pelekech	Lorus	Lokore	Pelekech	Kakuma	35° 10'24.2"E	03° 45'17.4"N	140	609	Medium	Volcanics	Dc	Pasture	2.88 - 11.0
38	West	Nawountos	Kalobayei	Nawountos	Kalobeyei	Kalobeyei	Kakuma	34° 14'41.5"E	03° 47'24.9"N	110	989	Medium	basement	Dc	Pasture	5.9
39	West	Lodukot	Oropoi	Lodukot	Natira	Kalobeyei	Kakuma	34° 28'35.7"E	03° 53'02.3"N	110	738	High	basement	Dc	Pasture/ high	16.4
40	West	Napak Egong	Letea	Napak Egong	Letea	Kalobeyei	Kakuma	34° 41'19.3"E	03° 20'23.5"N	150	769	high	Volcanics	Dc	Pasture/ high	0.54 - 6.78
41	West	Nakareterete		Nakareterete	Letea	Kalobeyei	Kakuma	34° 44'31.1"E	03° 23'10.5"N	130	748	high	volcanics	Dc	Pasture/ high	0.54 - 6.78
42	West	Muruanayeche		Muruanayeche	Letea	Kalobeyei	Kakuma	34° 45'52.8"E	03° 20'41.7"N	100	723	medium-high	basement	DC	Pasture/ high	0.54 - 6.79
43	West	Nalamacha	Nanam	Nalamacha	Nanam	Nanam	Lokichogio	34° 29'51.2"E	04° 11'56.6"N	200	578	medium-high	volcanics	DC	Pasture/ high	2.2 - 5.9
44	West	Kabot	Lorimet	Kabak-Lopiding	Loremet	Lopiding	Lokichogio	34° 18'32.3"E	04° 07'12.8"N	130	695	Medium-high	sediments	DC	Psture/ high	2.2 - 5.9
45	West	Loremet		Loremet	Loremet	Lopiding	Lokichogio	34° 17'47.7"E	04° 04'48.0"N	140	725	High	volcanics	DC	pasture/ high	2.2 - 5.9
46	West	Lodokech Askiria	Nadapal	Lodokech Askiria	Lokariwon	Nadapal	Lokichogio	34° 18'47.8"E	04° 22'08.0"N	200	641	Medium-high	volcanics	Dc	Pasture/ high	2.2 - 5.9
47	West	Narot	Lokichogio	Narot	Lokariwon	Lokichogio	Lokichogio	34° 23'19.4"E	04° 08'51.2"N	180	700	Medium	Volcanics	Dc	pasture/ high	2.2 - 5.9
48	West	Lomaniamania	Natira	Lomaniamania	Natira	Natira	Lokichogio	34° 37'12.1"E	03° 53'07.8"N	200	639	High	Volcanics	Dc	Pasture/ high	0.84 - 3.06
49	Loima	Logapol	Nakwei	Logapol	Nakwei	Nasiger	Lolgum	35° 25'47.8"E	03° 16'26.4"N	150	561	Medium	Volcanics	Dc	Pasture/ human	2.7 - 6.0
50	Central	Nakibuse	Eliye	Nakibuse	Eliye	Kang' atosa	Kalakol	35° 58'49.3"E	03° 15'58.3"N	180	407	High	sediments	Mud	pasture	12.0

* Direct Circulation

NB: The drilling depths are informed estimates. Drilling maybe terminated before the recommended depths if appreciable volumes are realised before attaining the recommended depth or if the EC values rise with depth.

