THE REPUBLIC OF SOUTH SUDAN

MINISTRY OF ELECTRICITY, DAMS, IRRIGATION & WATER RESOURCES

WATER SECTOR

IRRIGATION DEVELOPMENT MASTER PLAN

(FINAL REPORT)

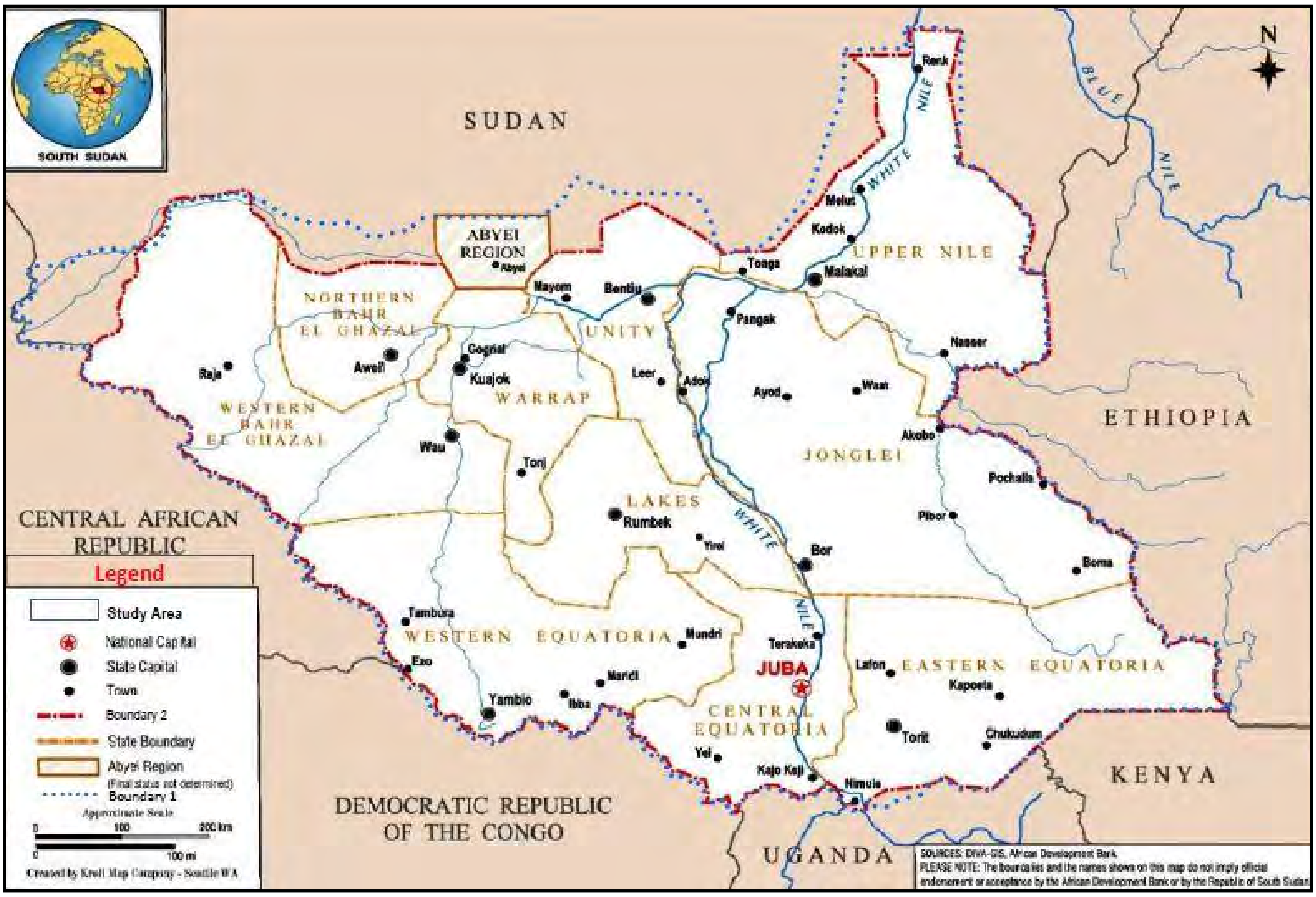
ANNEX 3: IRRIGATION DEVELOPMENT POTENTIAL ASSESSMENT

NOVEMBER 2015

THE PROJECT FOR IRRIGATION DEVELOPMENT MASTER PLAN IN THE REPUBLIC OF SOUTH SUDAN (RSS)

LOCATION MAP

Map of the Republic of South Sudan



Location Map: Adopted from African Development Bank

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IRRIGATION DEVELOPMENT POTENTIAL ASSESSMENT

1. METHODOLOGY

1.1 Overall Methodology

Shortage of fundamental data such as periodical and encompassing data on rainfall, river discharge, evapotranspiration, vegetation, soil, etc. is an issue in the RSS due to the affect of the civil war prolonged for about 50 years. Under this circumstance, IDMP-TTs have been conducting irrigation development potential assessment through the limited data of rainfall and river discharge, etc. which was supplemented by remote sensing, GIS /Remote sensing technology.

The assessment has two (2) stages: stage-1: rapid (low resolution) assessment on land productivity, water resource and socio-economic potentials at a nation-wide level for the definition of high potential areas; and stage-2: detailed (high resolution) assessment of potential for planning irrigation at selected areas based on high precision satellite data, etc. for the verifying priority areas and project sites.

The criteria and flow of irrigation development are shown in Table 1.1.1 and Figure 1.1.1 respectively.

Table 1.1.1 Criteria to Assess the Irrigation Development Potential

Assessment	Layer
Land Productivity Potential	Land cover, Slope, Temperature, Wetness, Soil, River Accessibility, Grazing area, Water bodies, etc.
Water Resources Potential	Rainfall, River discharge, Groundwater, Water use, etc.
Socio-economic Potential	Road accessibility, Population density, Protected area, Oil & gas concessions, Accessibility to market /Capital advantage, etc.

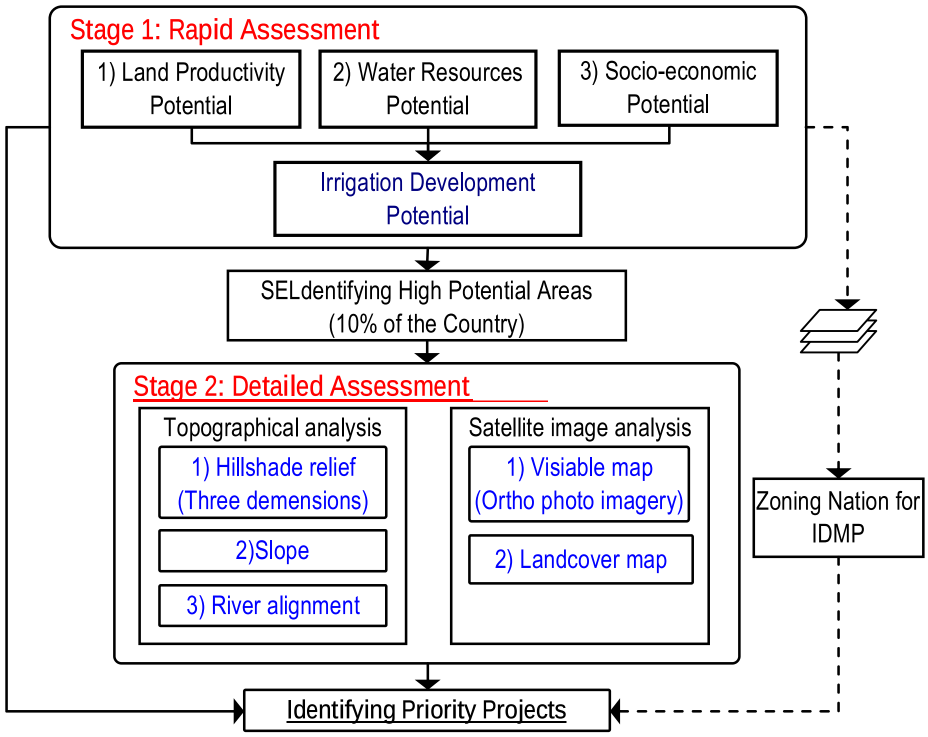


Figure 1.1.1 Flow of Irrigation Development Potential Assessment

1.2 Methodology of the Rapid Assessment

Rapid assessment on irrigation development potential at a nationwide level in RSS has been conducted using data publicized free of charge, including satellite data, elevation data, land cover data, soil data and so on.

Land cover data is one of the most important information for assessing land productivity potential, such as understanding of land which is currently used for farm land, and which can be diverted to farm land. In SIFSIA (Sudan Integrated Food Security Information for Action) prepared by FAO, Land Cover Atlas for the entire area of RSS is established by analysing LANDSAT dating from circa 2000 and circa 2005 ï 2007, and SPOT (Satellite Pour IôObservation de la Terra / Satellite for Observation of Earth) dating from circa 2006 ï 2008. Data from this system have been used as land cover information.

Topography data is important to understand slope, and global-level elevation data from SRTM (Shuttle Rader Topography Mission, 90 m spatial resolution) publicized free of charge by NASA (National Aeronautics and Space Administration) have been used. Also, SRTM data have been used to assess a layer of river accessibility.

Temperature data is important to assess cultivable temperature, especially from the point of view of high-temperature damage, and high temperature data of WorldClim-Global Climate Data have been used.

For soil moisture and aquifer data, which are important for understanding land productivity, Normalized Difference Wetness Index (NDWI) based on LANDSAT satellite data (solution: 30 m) and the soil data, Harmonized World Soil Database (HWSD) with a scale size at 1/2,000,000, have been used.

In consideration of restrictions of land use, data of protected area, oil & gas concessions, grazing, and water bodies have been used. In addition, data of road, population and state/county capitals have been used to assess road accessibility, population density and market area, which is important for understanding human as well as agricultural production movements.

After collecting and sorting the above data, outline assessment for nation-wide land productivity and socio-economic potentials through overlay analysis have been conducted by using GIS as shown in Figure 1.2.1. Assessment assumed 10 layers, where matters to evaluate and scoring of each element for the assessment have been decided through discussion among IDMP-TT members with government organizations / institutions in RSS.

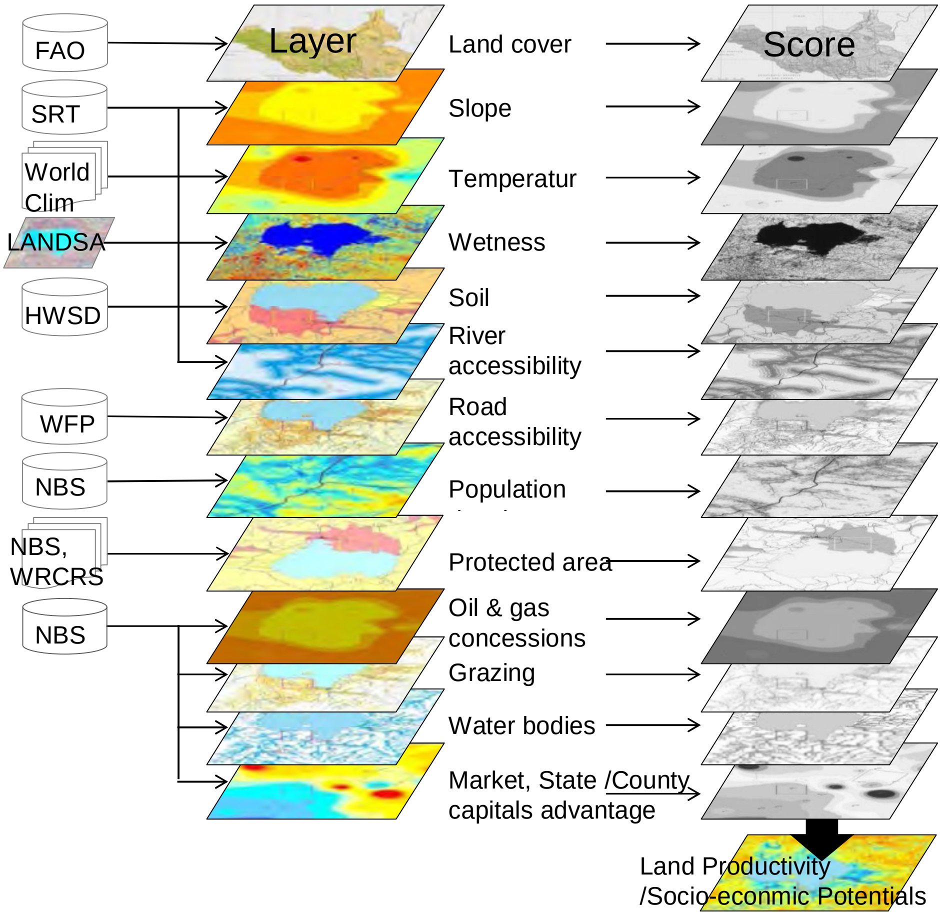


Figure 1.2.1 Image of Creation of Land Productivity / Socio-economic Potentials Map

2. LAND PRODUCTIVITY POTENTIAL ASSESSMENT

The data used to assess is shown in Table 2.1.