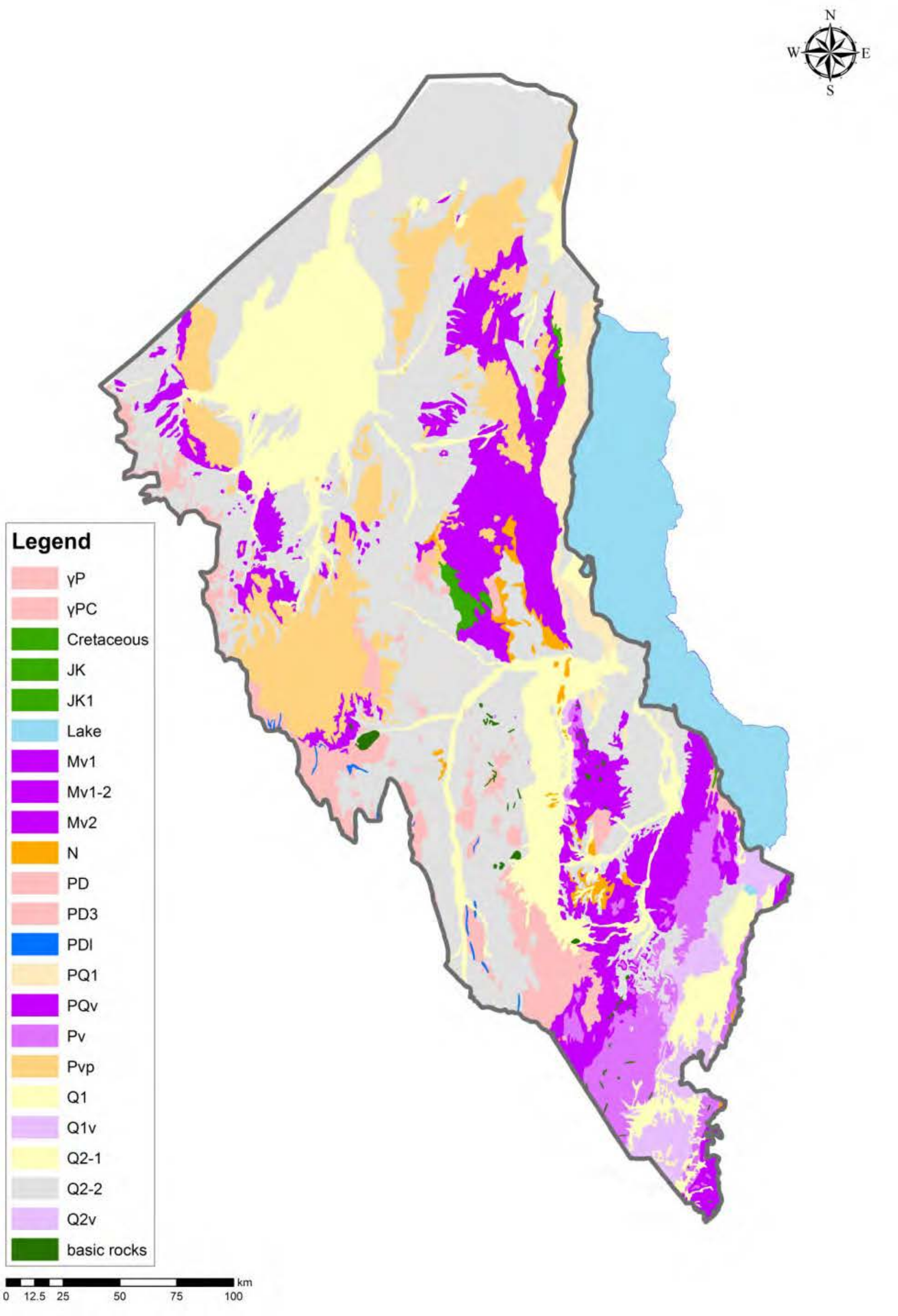
Source: JICA Project Team

Figures



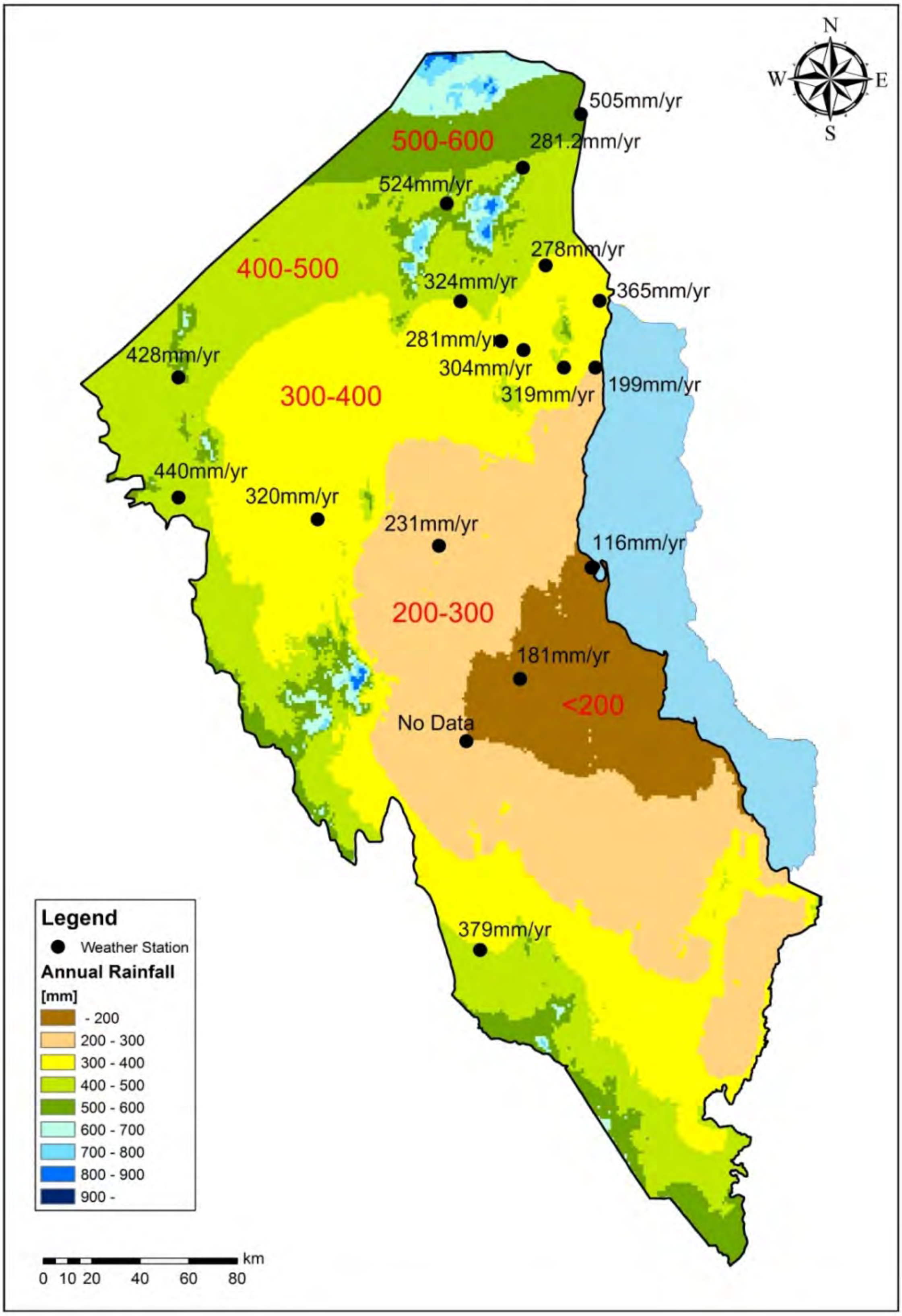
Source: JICA Project Team

Figure BE1.3.1 Topographical Map of Turkana



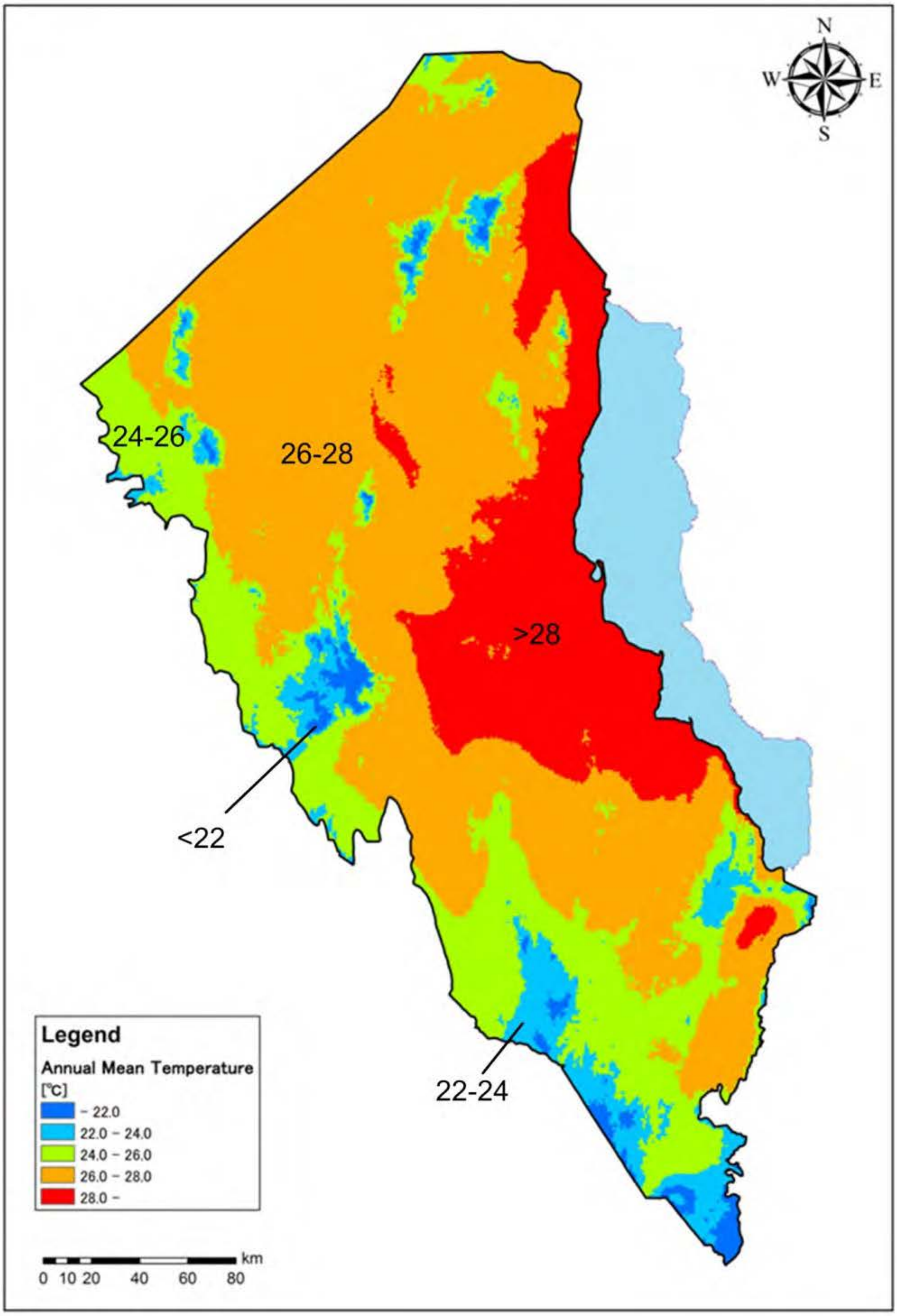
Source: JICA Project Team

Figure BE1.3.2 Geological Map of Turkana



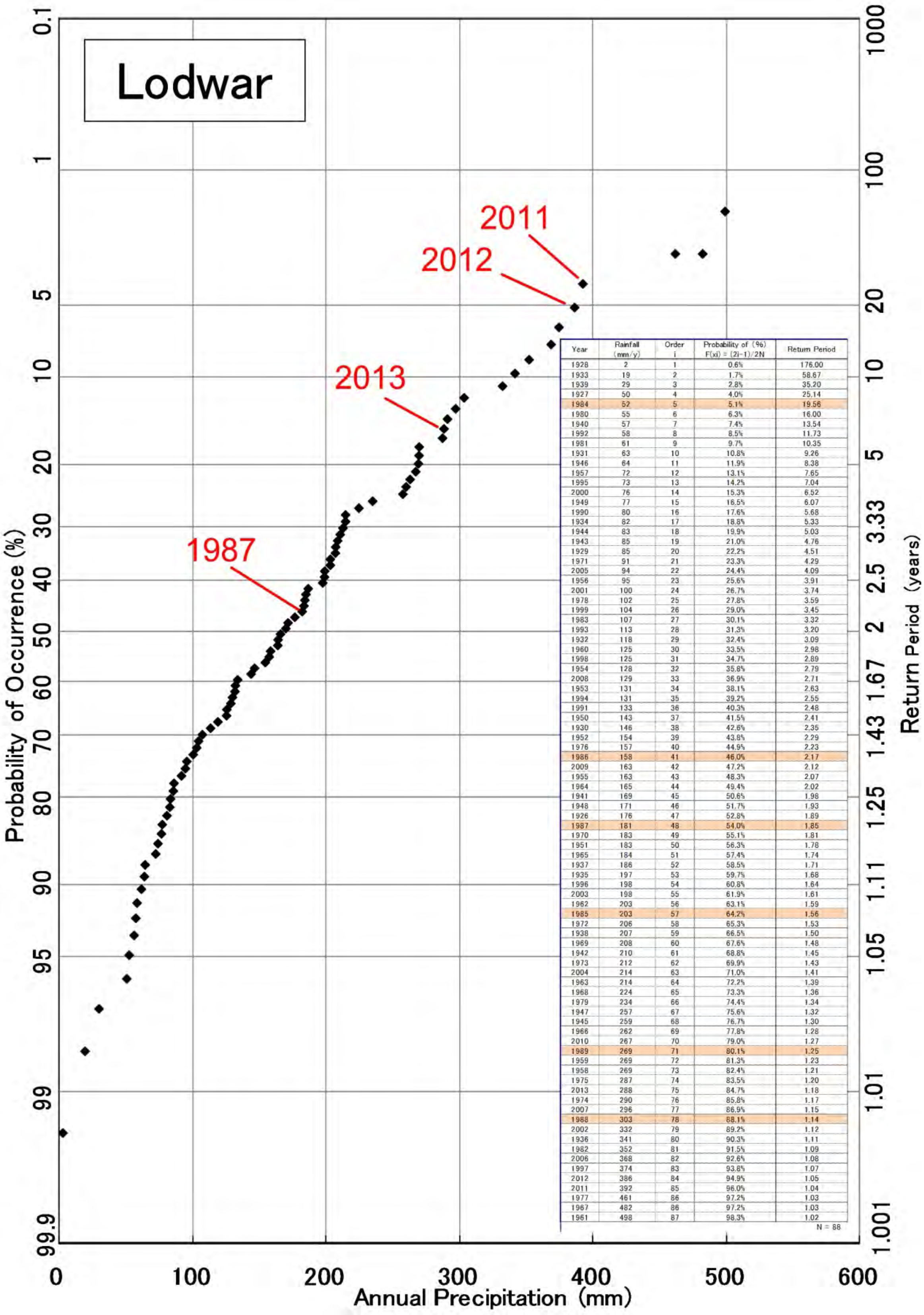
Source: JICA Project Team, WorldClim

Figure BE1.4.1 Annual Rainfall Distribution Map



Source: JICA Project Team

Figure BE1.4.2 Mean Annual Temperature Distribution

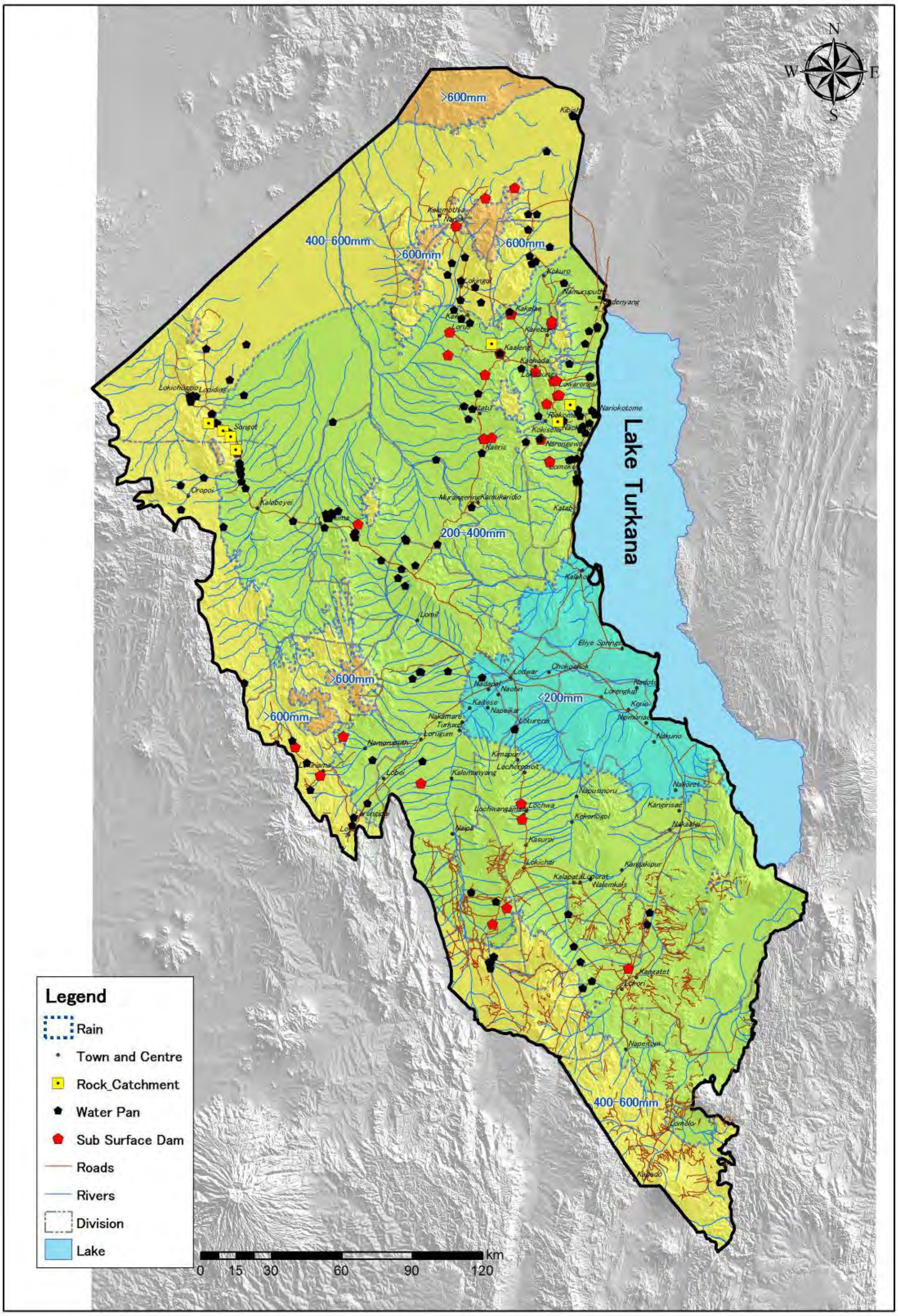


Year	Rainfall (mm/y)	Order i	Probability of (%) F(xi) = (2i-1)/2N	Return Period
1928	2	1	0.6%	176.00
1933	19	2	1.7%	58.67
1939	29	3	2.8%	35.20
1927	50	4	4.0%	25.14
1984	52	5	5.1%	19.56
1980	55	6	6.3%	16.00
1940	57	7	7.4%	13.54
1992	58	8	8.5%	11.73
1981	61	9	9.7%	10.35
1931	63	10	10.8%	9.26
1946	64	11	11.9%	8.38
1957	72	12	13.1%	7.65
1995	73	13	14.2%	7.04
2000	76	14	15.3%	6.52
1949	77	15	16.5%	6.07
1990	80	16	17.6%	5.68
1934	82	17	18.8%	5.33
1944	83	18	19.9%	5.03
1943	85	19	21.0%	4.76
1929	85	20	22.2%	4.51
1971	91	21	23.3%	4.29
2005	94	22	24.4%	4.09
1956	95	23	25.6%	3.91
2001	100	24	26.7%	3.74
1978	102	25	27.8%	3.59
1999	104	26	29.0%	3.45
1983	107	27	30.1%	3.32
1993	113	28	31.3%	3.20
1932	118	29	32.4%	3.09
1960	125	30	33.5%	2.98
1998	125	31	34.7%	2.89
1954	128	32	35.8%	2.79
2008	129	33	36.9%	2.71
1953	131	34	38.1%	2.63
1994	131	35	39.2%	2.55
1991	133	36	40.3%	2.48
1950	143	37	41.5%	2.41
1930	146	38	42.6%	2.35
1952	154	39	43.8%	2.29
1976	157	40	44.9%	2.23
1986	158	41	46.0%	2.17
2009	163	42	47.2%	2.12
1955	163	43	48.3%	2.07
1964	165	44	49.4%	2.02
1941	169	45	50.6%	1.98
1948	171	46	51.7%	1.93
1926	176	47	52.8%	1.89
1987	181	48	54.0%	1.85
1970	183	49	55.1%	1.81
1951	183	50	56.3%	1.78
1965	184	51	57.4%	1.74
1937	186	52	58.5%	1.71
1935	197	53	59.7%	1.68
1996	198	54	60.8%	1.64
2003	198	55	61.9%	1.61
1962	203	56	63.1%	1.59
1985	203	57	64.2%	1.56
1972	206	58	65.3%	1.53
1938	207	59	66.5%	1.50
1969	208	60	67.6%	1.48
1942	210	61	68.8%	1.45
1973	212	62	69.9%	1.43
2004	214	63	71.0%	1.41
1963	214	64	72.2%	1.39
1968	224	65	73.3%	1.36
1979	234	66	74.4%	1.34
1947	257	67	75.6%	1.32
1945	259	68	76.7%	1.30
1966	262	69	77.8%	1.28
2010	267	70	79.0%	1.27
1989	269	71	80.1%	1.25
1959	269	72	81.3%	1.23
1958	269	73	82.4%	1.21
1975	287	74	83.5%	1.20
2013	288	75	84.7%	1.18
1974	290	76	85.8%	1.17
2007	296	77	86.9%	1.15
1988	303	78	88.1%	1.14
2002	332	79	89.2%	1.12
1936	341	80	90.3%	1.11
1982	352	81	91.5%	1.09
2006	368	82	92.6%	1.08
1997	374	83	93.8%	1.07
2012	386	84	94.9%	1.05
2011	392	85	96.0%	1.04
1977	461	86	97.2%	1.03
1967	482	86	97.2%	1.03
1961	498	87	98.3%	1.02