Table 2.1 Data for Land Productivity Potential Assessment

Layer		Source	Remarks
1	Land cover	Land cover atlas - SIFSIA produced by FAO	Issued in 2011
2	Slope	SRTM-DEM produced by USGS	Spatial resolution: 90m
3	Temperature	WorldClim - Global Climate Data	Spatial resolution: 1km
4	Wetness	LANDSAT produced by USGS	Spatial resolution: 30m
5	Soil	Digital Atlas produced by NBS, Harmonized World Soil Database (HWSD)	Map scale: 1/2,000,000, Spatial resolution: 1km, Issued in 2009
6	River accessibility	SRTM-DEM produced by USGS	Spatial resolution: 90m
7	Grazing	Digital Atlas produced by NBS, MARF	Updated in 2010/11
8	Water bodies	Digital Atlas produced by NBS, FAO	Updated in 2004

SIFSIA: Sudan Integrated Food Security Information for Action
FAO: United Nations Food and Agriculture Organization
SRTM-DEM: Shuttle Radar Topography Mission - Digital Elevation Model
USGS: United States Geological Survey
NBS: National Bureau of Statics
MARF: Ministry of Agricultural Resources and Fisheries

2.1 Scoring of Each Layer

(1) Land cover

Atlas which is used for data source of land cover layer, was produced in 2011 by SIFSIA programme of FAO which is funded by the European Commission (EC). The land cover mapping activity was carried out with the interpretation of an integrated coverage of GLS (Global Land Survey) LANDSAT satellite images (2005 ï 2007) and updated higher resolution SPOT images (2006 ï 2008) covering the agricultural areas. This approach is adopted to improve the accuracy of the interpretation and to emphasize the land cover features in the agricultural production areas, derived from the existing Africover Sudan data base.

The final South Sudan land cover dataset can be summarized as follows:

- Approx. 100,000 polygons covering an interpreted area of about 658,870 km^2;
- 43 single classes used for the interpretation;
- 290 mixed units deriving from combinations of single classes; and
- 7 aggregated (generalized) classes,

The aggregated classes keep a good level of information though providing a quick estimate of the different land cover typologies. Thus, land cover statistics are extracted; almost 40% of the Country is covered by closed to sparse shrubs (SCO), 33% by closed to sparse trees (TCO), 23% by closed to sparse herbaceous vegetation (HCO), and only 4% is covered by agriculture area (AG) as shown in Figure 2.1.1.

Scoring of land cover layer is based on the suitability of each aggregated classes South Sudan for agricultural land development and farming as shown in Table 2.1.1 and scoring map of land cover is shown in Figure 2.1.2.

Table 2.1.1 Scoring of Land Cover Layer

Code	Description	Score
AG	Agriculture in terrestrial and aquatic/regularly flooded land	10
TCO	Trees closed to very open in terrestrial and aquatic/regularly flooded land	3
SCO	Shrubs closed to sparse in terrestrial and aquatic/regularly flooded land	5
HCO	Herbaceous closed to sparse in terrestrial and aquatic/regularly flooded land	8
URB	Urban areas	1
BS	Bare Rocks and Soil and/or Other Unconsolidated Material(s)	1
WAT	Seasonal/perennial, natural/(artificial) Water bodies	1

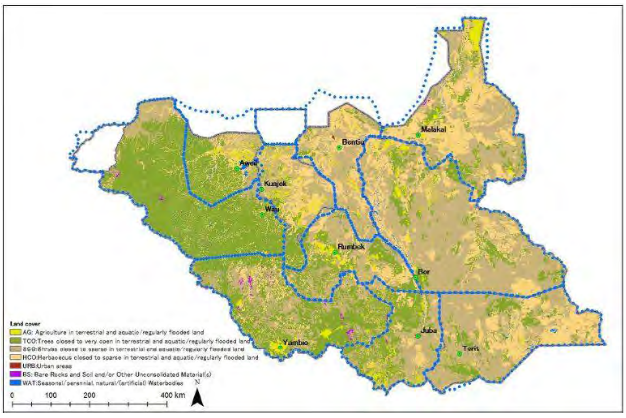


Figure 2.1.1 Created Map of Land Cover

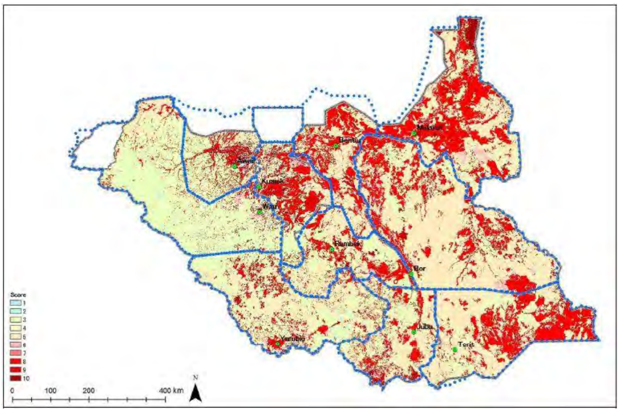


Figure 2.1.2 Scoring Map of Land Cover

(2) Slope

The Digital Elevation Models (DEMs) are input data which can be processed to extract topographic features such as contour, slope, direction (aspect), etc. The DEM represents a regular array of elevation points. In this phase of the Study, the STRM-DEM with spatial resolution 90 m is used for terrain-slope mapping and analysis for the country.

The slope measures the rate of change of elevation at a surface location. Slope may be expressed as percent slope or degree slope. Percent slope is 100 times the ratio of rise (vertical distance) over run (horizontal distance), whereas the degree slope is the arctangent of the ratio of run rise over. The results of the slope in Table 2.1.2 shows that the values of slopes for RSS are ranging from 0 to greater than 45 categorized by FAO/IIASA (International Institute for Applied Systems Analysis). Figure 2.1.3 shows that the slopes of the country is relatively having flat slope in the northern, central, western areas and parts of southern and eastern areas. The south-eastern and south-western areas and part of north-western area have hilly and steep slopes.

Slope scoring map indicates that the scored values ranging from 10 to 8 is consider very potentially suitability for irrigation values ranging from 6 to 8 potentially suitable for irrigation and values from 4 to 1 is less potentially suitable for irrigation.

The slope is important characteristic for assessing the terrain suitability for irrigation potential. The scoring is based on the idea that the flatter slopes are scored high and the steeper slopes evidently low as shown in Table 2.1.2 and scoring map is shown in Figure 2.1.4.

Table 2.1.2 Scoring of Slope Layer

Slope S (%)	Score	Comments
S < 0.5	10	very flat
0.5 < S < 2	10	flat
2 < S < 5	8	gently sloping
5 < S < 8	6	undulating
8 < S < 16	4	rolling
16 < S < 30	2	hilly
30 < S < 45	1	steep
45 < S	1	very steep

* Reference: ñTerrain-slope ratingò shown in ñGlobal Agro-ecological Zones Model

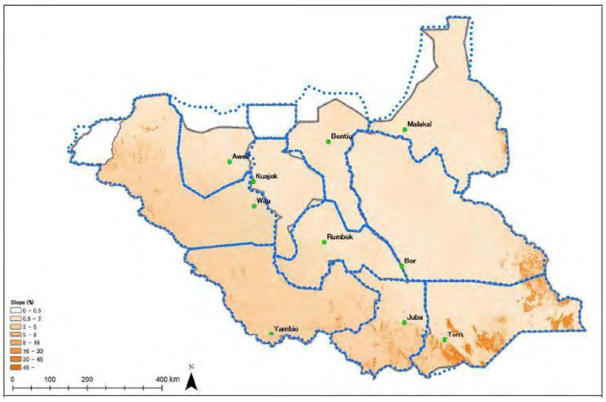


Figure 2.1.3 Created Map of Slope

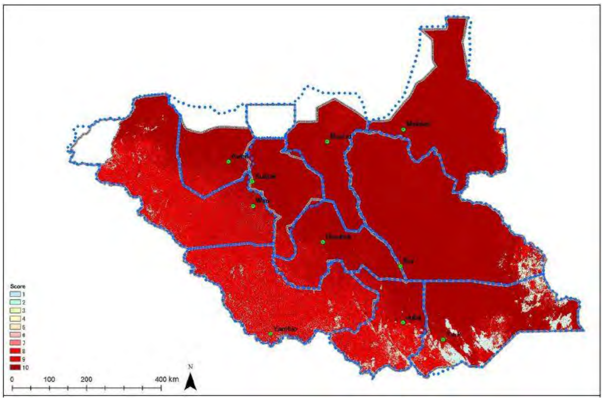


Figure 2.1.4 Scoring Map of Slope

(3) Temperature

WorldClim-Global Climate Data is a free climate data developed by produced by the Museum of Vertebrate Zoology, University of California. It can be used for mapping and spatial modelling in GIS or with other computer programs. In the Study, WorldClim-Global Climate Data with a spatial resolution of about 1 km is used for temperature mapping and analysis. Created map of temperature layer for rice shown in Figure 2.1.5

Air temperature is a major element to affect the productivity of agriculture crops by stress in each growing stage. Lethal temperature for Rice and Non-rice (upland crops) such maize and sorghum are examined. The lethal temperature of rice, maize and sorghum are 35˚C, 38 ˚C and 40˚C respectively. A particular day within a month when becomes more than 35˚C is occurred for 7 months a year in maximum in RSS.

Followings are considered for scoring shown in Table 2.1.3:

a) Maize is adopted as ñNon-riceò while monthly highest temperature more than 40˚C which is lethal temperature for sorghum, is not occurred in RSS[1];

b) A particular day of which highest temperature is occurred more than 35˚C for Rice and 38 ˚C for Non-rice (Maize) is counted one (1) month through the year; and

c) If the numbers of month more than each lethal temperature are zero (0), scoring is highest "10". Then, the numbers of month more than each lethal temperature are nine (9) and ten (10), scoring is lowest ñ1ò.

Table 2.1.3 Scoring of Temperature Layer (Rice and Non-rice)

Nos. of month(s) more than lethal temperature	Score
0	10
1	9
2	8
3	7
4	6
5	5
6	4
7	3
8	2
9	1
10	1

* Lethal Temperature;
35˚C for Rice, 38˚C for Non-rice (Maize):

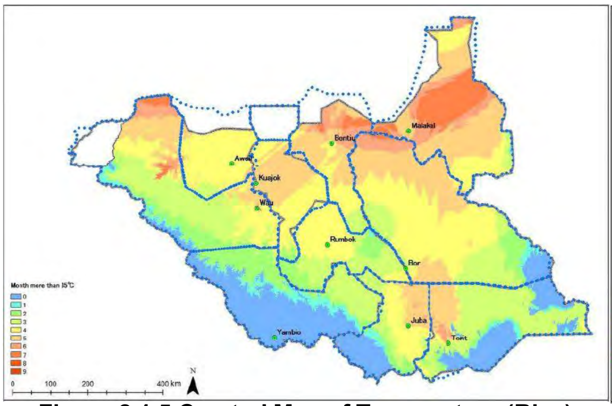


Figure 2.1.5 Created Map of Temperature (Rice)

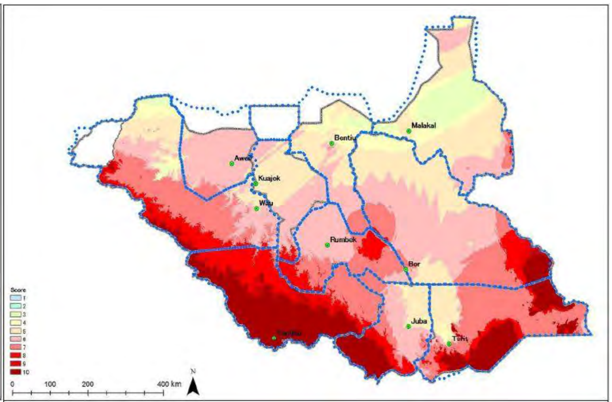


Figure 2.1.6 Scoring Map of Temperature (Rice)

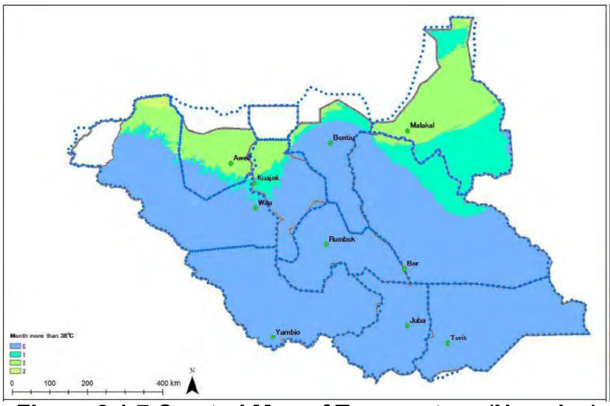


Figure 2.1.7 Created Map of Temperature (Non-rice)

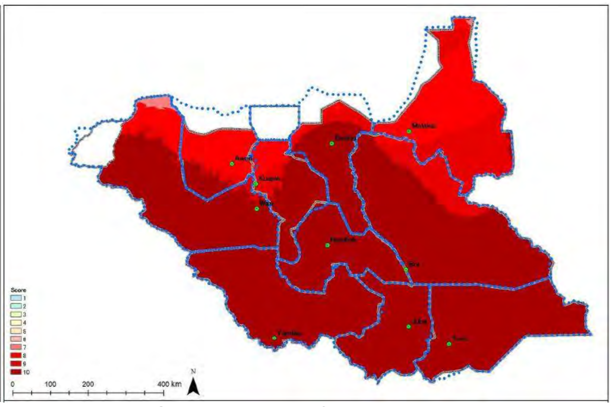


Figure 2.1.8 Scoring Map of Temperature (Non-rice)

(4) Wetness

LANDSAT data with spatial resolution of 30 m produced by USGS (United States Geological Survey)

[1] Sorghum fits in the same social/economic niche as maize, but is found in hotter and drier places. The reason sorghum has the advantage over maize in hot/dry places has to do with origins. Maize comes from the humid tropics, sorghum the semi-arid tropics.

was used for the analysis of wetness indexes which exist as solid, liquid and vapour. The wetness is one of the important factors for agricultural cultivation during the stages such seedling, growing, flowering of plant, and is influenced by different elements (e.g. weather, topography, land cover, rainfall, soil moisture contain, temperature and etc.).

Scoring of ten (10) for highest and one (1) for lowest are given at regular intervals to wetness index as shown in Table 2.1.4. And created map and scoring map are shown in Figure 2.1.9 and Figure 2.1.10 respectively.

Table 2.1.4 Scoring of Wetness Layer

Wetness Index	Score
Highest	10
↓	9
↓	↓
↓	2
Lowest	1

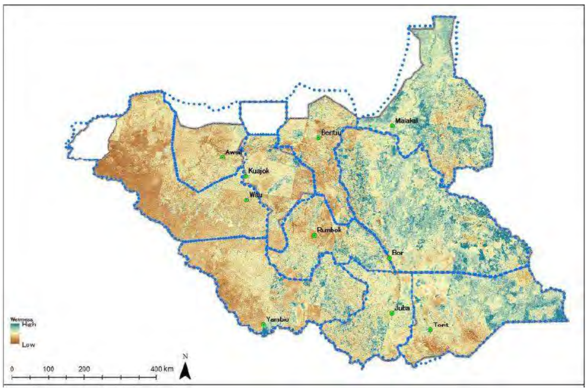


Figure 2.1.9 Created Map of Wetness

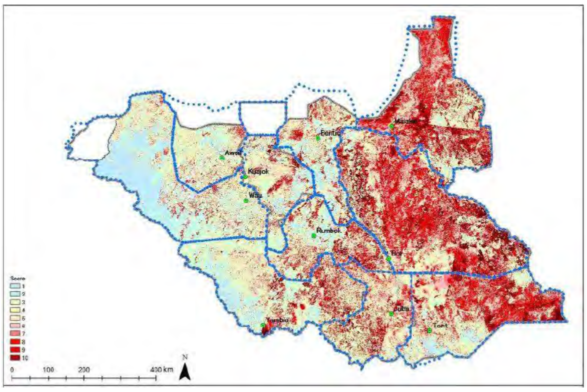


Figure 2.1.10 Scoring Map of Wetness

(5) Soil

Digital atlas with a spatial resolution 1 km is used for soil mapping and analysis. It was produced in 2009 by NBS based on HWSD (Harmonized World Soil Database). HWSD have been developed by the Land Use Change and Agriculture Program of IIASA (International Institute for Applied Systems Analysis) and FAO.

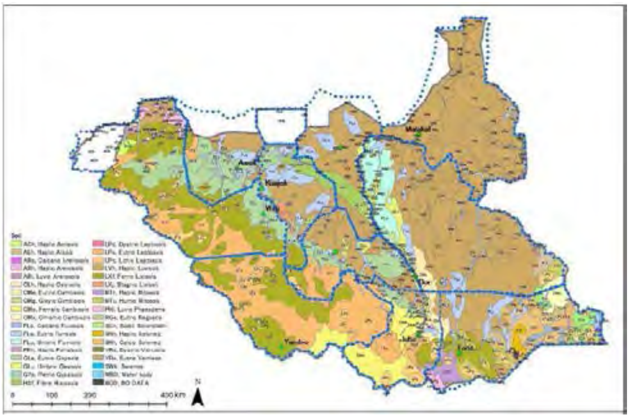


Figure 2.1.11 Created Map of Soil

In RSS, soil types are specified 34 in detail which are categorized into six (6) types: namely, 1) Vertisols, 2) Fluvisols, 3) Leptosols, 4) Lixisols, 5) Regosols and 6) Cambisols. 1) Vertisols called ñblack cotton soilsò widely covers in eastern part of RSS. 2) Fluvisols is found along rivers, lakes and alluvial plains. 3) Leptosols is laid in shallow place located over hard rock by containing calcareous material in south-western part. 4) Lixisols is formed with subsurface accumulation of low activity clays distributed in western part. 5) Regosols generally found in arid and semi-arid areas due to World Reference Base for Soil Resources in FAO is distributed from northwest toward to central area of RSS. 6) Cambisols formed medium and fine-textured materials cover a part of south and central area of RSS. The map created by FAO is shown in Figure 2.1.11.

Scorings methodology for 34 types of HWSD has been discussed through the meetings among IDMP-TT members, by separating the topsoil (0 ï 30 cm) and subsoil (30 ï 100 cm). The characteristics of these soil types are assessed in consideration with the soil suitability for irrigation based on the following six (6) factors for two (2) cases: ñRiceò and ñNon-riceò referring to the report of ñAssessment of the Irrigation Potential in Burundi, Eastern DRC, Kenya, Rwanda, South Sudan, Tanzania and Ugandaò issued by NBI in July 2012.

a) Organic carbon, b) Water holding capacity, c) Drainage capacity, d) pH, e) Texture and f) Salinity

Scoring criteria of above six (6) factors is shown in Table 2.1.5 to Table 2.1.10.

Table 2.1.5 Scoring Criteria - Organic Carbon (OC) *1)

Class	Score (Adopted) *2)		Score (NBI Report)	
(%)	Rice	Non-Rice	Rice	Non-Rice
<= 0.2	0	0	0%	0%
0.2 < OC <= 0.6	2.5	2.5	25%	25%
0.6 < OC <= 1.2	5	5	50%	50%
1.2 < OC <= 2.0	7.5	7.5	75%	75%
2.0 < OC	10	10	100%	100%

Notes
*1) Criteria: Apply to both "Topsoil" and "Subsoil".
*2) Score (Adopted): Rate on a scale of one (1) to ten (10) based on "Score (NBI Report)".

Table 2.1.6 Scoring Criteria - Water Holding Capacity (WHC) *1)

Class	Score (Adopted) *2)		Score (NBI Report)	
(mm/month)	Rice	Non-Rice	Rice	Non-Rice
150 < WHC	10	10	100%	100%
125 < WHC <= 150	8	8	80%	80%
100 < WHC <= 125	6	6	60%	60%
75 < WHC <= 100	4	4	40%	40%
50 < WHC <= 75	2	2	20%	20%
15 < WHC <= 50	0	0	0%	0%
WHC <= 15	0	0	N/A	N/A

Notes
*1) Criteria: Apply to both "Topsoil" and "Subsoil".
*2) Score (Adopted): Rate on a scale of one (1) to ten (10) based on "Score (NBI Report)".

Table 2.1.7 Scoring Criteria - Drainage Capacity *1)

Class	Score (Adopted) *2)		Score (NBI Report)	
	Rice	Non-Rice	Rice	Non-Rice
Excessively drained (open water)	0	0	0%	0%
Somewhat excessively drained	0	0	0%	0%
Well drained	5	10	50%	100%
Moderately well drained	5	7.5	50%	75%
Somewhat poorly drained / Inperfectly	5	5	50%	50%
Poorly drained / Poor	10	5	100%	50%
Very poorly drained / Very Poor	5	0	50%	0%

Notes
*1) Criteria: Apply to both "Topsoil" and "Subsoil".
*2) Score (Adopted): Rate on a scale of one (1) to ten (10) based on "Score (NBI Report)".

Table 2.1.8 Scoring Criteria - pH *1)

Class	Score (Adopted) *2)		Score (NBI Report)	
	Rice	Non-Rice	Rice	Non-Rice
pH <= 4.0	3	3	30%	30%
4.0 < pH <= 5.5	6	6	60%	60%
5.5 < pH <= 7.3	10	10	100%	100%
7.3 < pH <= 8.5	6	6	60%	60%
8.5 < pH	3	3	30%	30%

Notes
*1) Criteria: Apply to both "Topsoil" and "Subsoil".
*2) Score (Adopted): Rate on a scale of one (1) to ten (10) based on "Score (NBI Report)".