N = 88

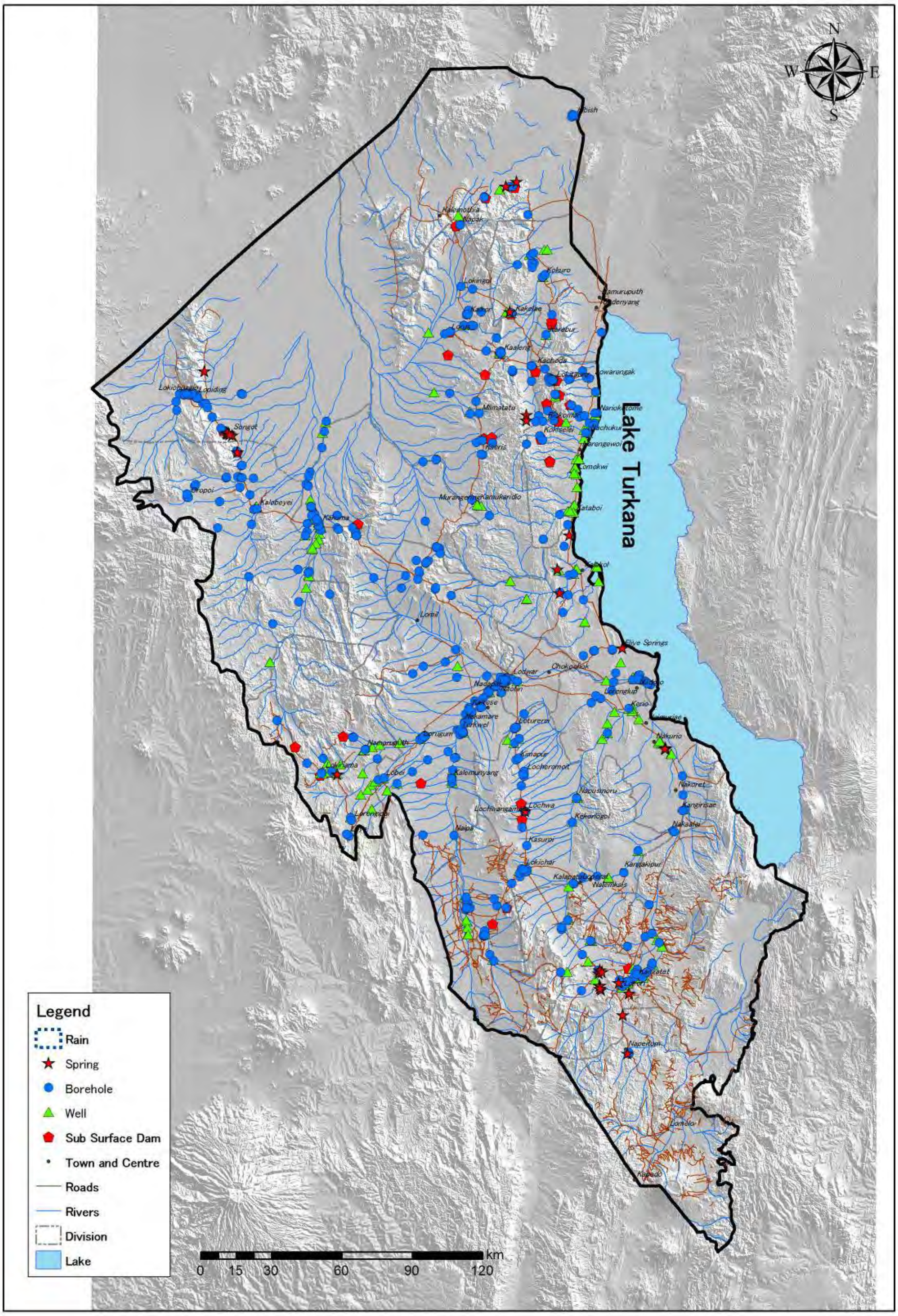
Source: JICA Project Team

Figure BE1.4.3 Annual Rainfall Probability of Occurrence and Return Period of Lodwar



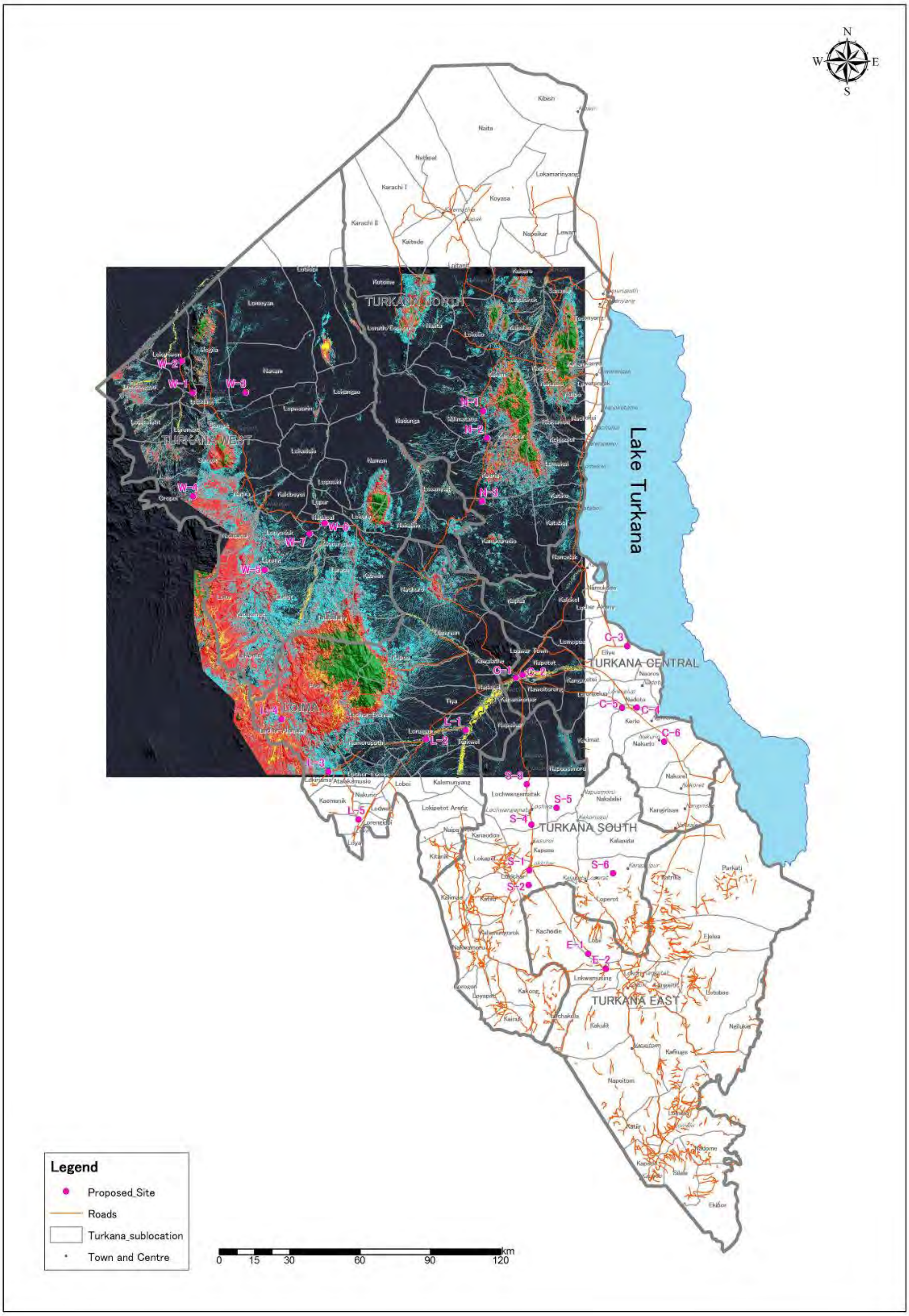
Source: JICA Project Team

Figure BE1.5.1 Surface Water Resources with Annual Rainfall Distribution in Turkana County