Table 2.1.9 Scoring Criteria - Texture *1)

Class	Score (Adopted) *2)		Score (NBI Report)	
	Rice	Non-Rice	Rice	Non-Rice
No Data (open water)	-	-	-	-
Clay (heavy)	10	0	100%	0%
Silty clay	9	1.5	↑	↓
Clay / Clay (light)	9	3	↑	↓
Silty clay loam	8	5	↑	↓
Clay loam	8	6.5	↑	↓
Silt	7	8	↑	↓
Silt loam	6	10	↑	100%
Sandy clay	5	8	↑	↑
Loam	4	6.5	↑	↑
Sandy clay loam	3	5	↑	↑
Sandy loam	2	3	↑	↑
Loamy sand	1	1.5	↑	↑
Sand	0	0	0%	0%

Notes
*1) Criteria: Apply to both "Topsoil" and "Subsoil".
*2) Score (Adopted): Rate on a scale of one (1) to ten (10) based on "Score (NBI Report)".

Table 2.1.10 Scoring Criteria - Salinity (Ece) *1)

Class		Score (Adopted) *2)		Score (NBI Report)	
		Rice	Non-Rice	Rice	Non-Rice
ECe = 0	Non-saline/No Data	10	10	100%	100%
0 < ECe <= 0.7	Non-saline	10	10	100%	100%
0.7 < ECe <= 2	Slightly saline	10	10	100%	100%
2 < ECe <= 10	Moderatly saline	5	5	50%	50%
10 < ECe <= 25	Highly saline	2.5	2.5	25%	25%
25 < ECe <= 45	Very highly saline	0	0	0%	0%

Notes
*1) Criteria: Apply to both "Topsoil" and "Subsoil".
*2) Score (Adopted): Rate on a scale of one (1) to ten (10) based on "Score (NBI Report)".

In consideration of weighting of the above six (6) factors, scorings for 34 soil types have been finalized as shown in Table 2.1.11 for "Rice" and 2.1.12 for "Non-rice", with additional consideration while pH and Texture criteria are fundamental elements for crops, if the both scores are less than "3", the final scoring of those soil type makes "1".

Table 2.1.11 Scoring of Soil Layer (Rice)

S/No.	Soil Code	Soil Unit Name	Score	S/No.	Soil Code	Soil Unit Name	Score
1	VRe	Eutric Vertisols	8	18	GLu	Umbric Gleysols	8
2	VRd	Dystric Vertisols	8	19	HSf	Fibric Histosols	8
3	FLu	Umbric Fluvisols	7	20	SNh	Haplic Solonetz	6
4	FLe	Eutric Fluvisols	7	21	SNk	Calcic Solonetz	6
5	FLc	Calcaric Fluvisols	6	22	NTh	Haplic Nitisols	7
6	FLd	Dystric Fluvisols	6	23	NTu	Humic Nitisols	8
7	LPd	Dystric Leptosols	5	24	LVh	Haplic Luvisols	6
8	LPe	Eutric Leptosols	6	25	ARh	Haplic Arenosols	1
9	LPq	Lithic Leptosols	5	26	ARl	Luvic Arenosols	1
10	LXf	Ferric Lixisols	1	27	ARc	Calcaric Arenosols	1
11	LXj	Stagnic Lixisols	8	28	ACh	Haplic Acrisols	6
12	RGe	Eutric Regosols	1	29	SCn	Sodic Solonchaks	6
13	CMe	Eutric Cambisols	7	30	PHl	Luvic Phaeozems	8
14	CMg	Gleyic Cambisols	8	31	ALh	Haplic Alisols	6
15	CMo	Ferralic Cambisols	7	32	CLh	Haplic Calcisols	6
16	CMx	Chromic Cambisols	8	33	FRh	Haplic Ferralsols	6
17	GLe	Eutric Gleysols	8	34	GYp	Petric Gypsisols	5

Table 2.1.12 Scoring of Soil Layer (Non-rice)

S/No.	Soil Code	Soil Unit Name	Score	S/No.	Soil Code	Soil Unit Name	Score
1	VRe	Eutric Vertisols	6	18	GLu	Umbric Gleysols	7
2	VRd	Dystric Vertisols	6	19	HSf	Fibric Histosols	7
3	FLu	Umbric Fluvisols	8	20	SNh	Haplic Solonetz	7
4	FLe	Eutric Fluvisols	8	21	SNk	Calcic Solonetz	7
5	FLc	Calcaric Fluvisols	7	22	NTh	Haplic Nitisols	7
6	FLd	Dystric Fluvisols	7	23	NTu	Humic Nitisols	1
7	LPd	Dystric Leptosols	5	24	LVh	Haplic Luvisols	7
8	LPe	Eutric Leptosols	6	25	ARh	Haplic Arenosols	1
9	LPq	Lithic Leptosols	5	26	ARl	Luvic Arenosols	1
10	LXf	Ferric Lixisols	7	27	ARc	Calcaric Arenosols	1
11	LXj	Stagnic Lixisols	7	28	ACh	Haplic Acrisols	7
12	RGe	Eutric Regosols	7	29	SCn	Sodic Solonchaks	6
13	CMe	Eutric Cambisols	8	30	PHl	Luvic Phaeozems	8
14	CMg	Gleyic Cambisols	7	31	ALh	Haplic Alisols	7
15	CMo	Ferralic Cambisols	7	32	CLh	Haplic Calcisols	7
16	CMx	Chromic Cambisols	8	33	FRh	Haplic Ferralsols	7
17	GLe	Eutric Gleysols	7	34	GYp	Petric Gypsisols	6

Figure 2.1.11 shows created map, and also scoring map for "Rice" and "Non-rice" are shown in Figure 2.1.12 and Figure 2.1.13 respectively.

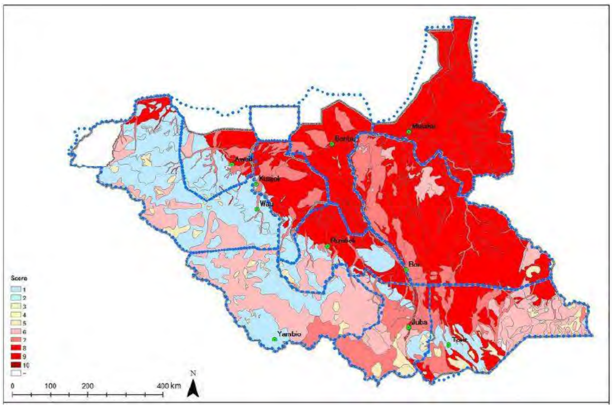


Figure 2.1.12 Scoring Map of Soil (Rice)

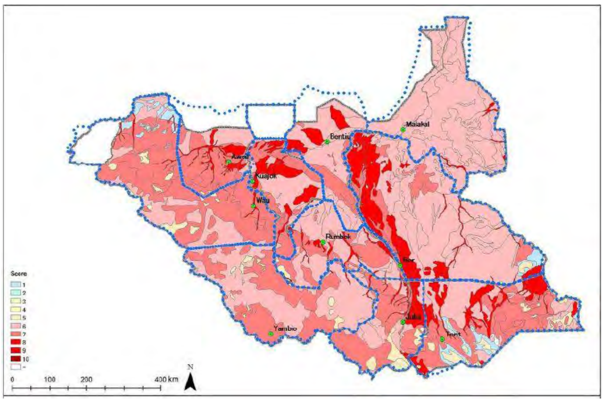


Figure 2.1.13 Scoring Map of Soil (Non-rice)

(6) River accessibility

Map of river network was created with data obtaining from SRTM-DEM with a spatial resolution of 90 m originally produced by USGS as shown in Figure 2.1.14.

Layer of river accessibility is considered based on distance to availability of water source for irrigation development. Accordingly, high scores with "10" to "6" are given to particular places by distance from the river 0 to 5 km with intervals of one (1) km, and low scores "5" to "1" are given with intervals of 2.5 to 5.0 km. The scoring of river accessibility is shown in Table 2.1.13 and created map is shown in Figure 2.1.15.

Table 2.1.13 Scoring of River Accessibility Layer

Distance to Rivers D (km)	Score
D < 1	10
1 < D < 2	9
2 < D < 3	8
3 < D < 4	7
4 < D < 5	6
5 < D < 7.5	5
7.5 < D < 10	4
10 < D < 15	3
15 < D < 20	2
20 < D	1

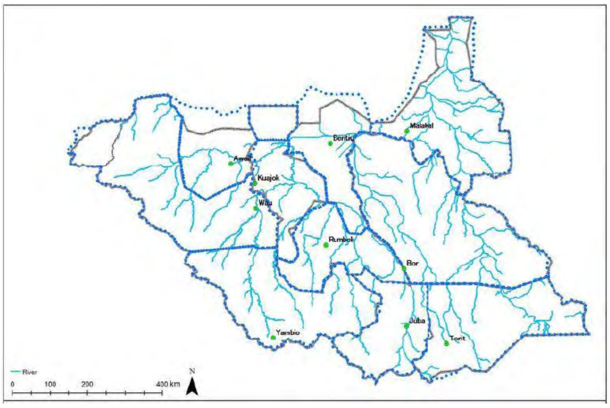


Figure 2.1.14 Created Map of River Accessibility

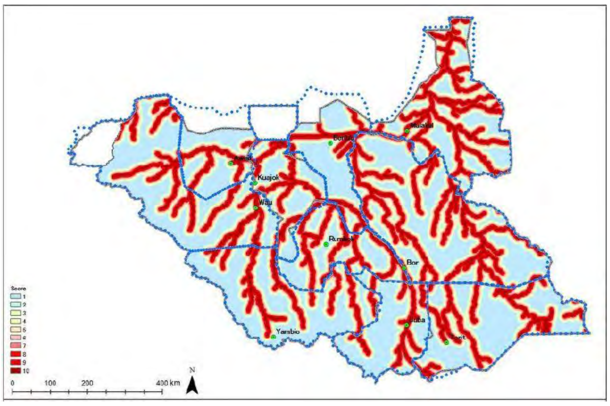


Figure 2.1.15 Scoring Map of River Accessibility

(7) Grazing area

Digital atlas produced by NBS in cooperation with former Ministry of Animal Resources and Fisheries (MARF) is used for mapping and analysis for grazing area, which are located around water bodies (rivers, lakes, streams, ponds, etc.) and are distributed in nationwide in RSS as shown in Figure 2.1.16.

Score "5" is given to grazing areas and "10" for others in consideration of the suitability for farming through discussions of IDMP-TTs with confirmation of former MARF as shown in Table 2.1.14. Scoring map is shown in Figure 2.1.17.

Table 2.1.14 Scoring of Grazing Layer

Class	Score
Grazing	5
Others	10

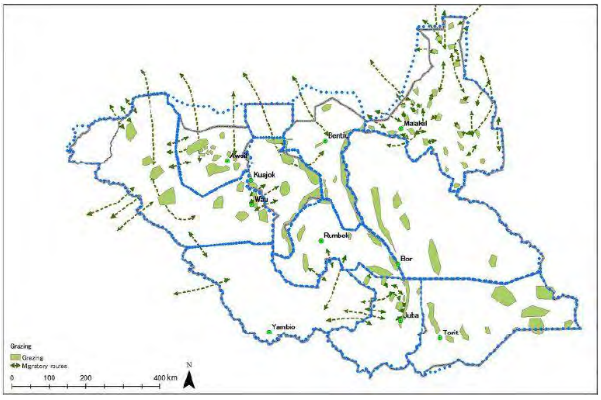


Figure 2.1.16 Created Map of Grazing Area

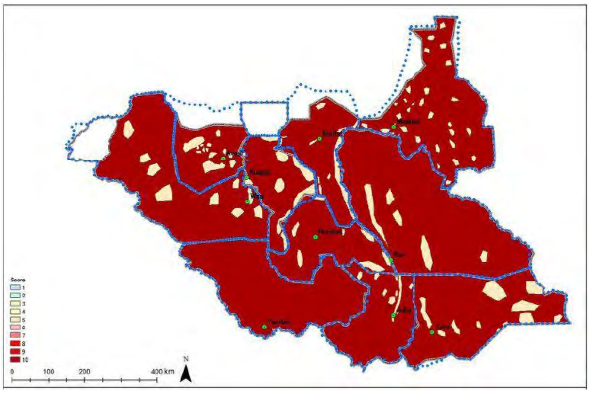


Figure 2.1.17 Scoring Map of Grazing Area

(8) Water bodies

The data of water bodies layer is collected from Digital atlas produced by NBS and FAO updated in 2004. In RSS water bodies are formed by lakes, swamps and basins providing through river water. Water bodies are mainly found in three (3) river basins: namely, 1) Bahr el Jebel Basin, 2) Bahr el Ghazal and 3) Sobat Basin out of four(4) of RSS referring to Figure 2.1.18.

Table 2.1.15 Scoring of Water Bodies Layer

Class	Score
Water Body Area	3
Others	10

For the scoring, "3" is given to the location of water bodies and "10" for others in consideration of possibility to be developed for agricultural land as shown in Table 2.1.15. Scoring map is shown in Figure 2.1.19.

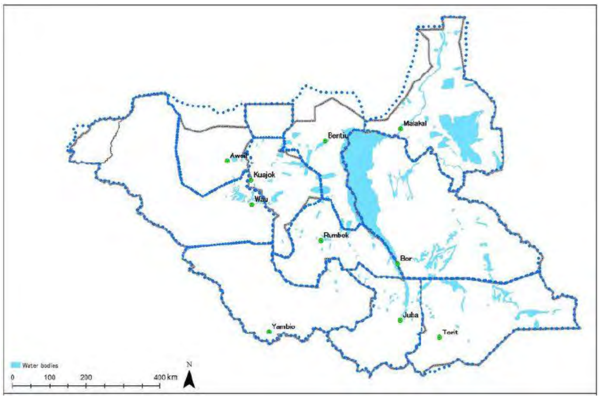


Figure 2.1.18 Created Map of Water Bodies

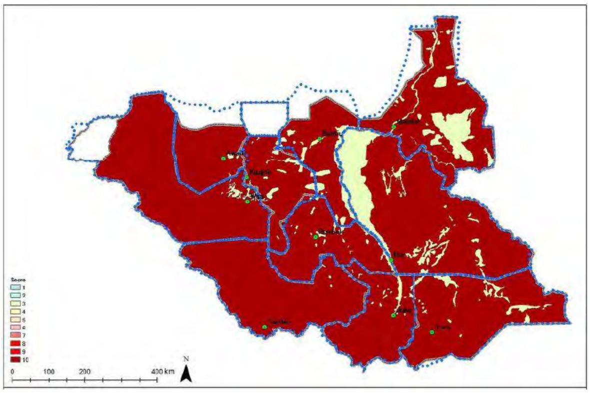


Figure 2.1.19 Scoring Map of Water Bodies

2.2 Weighting of Layers for the Land Productivity Potential Assessment

Eight (8) numbers of layer for the Land Productivity Potential Assessment defined at the section of "2.1 Scouring of Each Layer", in addition, two (2) layers: namely, ñTemperatureò and ñSoilò of which separately assessed for ñNon-riceò and ñRiceò respectively. 10 layers, then, in total were used for the assessment of the Land Productivity Potential. IDMP-TT members discussed and categorized them into two (2) by groups, i.e. Step-1 and Step-2 in the view point of impact to land and crop productivity with weighting rate 5:3 for the two (2) each steps as shown in Table 2.2.1.

1) Step-1: Direct impact in comparatively high to the land and crop productivity and
2) Step-2: Direct impact in comparatively low to the land and crop productivity.

Table 2.2.1 Weighting for Each Layer

	Group of Step-1 Weighting : 5	Group of Step-2 Weighting : 3	Step-3 (Socio-economic Potential)
Layers	1.Temperature for Non-rice	6. Land cover	**Refer to "3 Socio-economic Potential Assessment"**
	2.Temperature for Rice	7. Wetness	
	3.Slope	8. River accessibility	
	4.Soil for Non-rice	9. Grazing area	
	5.Soil for Rice	10.Water bodies	

Factors, which give impact to socio-economic features such as road accessibility, population, marketing, etc. are categorized into Step-3 based on the discussion among TT members, of which details are explained at the section of "3 Socio-economic Potential Assessment". Procedure of assessment is shown in Figure 2.2.1. Potentials of 1) Land Productivity and 2) Socio-economic will be combined after the evaluation of Step-1 and Step-2 as Step-5.

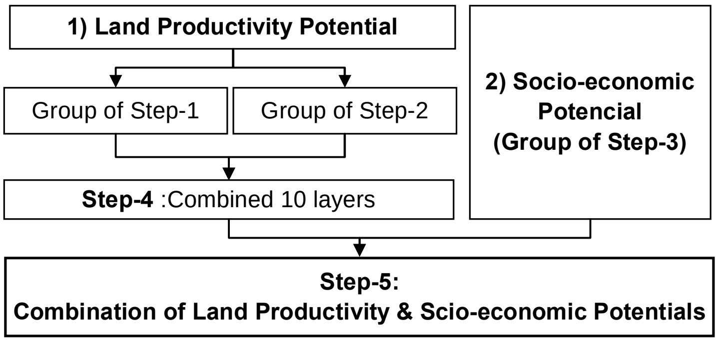


Figure 2.2.1 Procedure of Evaluation

2.3 Compilation of Layers

(1) Values of each step

Since each layer has been scored from 1 to 10 in maximum with the specified interval based on the evaluation, the groups of each Step-1 and Step-2 have 50 values in maximum and 400 values for Step-4, 650 values for Step-5 respectively, of which calculated as shown in Table 2.3.1.

Table 2.3.1 Compiled Values for Each Step

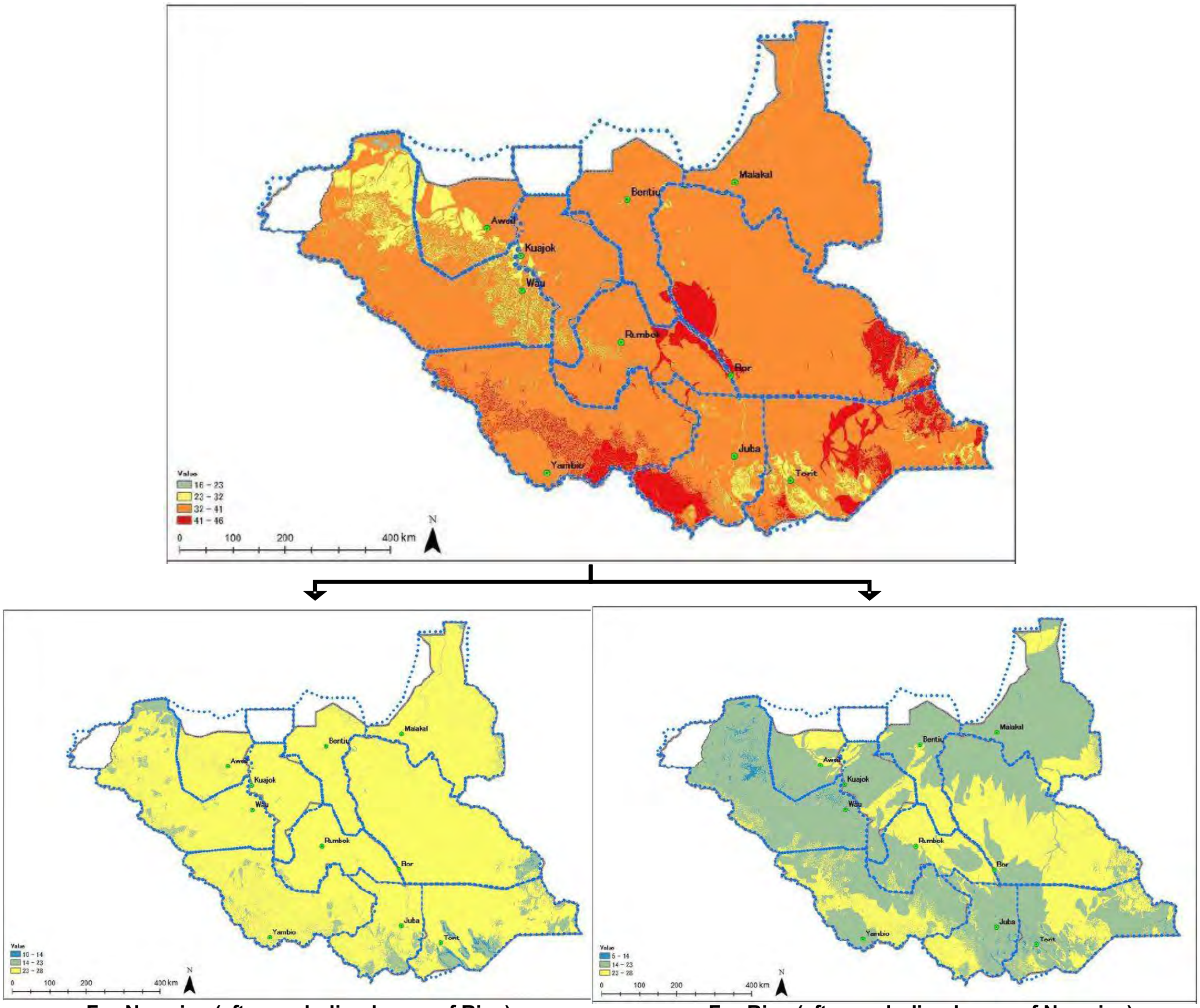
Group of each Step-1, 2 & 3	Step-4 (compiled by Step-1&2)	Step-5 (compiled by Step-1&2&3)
10 scores x 5 layers =50 values in maximum	10 scores x 5 layers x 5 weights +10 scores x 5 layers x 3 weights =400 values in maximum	10 scores x 5 layers x 5 weights +10 scores x 5 layers x 3 weights +10 scores x 5 layers x 5 weight =650 values in maximum

(2) Assessment of each step

1) Step-1 (Impact in comparative high to the land and crop productivity)

Figure 2.3.1 shows potential maps of Step-1 group which are overlaid by ñ1&2.Temperature (for Rice and Non-rice)ò, ñ3.Slopeò and ñ4&5.Soil (for Rice and Non-rice)ò layers as referred to Table 2.2.1. Level of potential indicates high in red, medium in yellow and low in blue colours with dark to light. Since the above figure of the Figure 2.3.1 duplicated two (2) evaluations of layers for ñNon-riceò and ñRiceò, then, below two (2) figures show potentials for ñNon-riceò and ñRiceò respectively. For instance, evaluation for Non-riceò shows after excluding layers of ñ2.Temperature for Riceò and ñ5.Soil for Riceò.

Step-1: Land Productivity Potential Map



For Non-rice (after excluding layers of Rice) **For Rice (after excluding layers of Non-rice)**

Figure 2.3.1 Potential Maps of Step-1 Group

2) Step-2 (Impact in comparative low to the land and crop productivity)

Figure 2.3.2 shows result of the assessment for Step-2 group by overlaying of ñ6.Land coverò, ñ7.Wetnessò, ñ8.River accessibilityò, 9.Grazing areaò and ñ10.Water bodiesò layers.