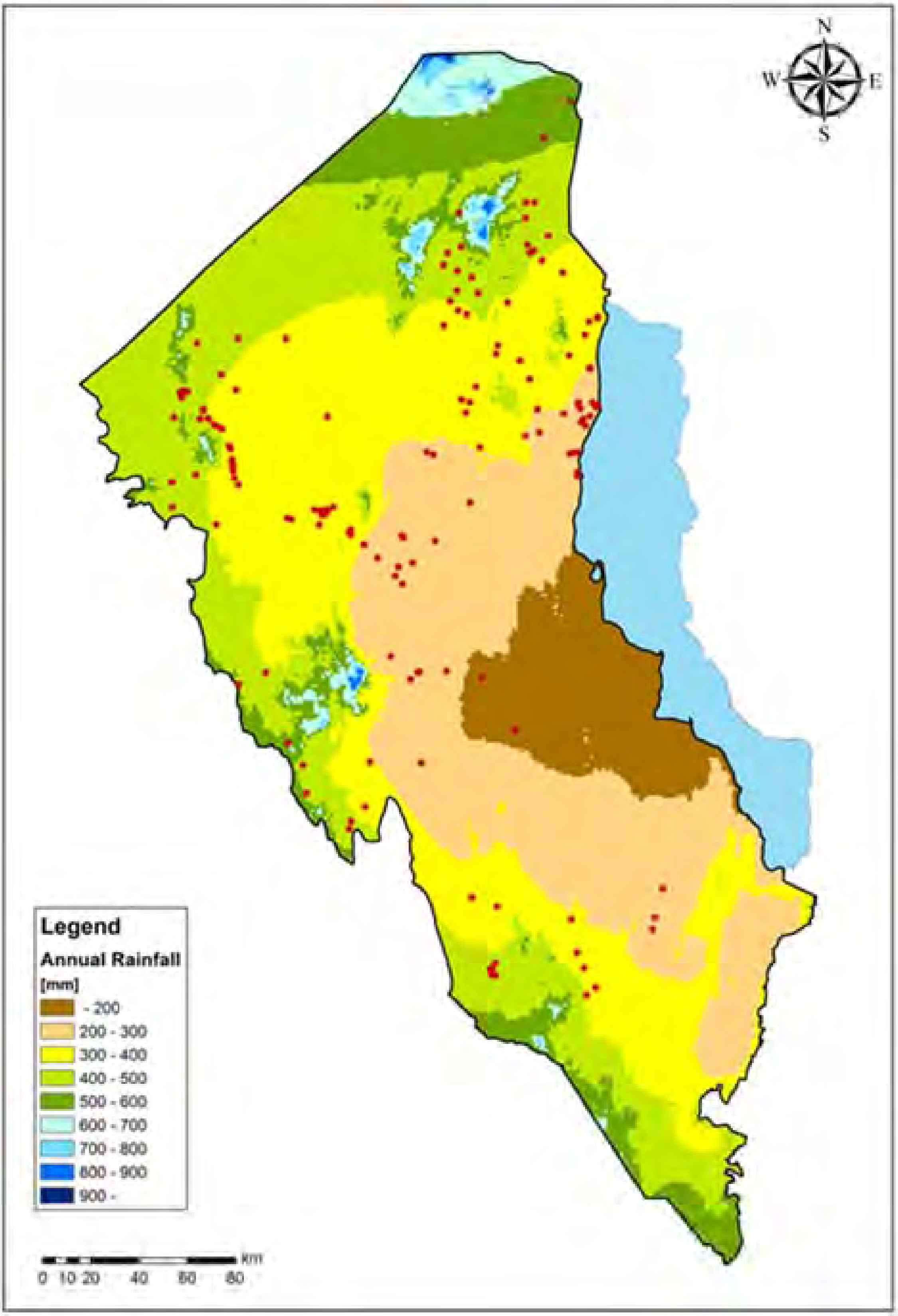
Source: JICA Project Team

Figure BE1.5.2 Groundwater Resources in Turkana County



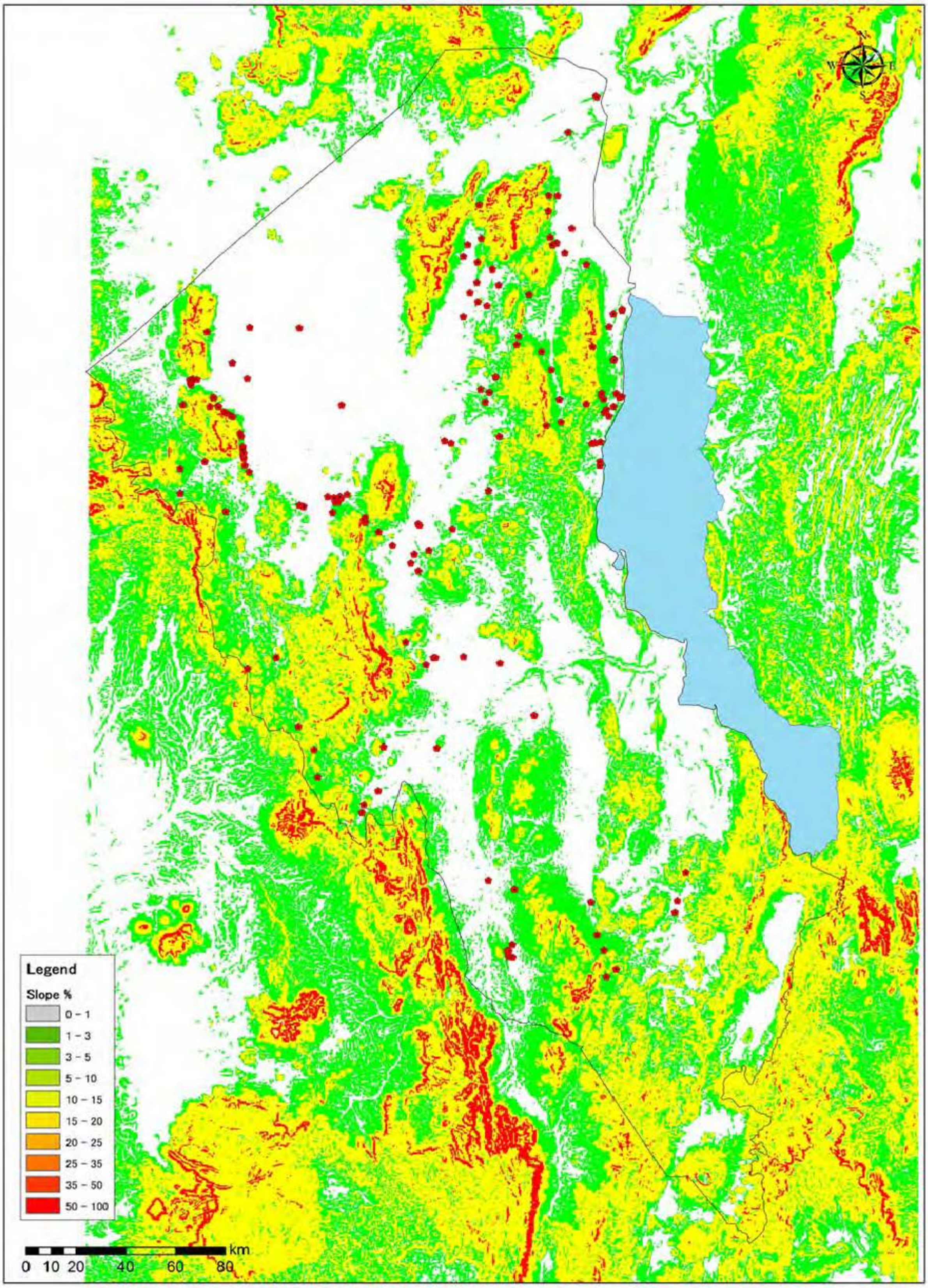
Source: UNESCO (2012), JICA Project Team

Figure BE1.7.1 Proposed Site for Drilling with Groundwater Potential Map in Turkana County