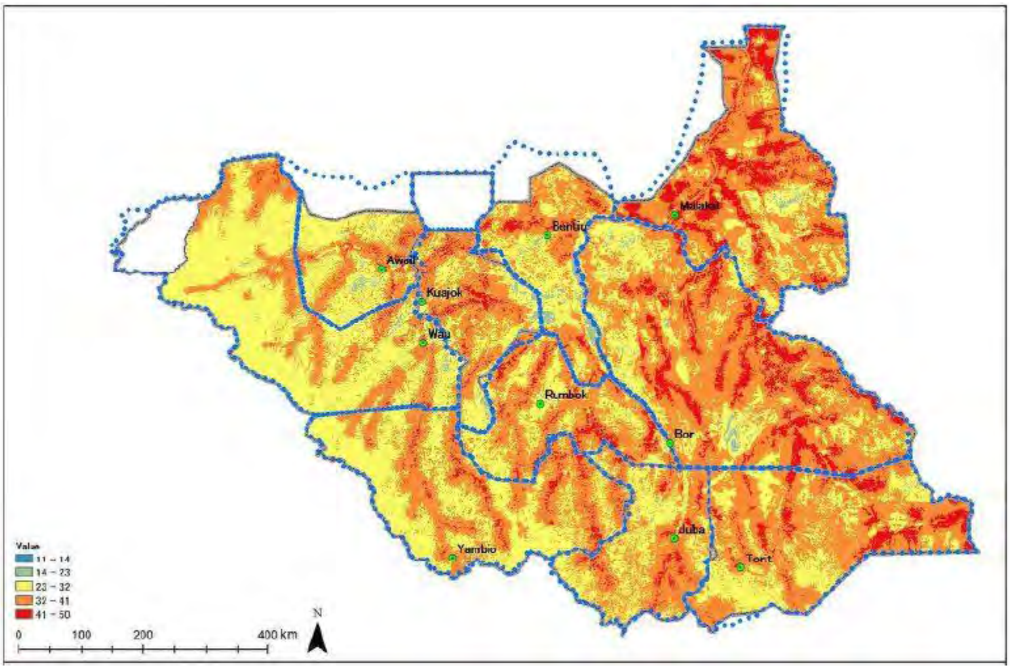
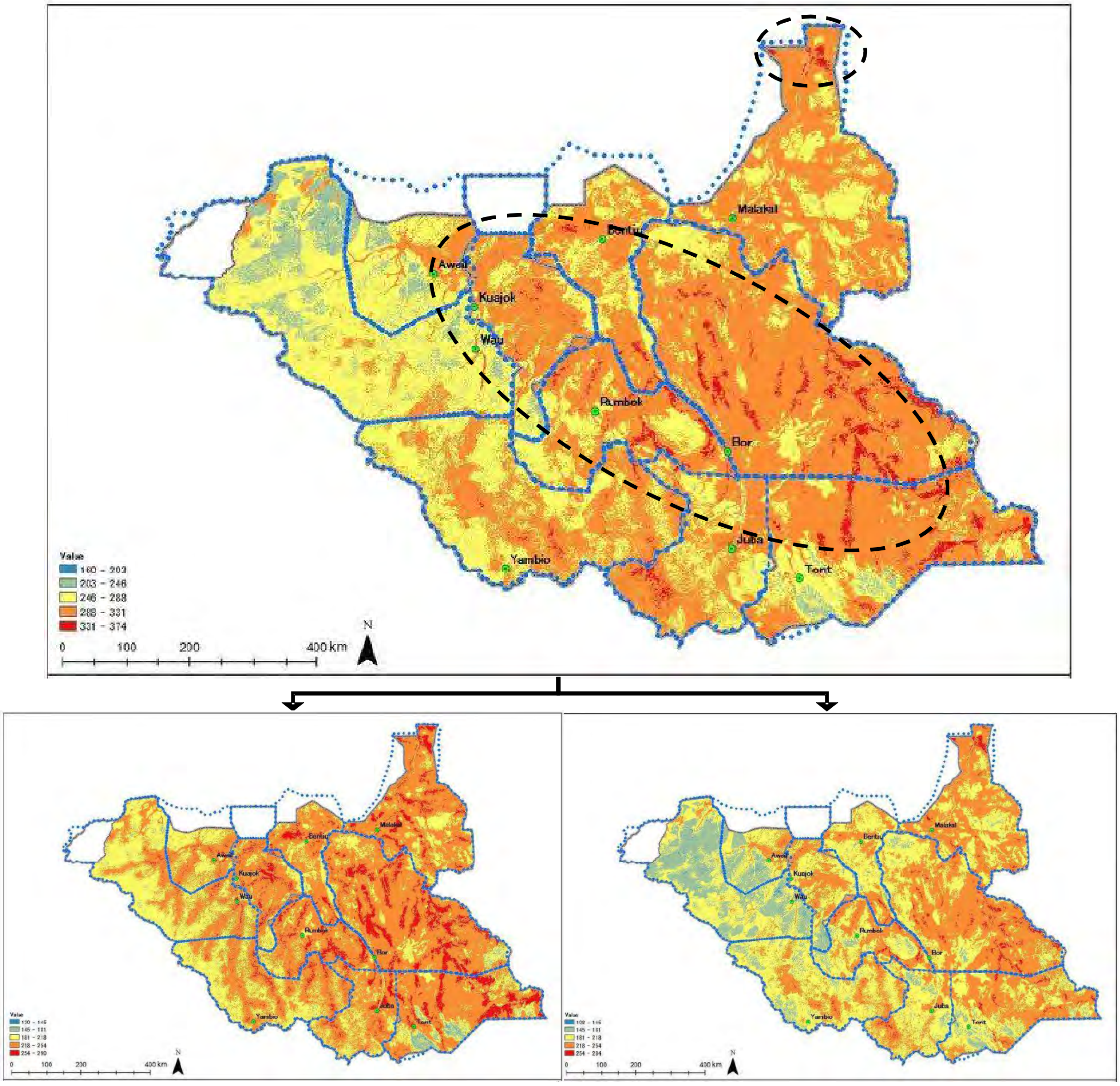


Figure 2.3.2 Assessment of Step-2 Group

3) Step-4: Land Productivity Potential Map (Combined Step-1 and Step-2 groups)

Step-4 combined groups of Step-1 and Step-2 without adding the Step-3 group for socio-economic potential assessment, is the actual result of the Land Productivity Potential assessment. Figure 2.3.3 indicates that extends of light red with dotted dark red are high potential area for the land productivity (marked by dotted in black circle), which are located in Jonglei and Lakes states and parts of Central Equatoria, Warrap, Unity and Bahar el Ghazal states, and Renk county in Upper Nile state. Also, the below two (2) Figures show the evaluation for ñNon-riceò and ñRiceò respectively.

Step-4: Land Productivity Potential Map



For Non-rice (after excluding layers of Rice) **For Rice (after excluding layers of Non-rice)**

Figure 2.3.3 Assessment of Step-4

3. SOCIO-ECONOMIC POTENTIAL ASSESSMENT

3.1 Methodology

Eight (8) layers shown in Table 3.1.1 for Socio-economic Potential are examined for the assessment through discussions of IDMP-TT members. Out of 8, two (2) layers of "7.Cerial harvested area" and "8.Poverty headcount rate" were excluded for the assessment since data for those layers has not shown reality due that available data covers only state, not county level.

Table 3.1.1 Layers for Socio-economic Potential Assessment

	Layer	Source	Remarks
1	Road accessibility	Transport overview map - assessed and unassesed roads produced by WFP	Updated in May, 2013
2	Population density	Population data produced by NBS	Updated in 2013
3	Protected area	Digital Atlas produced by NBS, International Resource Group, Digitized by CRMA / Wildlife Research Centre Remote Sensing Authority	Map scale: 1/1,200,000, Updated in 2007
4	Oil and gas concessions	Digital Atlas produced by NBS, ECOS	Updated in 2007
5	Market / State Capital Advantage (SCA)	Digital Atlas produced by NBS	Created from the state capital data
6	County Capital Advantage (CCA)	Digital Atlas produced by NBS	Location confirmed from the topographic map
7	Cereal harvest area	FAO/WFP Crop and Food Security Assessment Mission to South Sudan, 22 February 2013	Not used
8	Poverty headcount rate	A Poverty Profile for the southern state of Sudan by WB, March 2011	Not used

WFP: United Nations World Food Programme
NBS: National Bureau of Statics
CRMA: Crisis and Recovery Mapping and Analysis
ECOS: European Coalition on Oil in Sudan

Also, layers of "5.Market /State Capital Advantage (SCA)" and "6.County Capital Advantage (CCA)" shown the above Table were combined one(1) layer while accessibility to market facilities and capital advantage are evaluated as same valuation, of which details are shown in clause "(5) Market, SCA and CCA".

3.2 Scoring of Each Layer

(1) Road accessibility

Transport overview map was obtained by Ministry of Roads and Bridges (MRB). It is originally produced by WFP and updated in May 2013. The roads in RSS are classified into four (4) classes. Three (3) classes out of 4: namely, 1) primary road, 2) secondary road and 3) tertiary road are taken for the assessment of road accessibility. Classification of 4) track and local/urban roads is neglected for the assessment. Distance from the particular place has scored by 10 km interval each as shown in Table 3.2.1. Also, road classification specified its importance is considered as weighting 10:7:5 for three (3) classes as shown in Table 3.2.2.

Table 3.2.1 Scoring of Road Accessibility Layer

Distance to Roads D (km)	Score
D < 10	10
10 < D < 20	9
20 < D < 30	8
30 < D < 40	7
40 < D < 50	6
50 < D < 60	5
60 < D < 70	4
70 < D < 80	3
80 < D < 90	2
90 < D	1

Table 3.2.2 Classification of Road

Road Class	Definition	Specification	Weight
1) Primary	International road, and roads connecting capital to capital between states	4 lanes with 3.5m width (approx. 15m), Asphalt pavement	10
2) Secondary	Road to state capital with in state	4 lanes with 3.5m width (approx. 15m), Gravel pavement	7
3) Tertiary	Road to state within county	2 lanes with 3.5m width (approx. 8m), Unpaved road	5
4) Track, Local /Urban	Mainly used for agricultural production	No particular specification	neglect

Figure 3.2.1 and Figure 3.2.2 show created map and scoring map respectively.

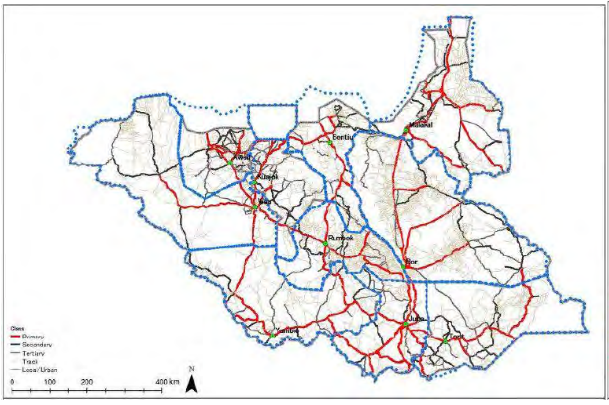


Figure 3.2.1 Created Map of Road Accessibility

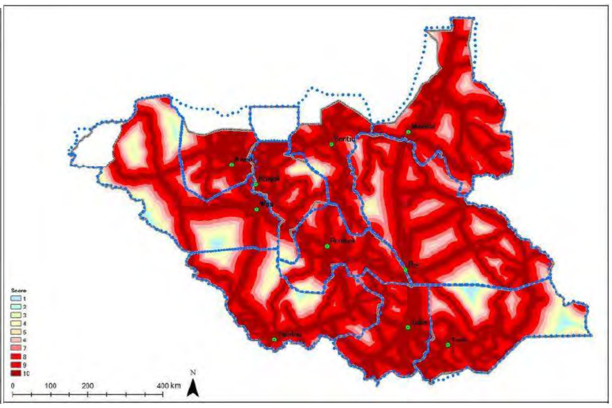


Figure 3.2.2 Scoring Map of Road Accessibility

(2) Population Density (PD)

Estimate of population is produced by NBS to collect information through countryôs statistical office. The census provides the most reliable picture of a country's population since the data is collected at a specified time from the entire population in contrast to other surveys. When annual estimation is required, the population is updated by adding numbers of birth with subtracting death and adding net international migration. In the Study, the latest version of digital atlas produced by NBS based on the National Census 2008 is used for mapping and analysis.