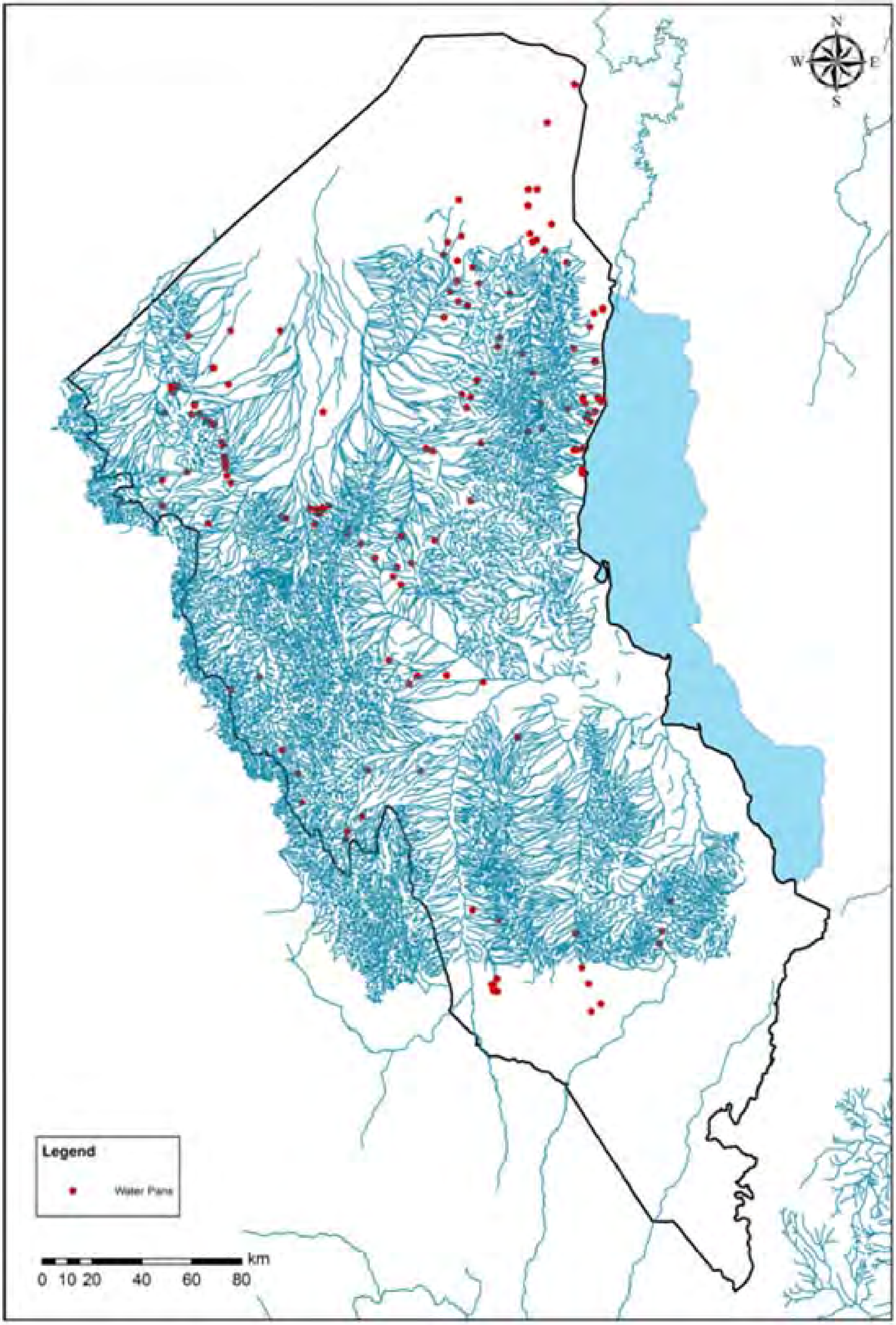
Source: JICA Project Team

Figure BE2.2.1 Distribution of Existing Water Pans and Annual Rainfall



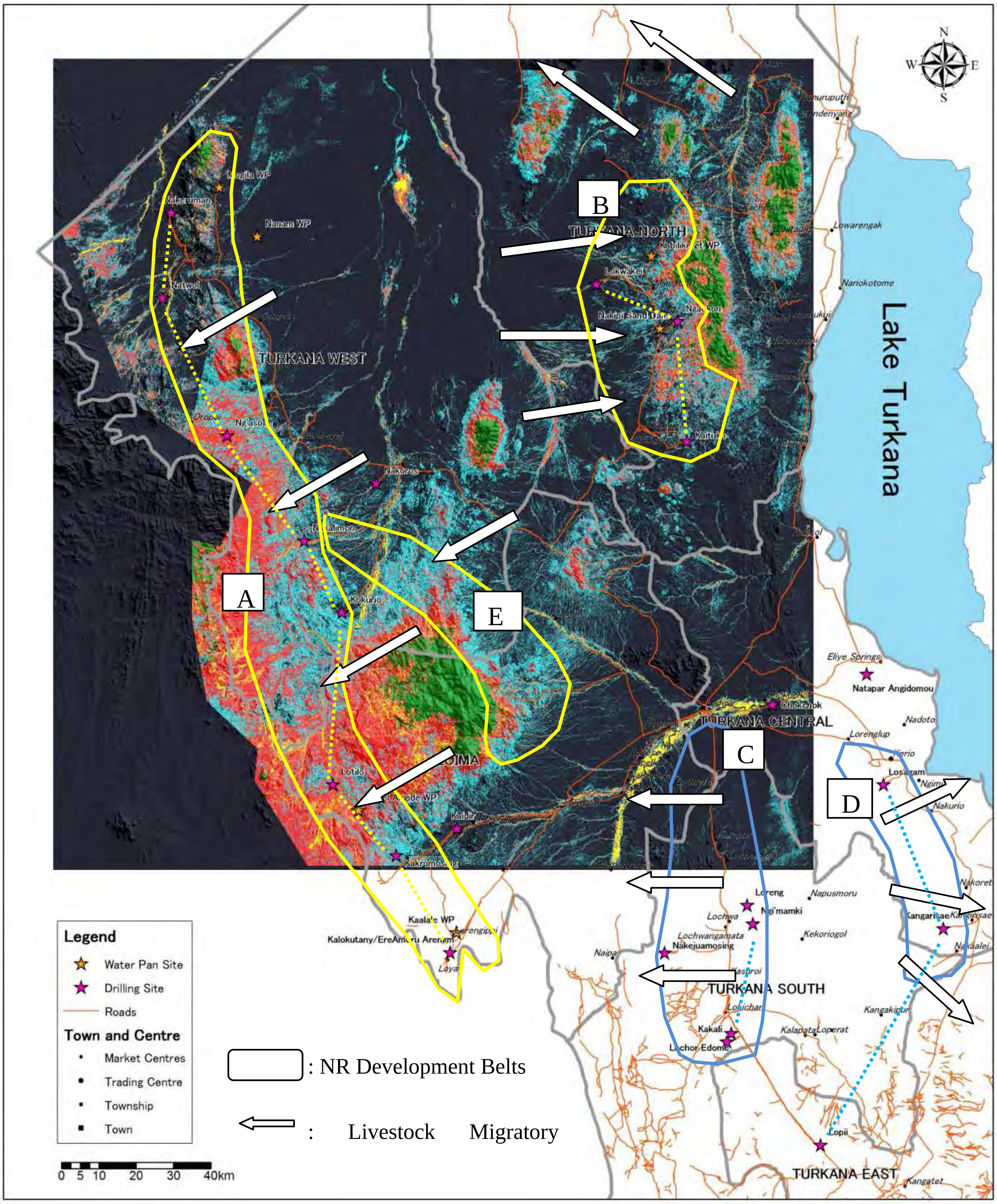
Source: JICA Project Team

Figure BE2.2.2 Distribution of Existing Water Pans and Land Slope



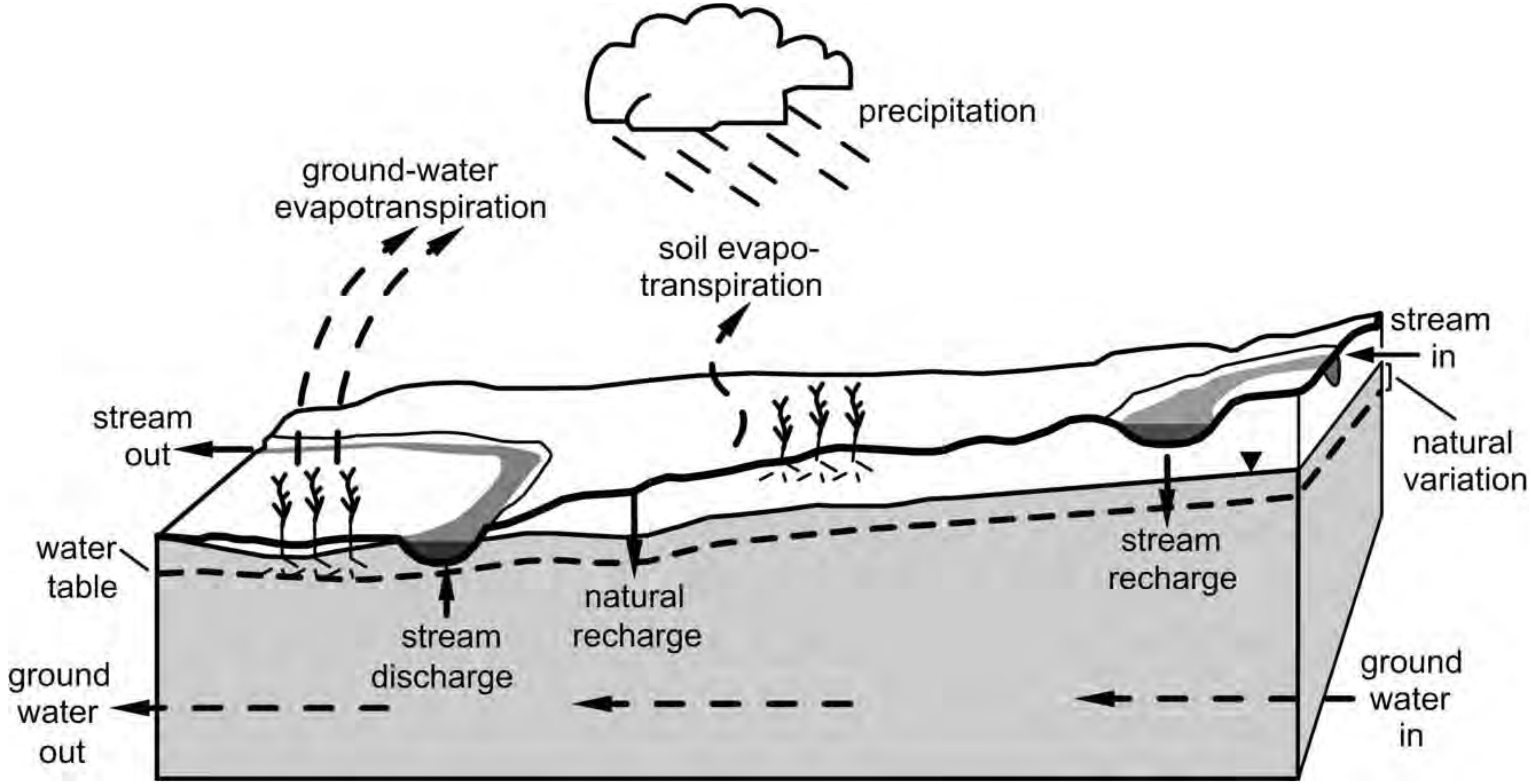
Source: JICA Project Team

Figure BE2.2.3 Existing Water Pan and Lagas



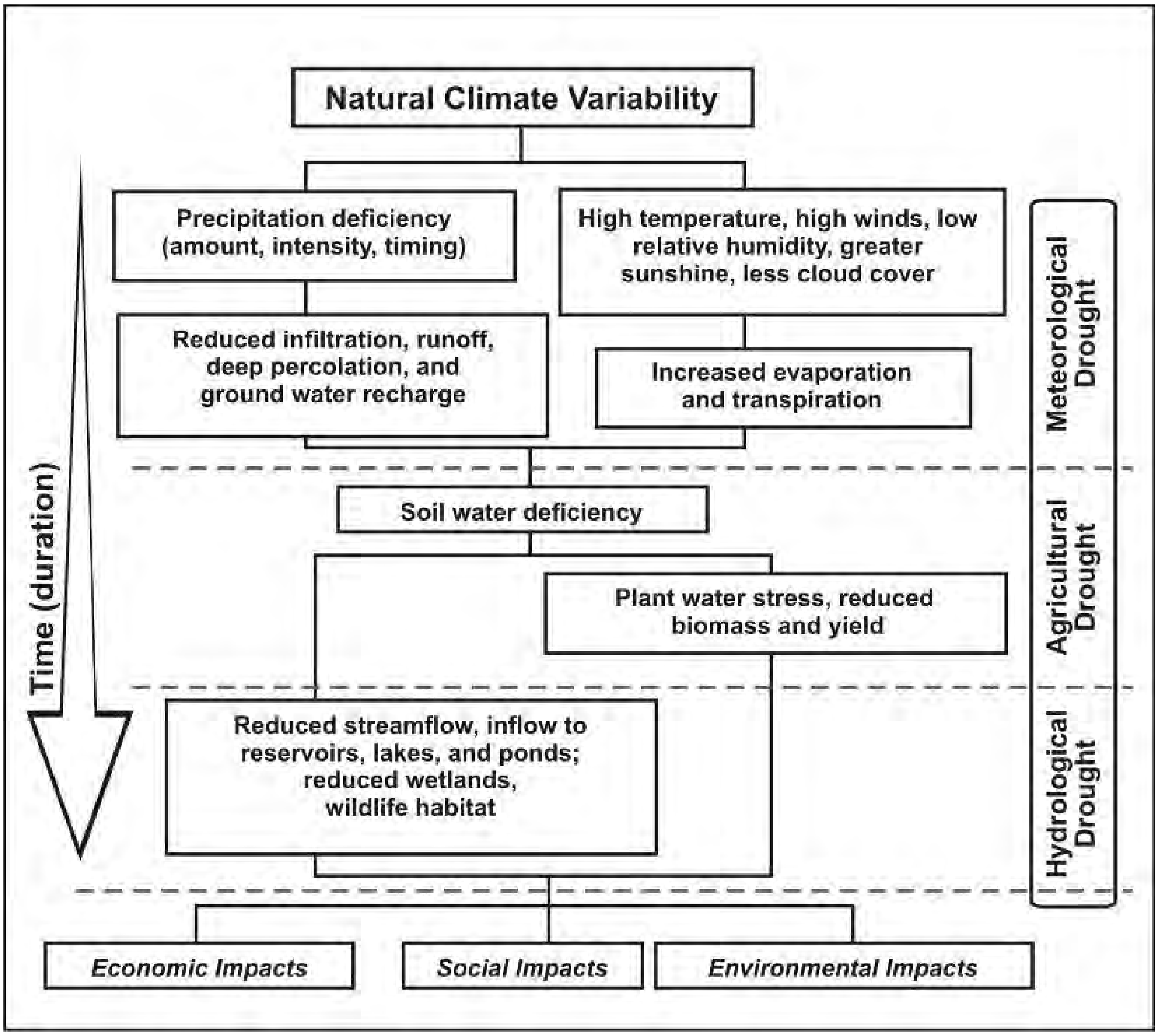
Source: UNICEF and JICA Project Team

Figure BE2.3.1 Natural Resource Development Belts



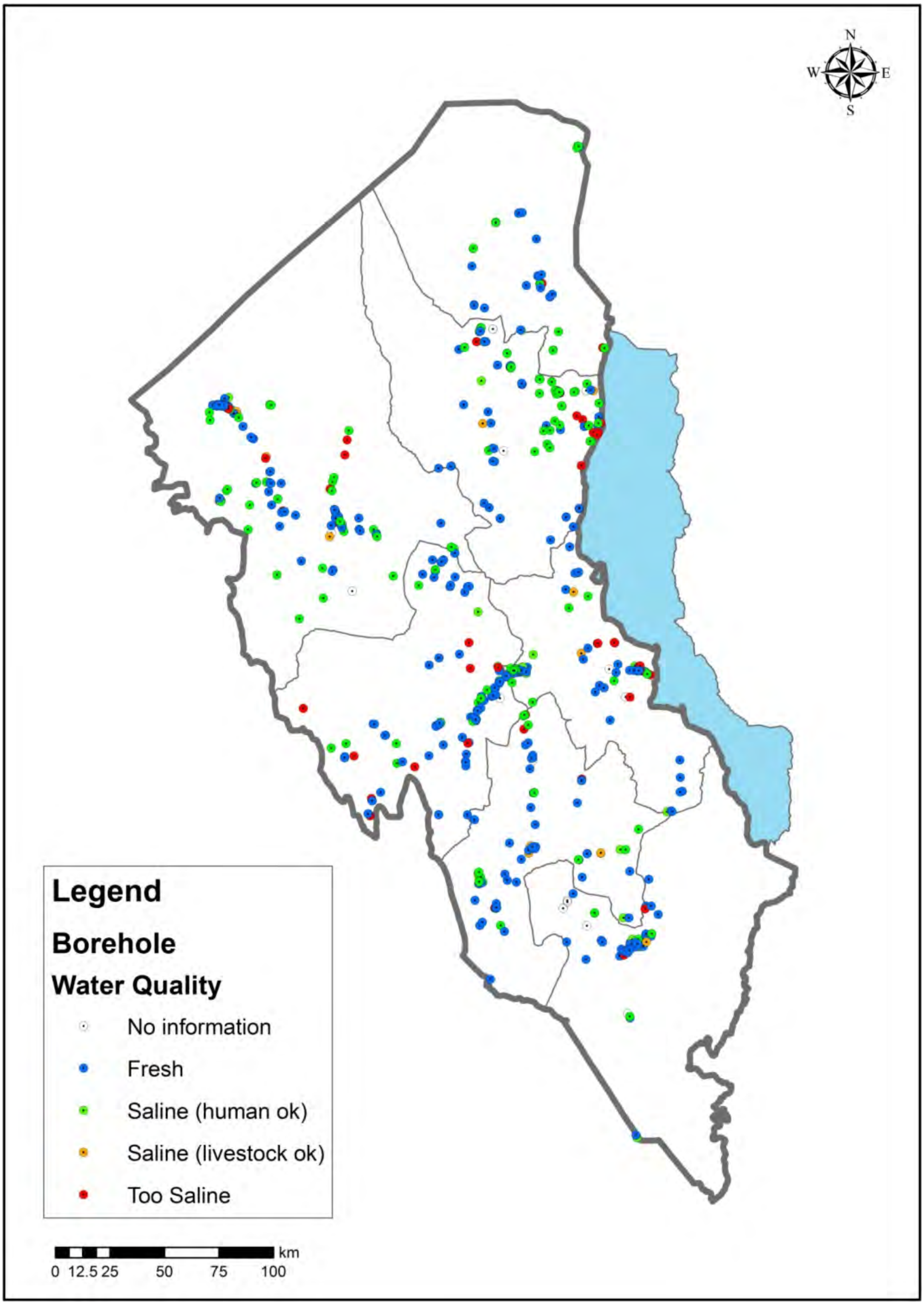
Source: Kansas Ground Water, http://www.kgs.ku.edu/Publications/Bulletins/ED10/07_manage.html

Figure BE3.1.1 Soil Evapotranspiration and Goundwater Evapotranspiration



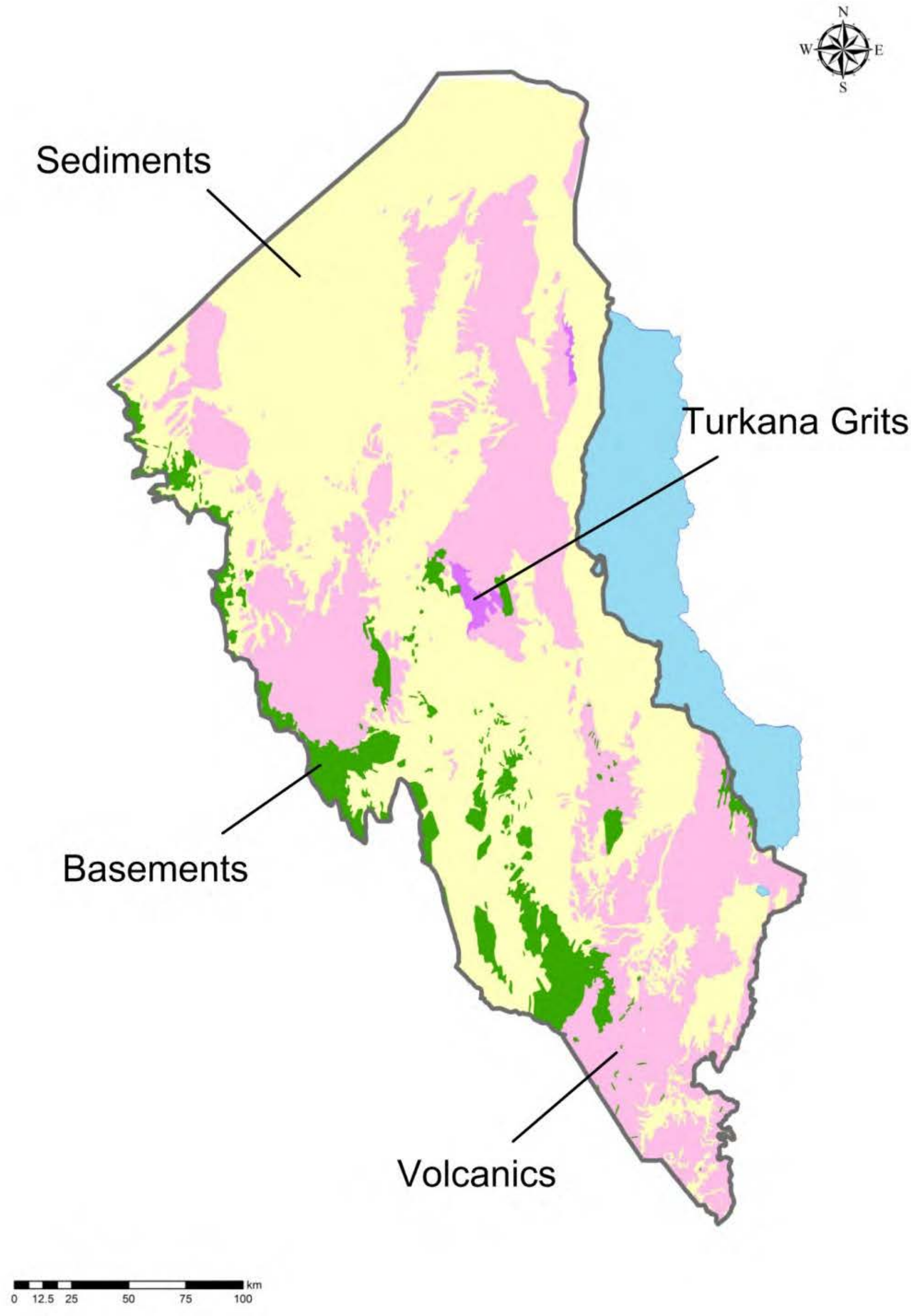
Source: National Drought Mitigation Center, http://drought.unl.edu/DroughtBasics/TypesofDrought.aspx

Figure BE3.1.2 Progression of Drought



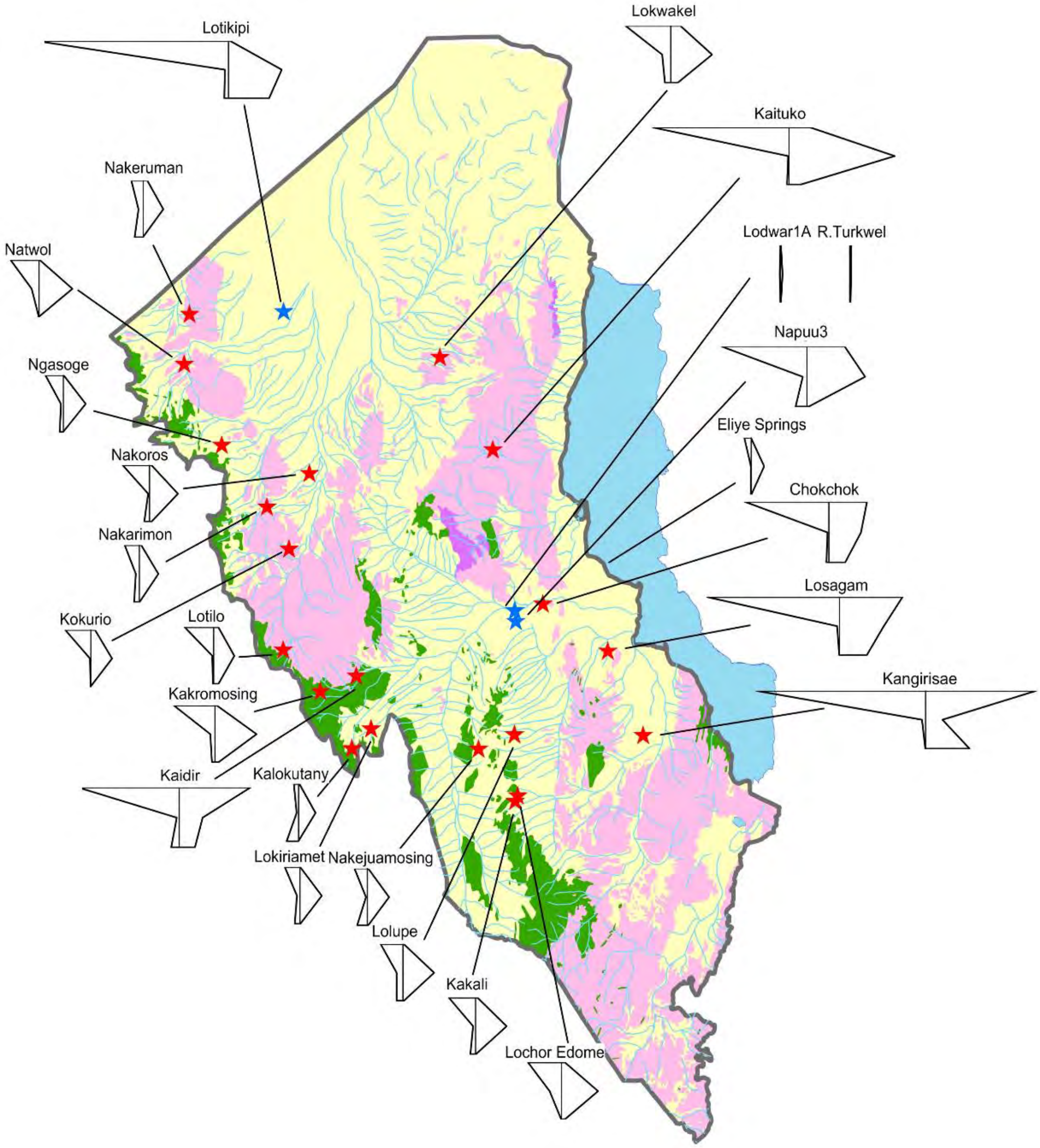
Source: JICA Project Team

Figure BE3.2.1 Compiled Turkana Borehole Locations with Water Quality



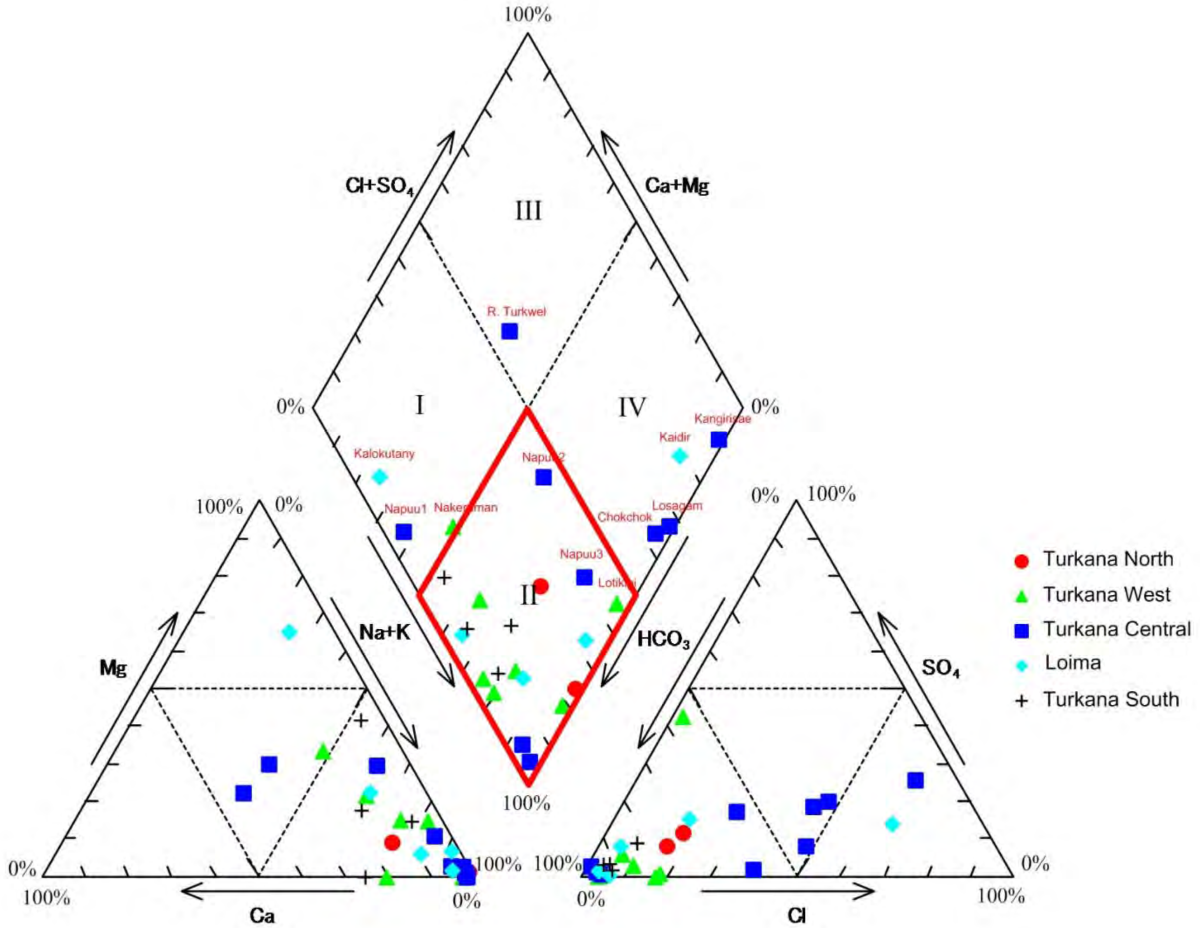
Source: JICA Project Team

Figure BE3.2.2 Simplified Geology



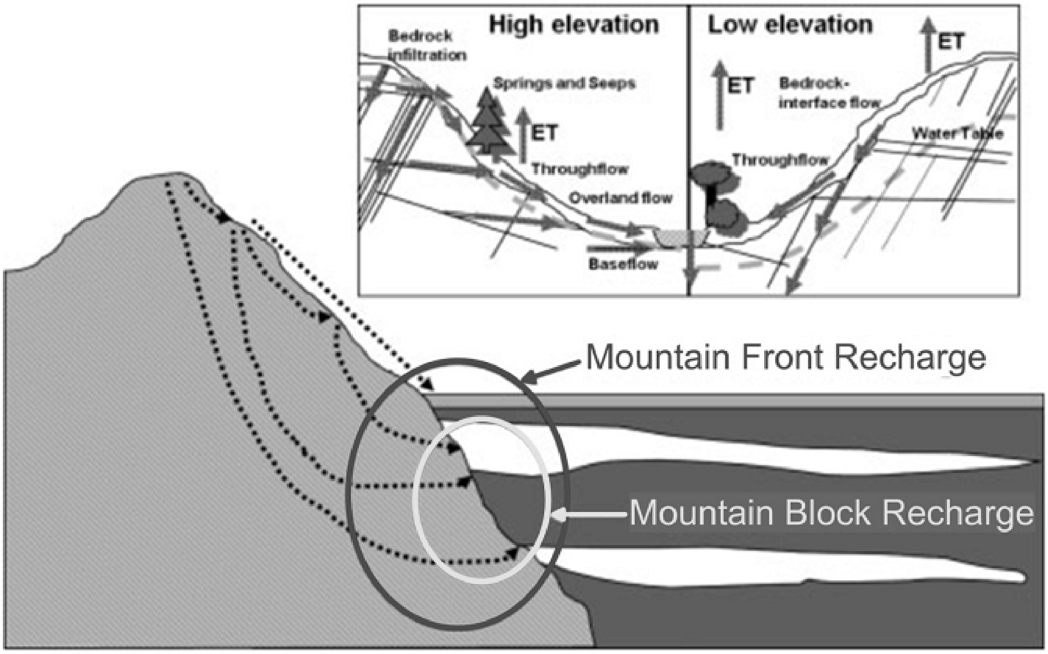
Source: JICA Project Team

Figure BE3.2.3 Turkana Water Quality Indicated by Stiff Diagram



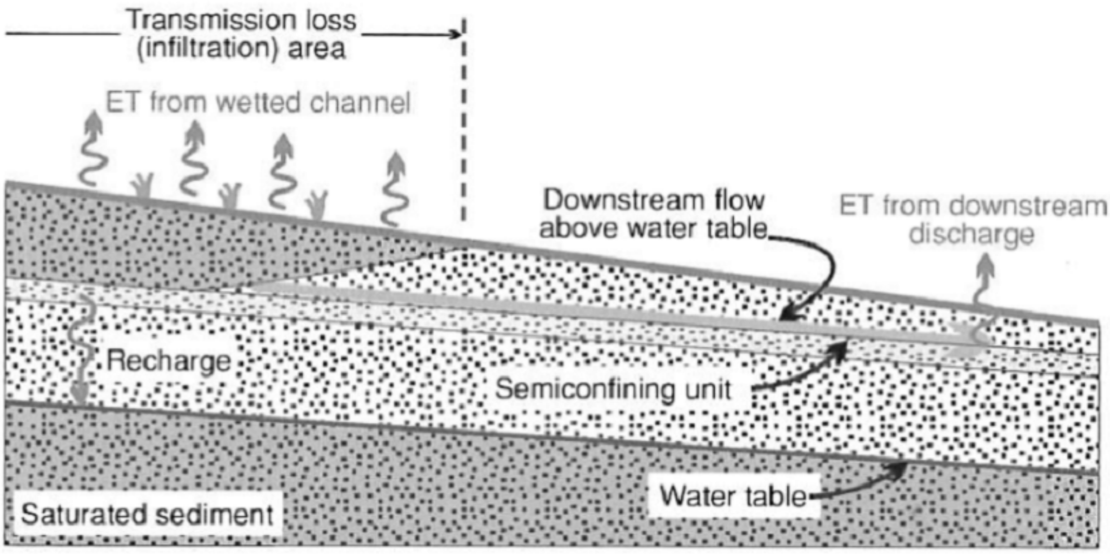
Source: JICA Project Team

Figure BE3.2.4 Piper Diagram



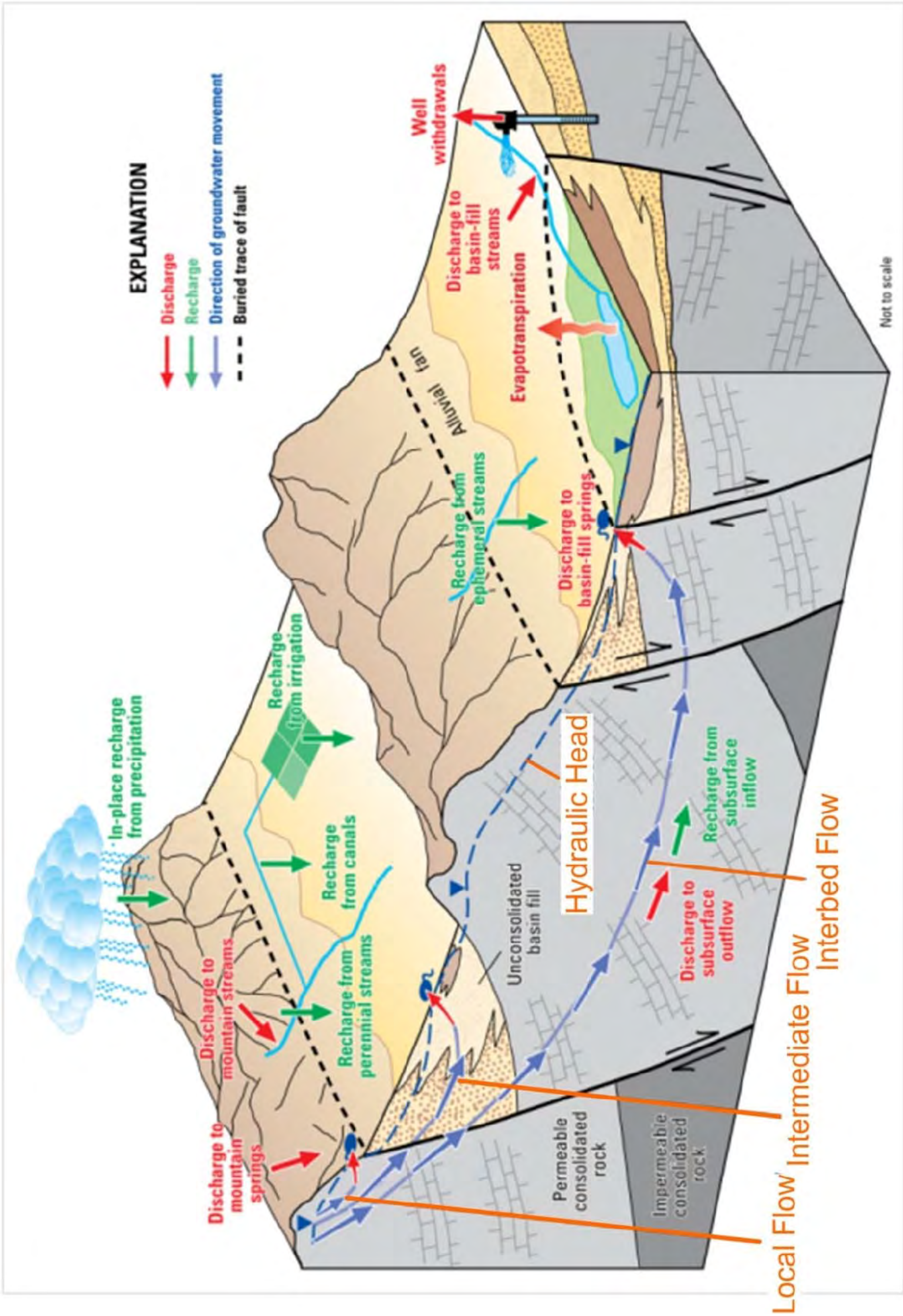