Table 3.2.3 Scoring of Population Density Layer

Population Density P (head/sq.km)	Score
PD < 3	1
3 < PD < 10	2
10 < PD < 20	3
20 < PD < 50	4
50 < PD < 100	5
100 < PD < 200	6
200 < PD < 500	7
500 < PD < 1,000	8
1,000 < PD < 2,000	9
2,000 < PD	10

The latest record of total population of RSS is 10.8 million in 2012, which has increased more than 250% from 3.0 million in 1960. Population density map shown in Figure 3.2.3 indicates that Malakal county of Upper Nile State is highest in RSS, and Morobo and Kajo-keji counties of Central Equatoria state are ranked next.

Scoring is based on the idea that area of high population density has higher food/agricultural demand, as shown in Table 3.2.3 And Figure 3.2.4 shows scoring map of population density.

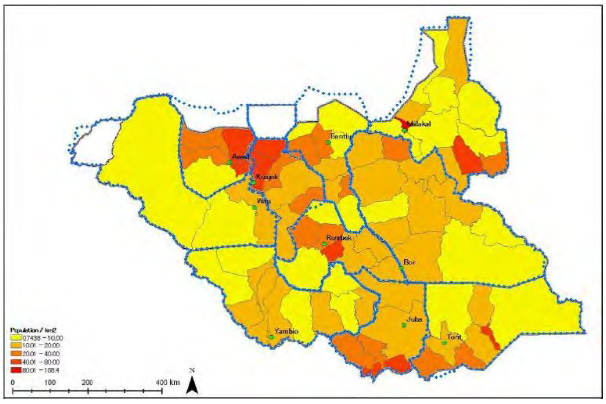


Figure 3.2.3 Created Map of Population Density

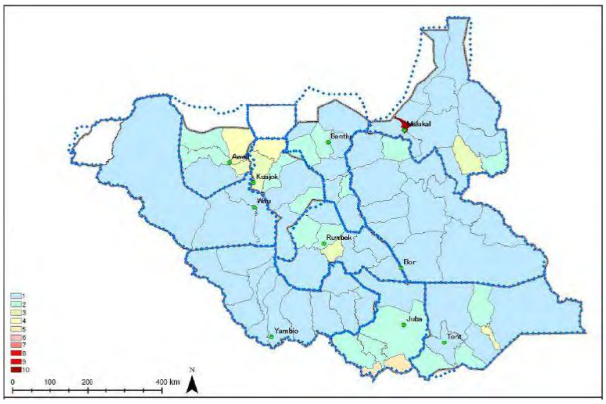


Figure 3.2.4 Scoring Map of Population Density

(3) Protected area

The sources of the information of protected area such as National Park, Game Reserve and Ramsar Convention area are from digital atlas produced by NBS, digitized by Crisis and Recovery Mapping and Analysis (CRMA) / Wildlife Research Centre Remote Sensing Authority. Locations of protected areas were modified according to information through the meeting with 1) Director for Research and Monitoring and 2) Director of Planning and Budgeting, former Ministry of Wildlife Conservation and Tourism (MWCT) in Juba through a series of discussions with IDMP-TT members.

The protected area is classified into three (3) areas/sites as shown in Table 3.2.4 and Figure 3.2.5.

Table 3.2.4 Classification of Protected Area

Protected Area	Name	State
National Park	Southern National Park	Western Equatoria, Warrap, Lakes
	Nimule National Park	Eastern Equatoria
	Boma National Park	Jonglei, Eastern Equatoria
	Lantoto National Park	Central Equatoria
	Shambe National Park	Lakes
	Bandigilo National Park	Eastern Equatoria, Central Equatoria
Game Reserve	Zeraf Game Reserve	Jonglei
	Fanyikang Game Reserve	Upper Nile
	Juba Game Reserve	Central Equatoria
	Bire Kapatuos Game Reserve	Western Equatoria
	Game Reserve	Western Equatoria
	Bangangai Game Reserve	Western Equatoria
	Kidepo Game Reserve	Eastern Equatoria
	Chelkou Game Reserve	Northern Bahr el Ghazal
	Ashana Game Reserve	Northern Bahr el Ghazal
	Numatina Game Reserve	Western Bahr el Ghazal
	Mesha Game Reserve	Warrap, Unity, Lakes
	Boro Game Reserve	Western Bahr el Ghazal
Ramsar Convention Area	Ramsar Area	Upper Nile, Jonglei, Unity, Lakes

Scoring for protected area layer is based on the suitability for agricultural land development and farming as shown in Table 3.2.5, which were agreed by MWCT who administrate National Park and Game Reserve and Ministry of Environment (MED) which has jurisdiction Ramsar convention area. In addition, it was agreed that national parks should be

Table 3.2.5 Scoring of Protected Area Layer

Class	Score
National Park	-
Game Reserve	1
Ramsar Area	2
Others	10

excluded from area for irrigation development with request for natural conservation policy.

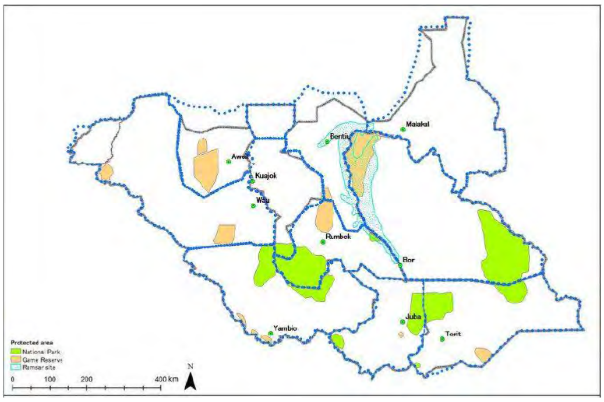


Figure 3.2.5 Created Map of Protected Area

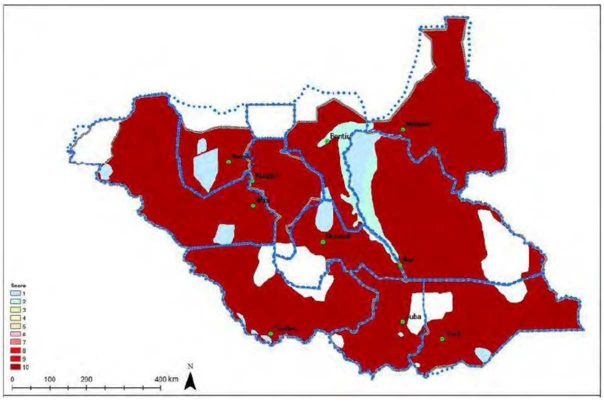


Figure 3.2.6 Scoring Map of Protected Area

(4) Oil & gas concessions

Digital atlas produced by NBS and European Coalition on Oil in Sudan (ECOS) is adopted as data source for mapping and analysis. Two (2) rift basins are distributed in the country with around 100 km width as shown in Figure 3.2.7. One is located at north to central of the country through Northern Bhar el Ghazal, Warrap, Unity, Lakes, Jonglei, Central Equatoria and Eastern Equatoria states. The other one is located through Upper Nile to Jonglei states along with boundary of Ethiopia.

Table 3.2.6 Scoring of Oil & Gas Concession Layer

Class	Score
Rift basin	8
Concession area	9
Others	10

Oil & gas concession areas cover all of Unity State and part of Northern Bahr el Ghazal, Warrap, Lakes, Jonglei, Upper Nile, Central Equatoria and Eastern Equatoria State, and those areas reach to most of half of the country as shown in Figure 3.2.7.

Scoring of for layer is based on the suitability for agricultural land development referring to the comments of Ministry of Petroleum and Mining as shown in Table 3.2.6 and Figure 3.2.7.

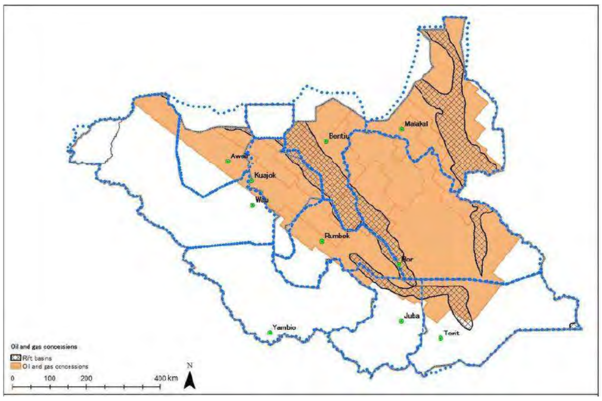


Figure 3.2.7 Created Map of Oil & Gas Concessions

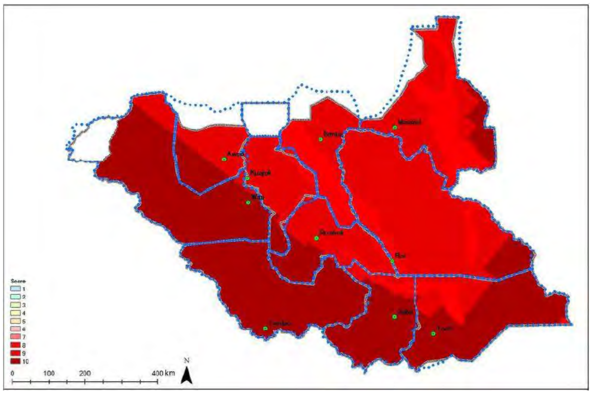


Figure 3.2.8 Scoring Map of Oil & Gas Concessions

(5) Market, State Capital Advantage (SCA) and County Capital Advantage (CCA)

Table 3.2.7 Scoring of CCA

Distance to County Capital (km)	Score
D < 25	3
25 < D	1

Major market facilities give an advantage to particular areas located near by State Capitals for encouraging agricultural production under irrigation development. However, this factor seems to be duplicated with layer of population density. In this point of view, IDMP-TTs decided to extend target until county level not only states, named "layer of County Capital Advantage (CCA)", of which administrative offices have the agricultural information including of input, marketing, extension services and so on. Locations of 79 counties are found from 1/50,000 topographic maps and digitized on the layer shown in Figure 3.2.9. And score is given "3" within 25 km of county capitals as shown in Table 3.2.7 and Figure 3.2.10.

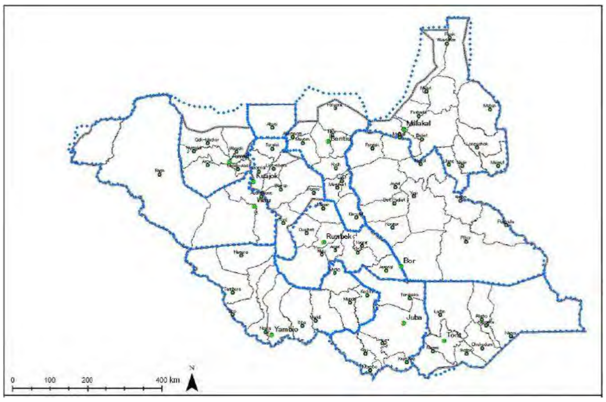


Figure 3.2.9 Created Map of CCA

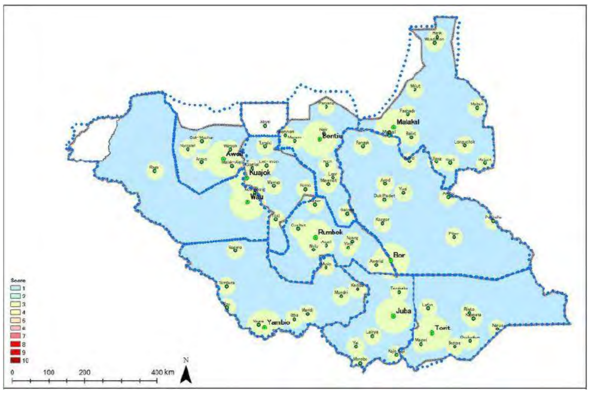


Figure 3.2.10 Scoring Map of CCA

3.3 Compilation of Layers (Step-3) for Socio-economic Potential Assessment

Figure 3.3.1 shows potential map of Step-3 group overlaid by "1) Road accessibility", "2) Population density", "3) Protected area", "4) Oil & gas concessions" and "5) County Capital Advantage (CCA)". Level of potential indicates high in red, medium in yellow and low in blue colours with dark to light.