Source: Pam Aishin and James P MacNamara, 2011

Figure BE3.2.5 Groundwater Recharge and Complex Flow in Mountain Ranges



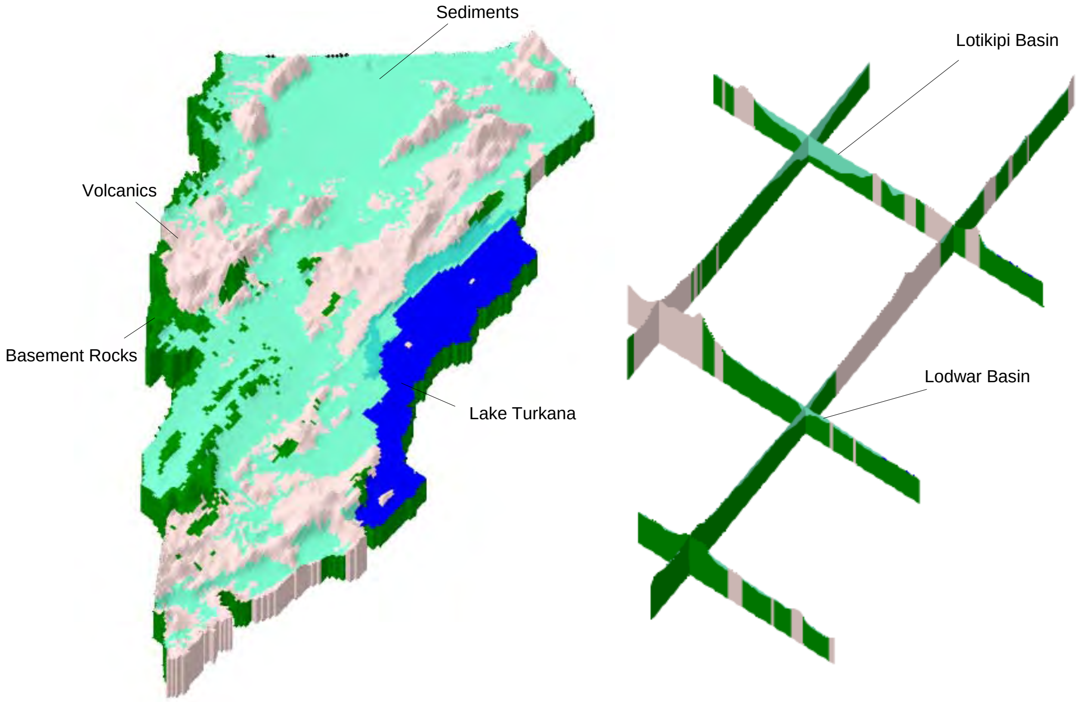
Source: Robert Maliva and Thomas Missimer, 2012

Figure BE3.2.6 Evapotranspiration from Laggas



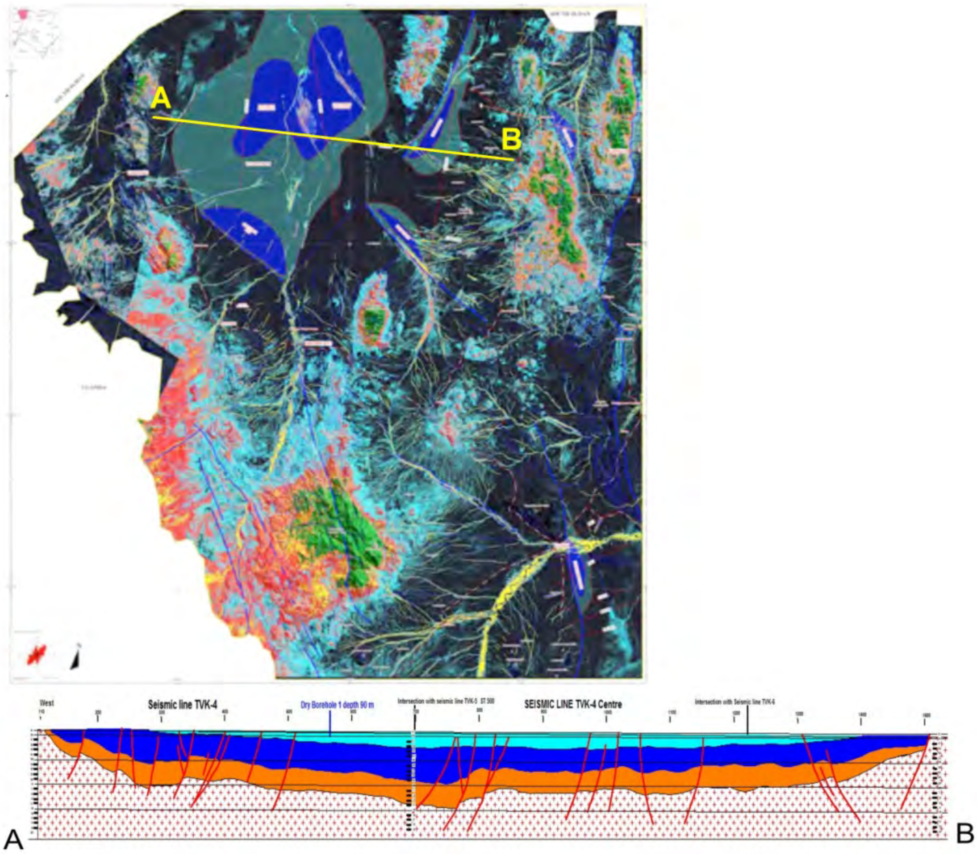
Source: US Geological Survey, 2010

Figure BE3.3.1 Conceptualized Groundwater Flow in Arid and Semi-Arid Regions



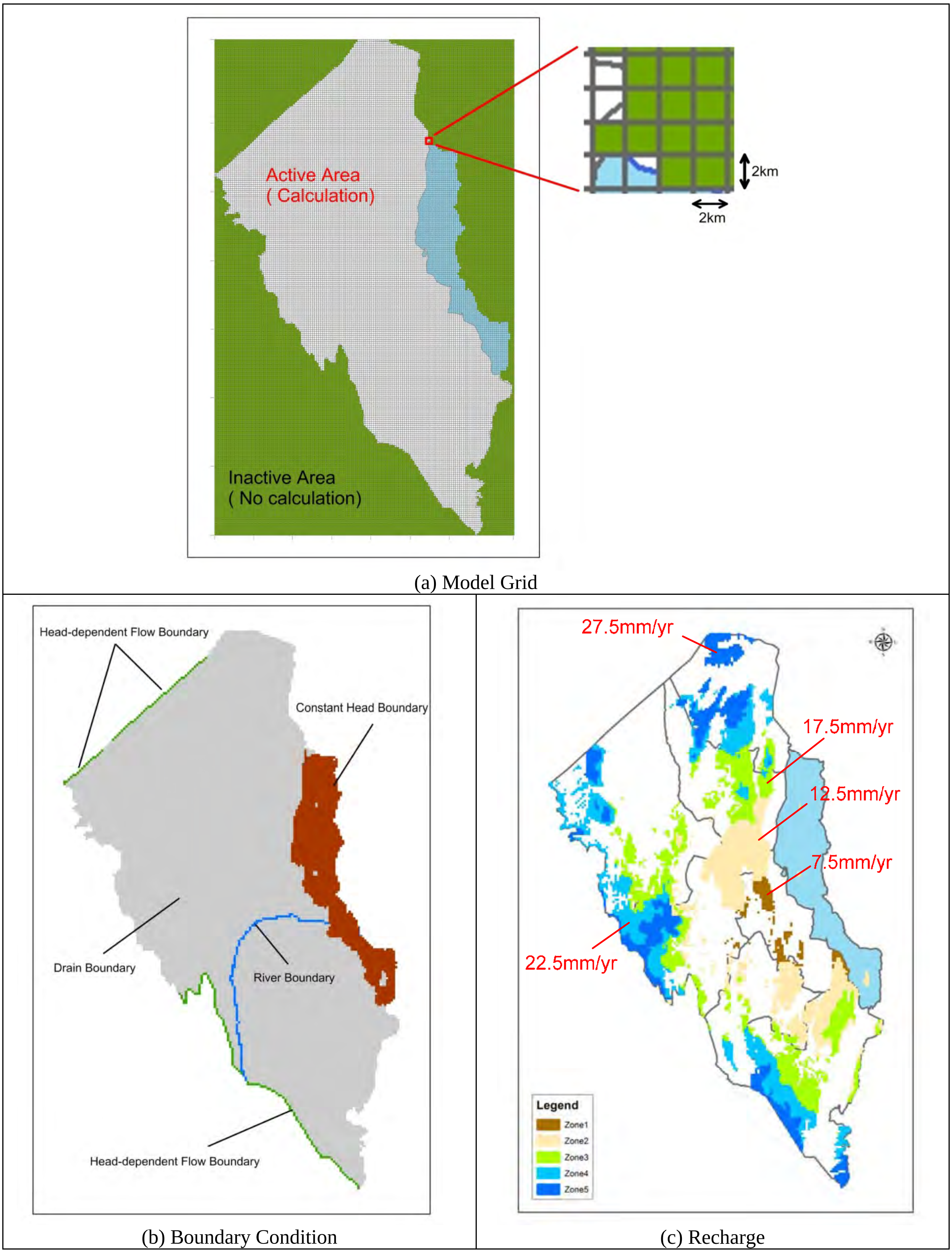
Source: JICA Project Team

Figure BE3.3.2 Hydrogeological Units (Left: Birds View, Right: Panel Diagram)



Source: JICA Project Team

Figure BE3.3.3 Seven Deep Basin Structures Introduced by UNESCO



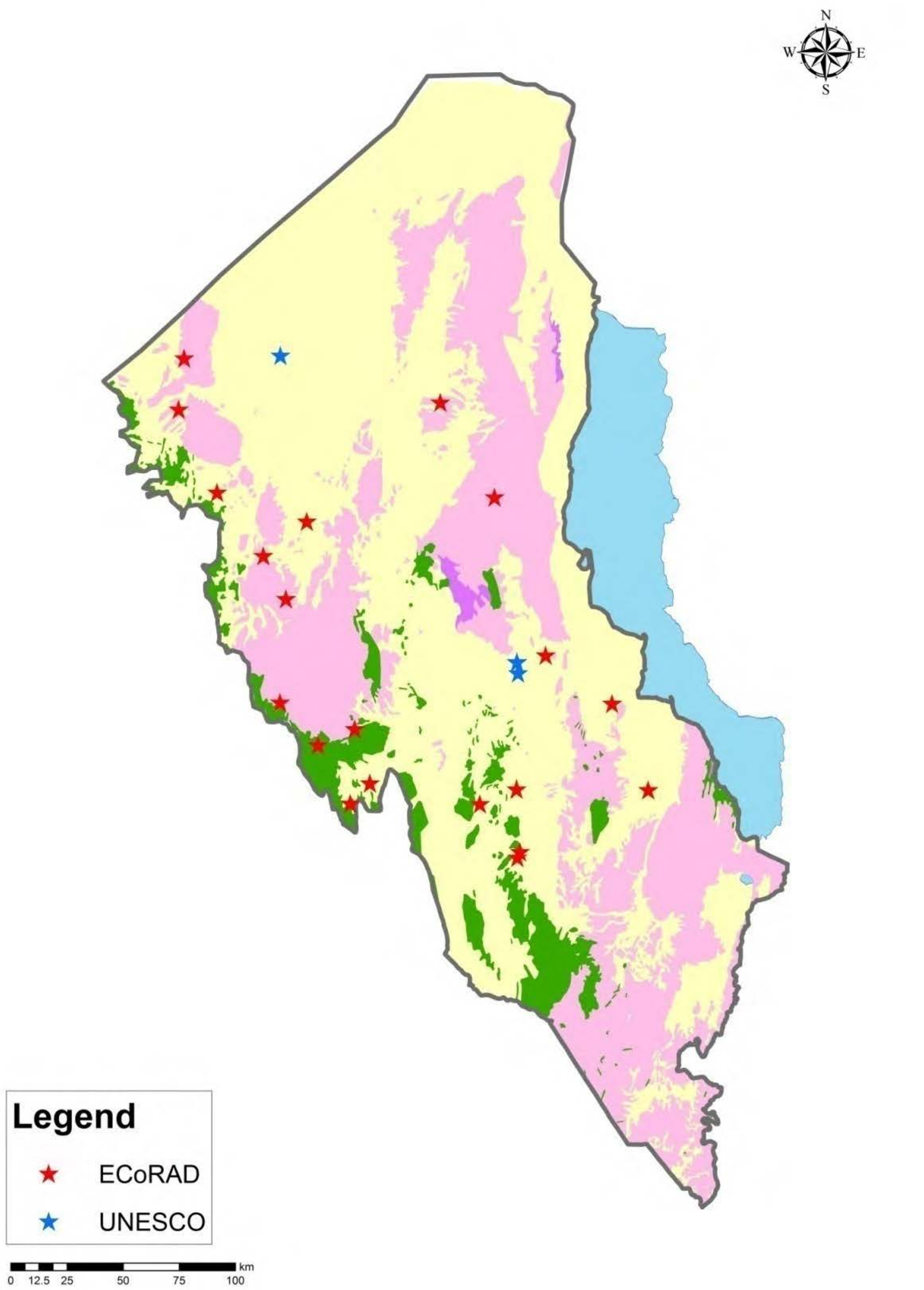
(a) Model Grid

(b) Boundary Condition

(c) Recharge

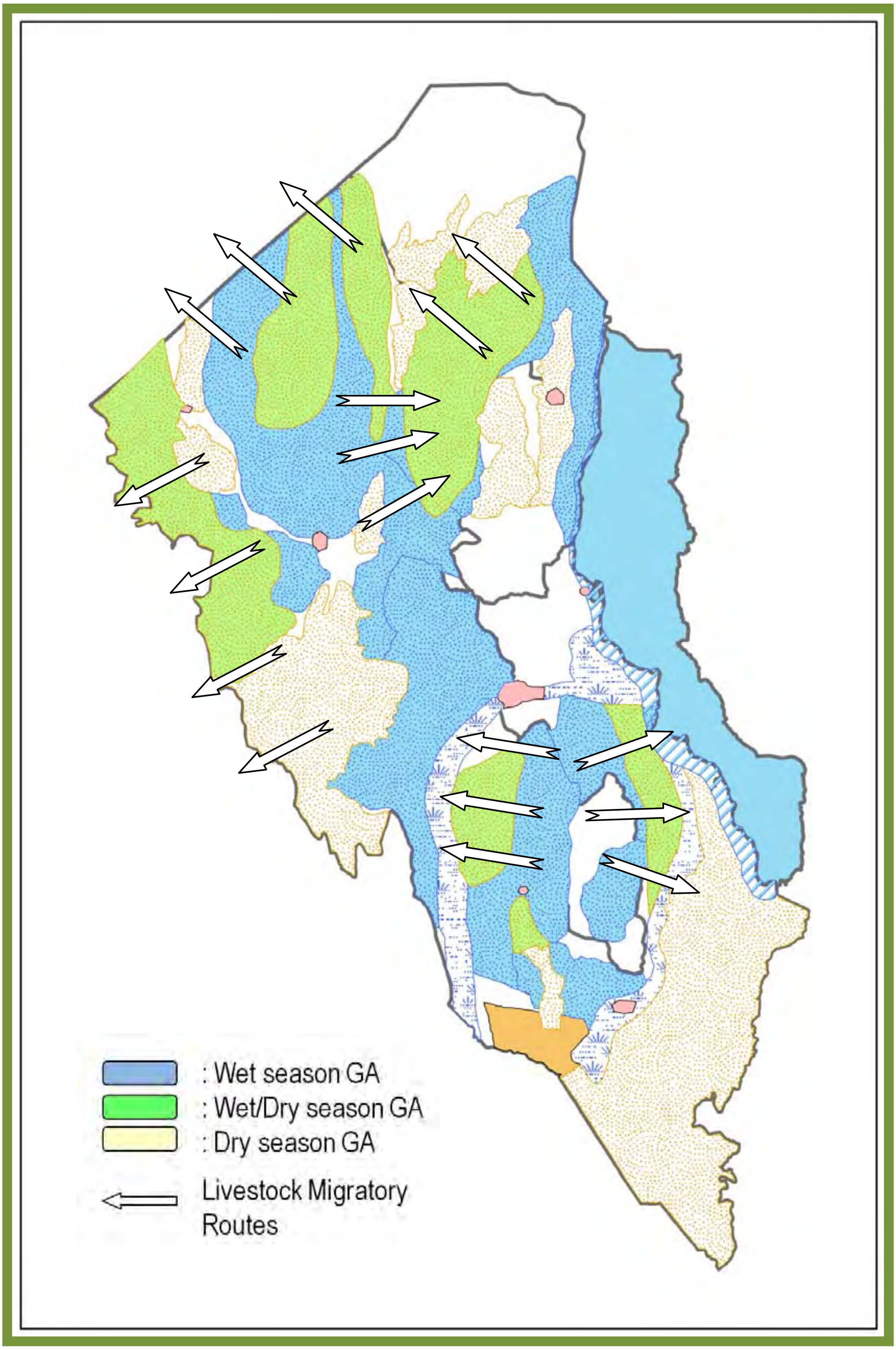
Source: JICA Project Team

Figure BE3.3.4 Groundwater Flow Model Grid, Boundary Condition and Recharge



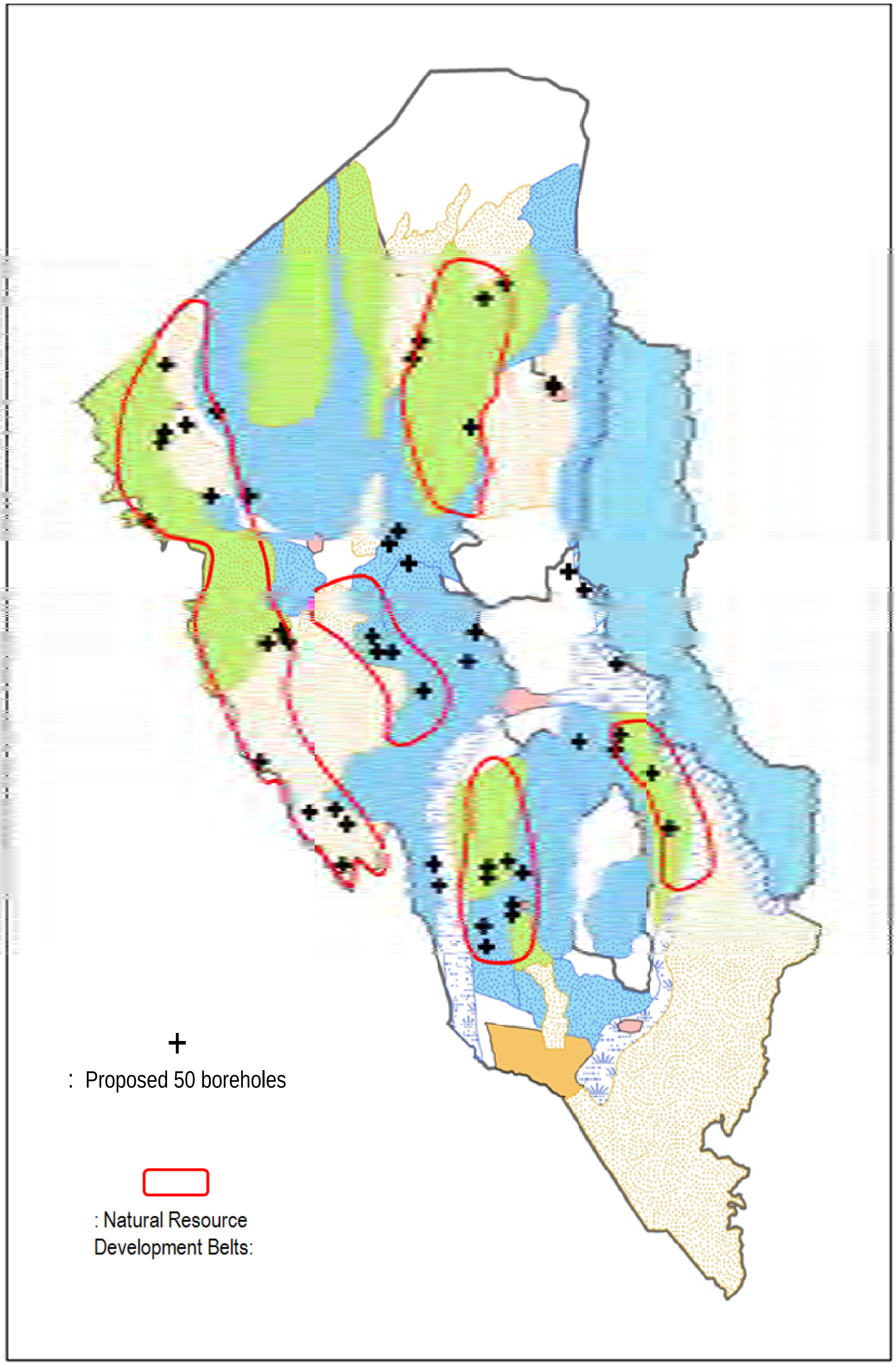
Source: JICA Project Team

Figure BE3.3.5 Calibration Target of Groundwater Flow Simulation



Source: JICA Project Team

Figure BE3.6.1 Distribution Condition of Grazing Areas



Source: JICA Project Team

Figure BE3.6.2 Natural Resource Development Belts and Proposed 50 Borehole Sites