The map makes national parks in blank (white colour inside of the national land) with "0" score where development is strictly prohibited in future. And most of lower potential areas described by blue and/or light yellow are located within game reserves and Ramsar convention area.

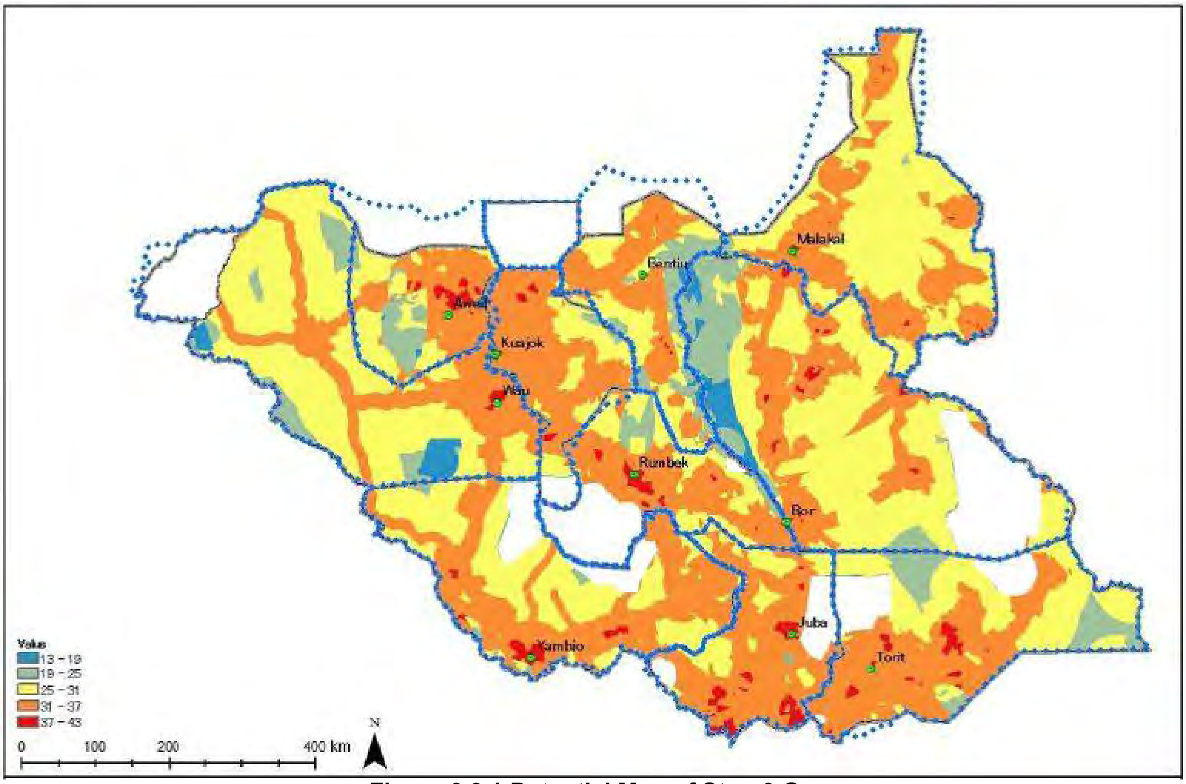


Figure 3.3.1 Potential Map of Step-3 Group

3.4 Assessment after Combination of Land Productivity and Socio-economic Potentials

(1) Step-5: combination of groups of Step-1, Step-2 and Step-3

Land Productivity Potential map (i.e. Step-4) is overlaid with Step-3 group as Step-5 shown in Figure 3.4.1. It gives clearer identification of the high potential areas marked by dotted black circle in comparison with the map of Step-4 (Land Productivity Potential Map). The map shows that high potential areas mostly cover nine (9) cities: namely, Juba, Rumbek Wau, Kuajok, Aweil, Yambio, Torit, Bor and Malakal.

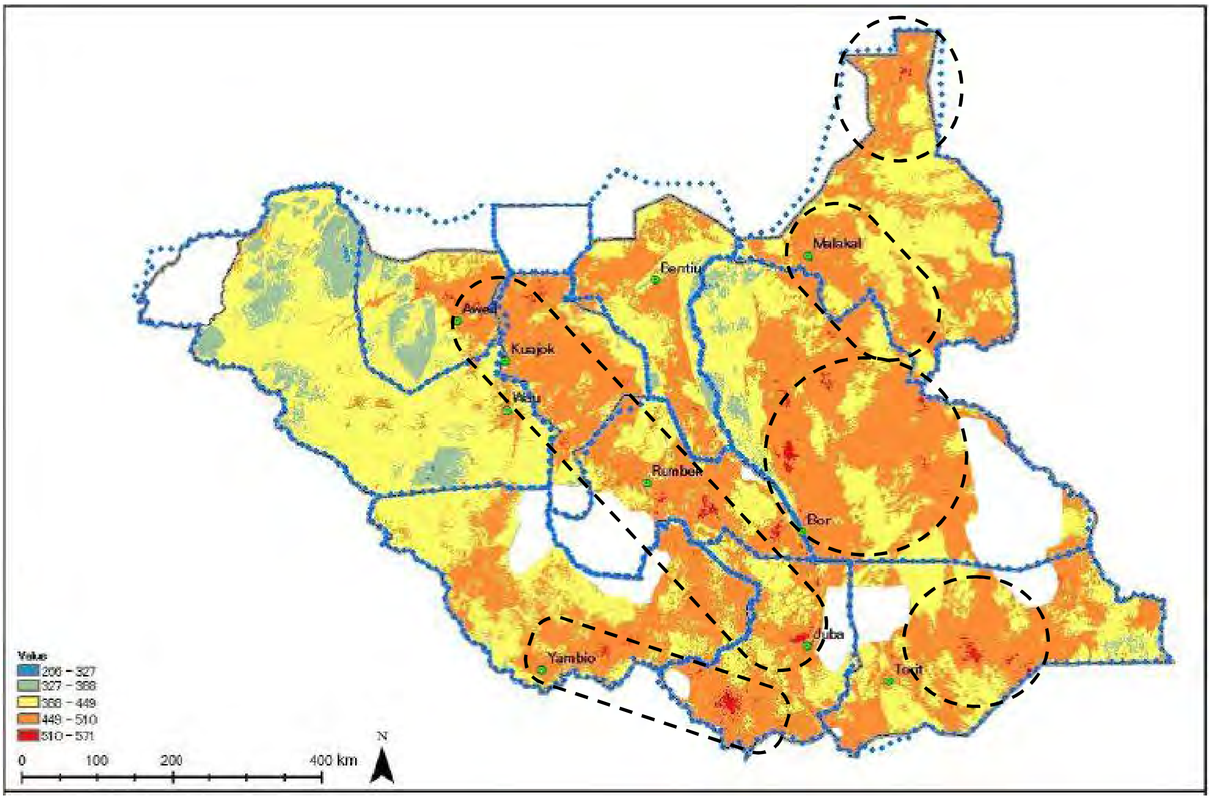


Figure 3.4.1 Step-5 Land Productivity with Socio-economic Potential Assessments

(2) Toward selection of high resolution areas for the detailed assessment

Irrigation development potential assessment is composed of 1) Land Productivity, 2) Socio-economic and 3) Water Resources potentials of which flow shown in Figure 3.4.2, and it will be categorized zoning for irrigation development including selection of prioritized areas for high resolution assessment.

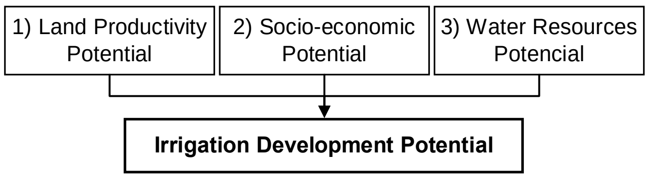


Figure 3.4.2 Flow of Irrigation Development Potential

Furthermore, the purpose of focusing on higher potential areas, the potential map of Step-5 (Figure 3.4.1) was adjusted visually that higher potential area by showing dark red colour becomes 15% of the country. High resolution area for detailed assessment, then, was selected by contrasting with water resources potential assessment to be described in the following sections in this report.

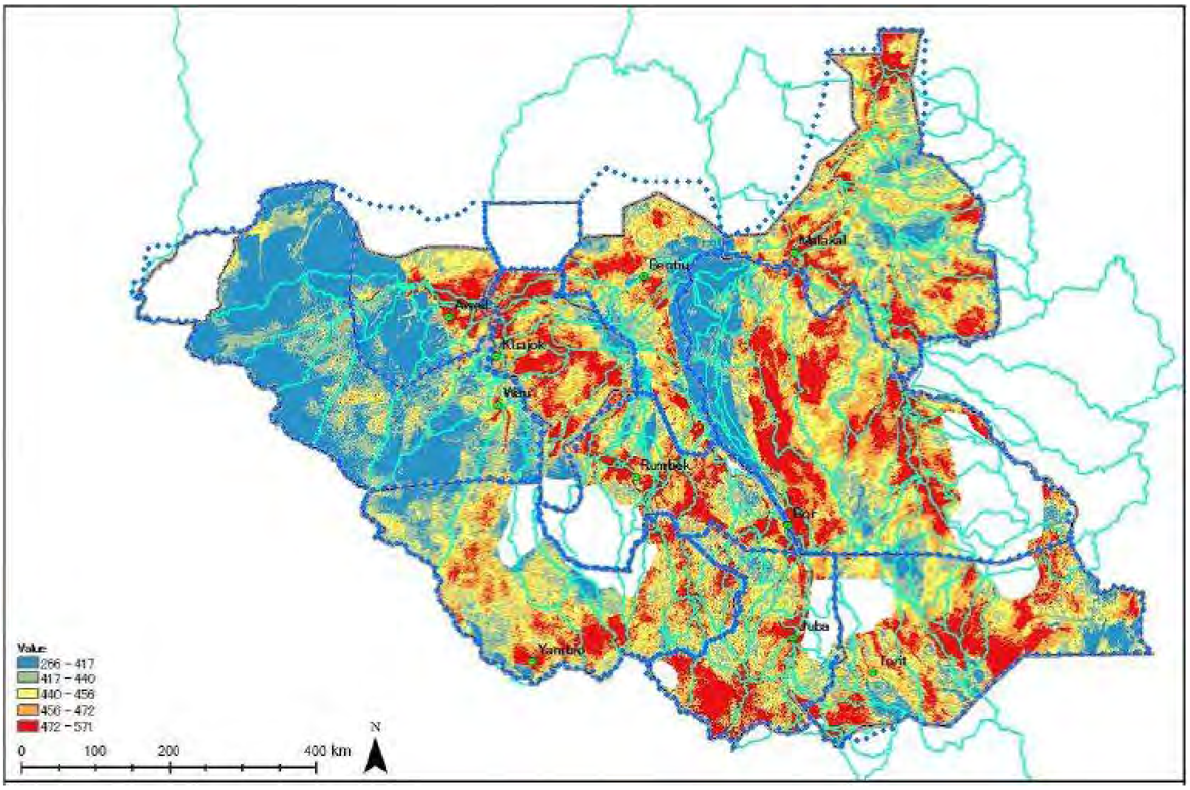


Figure 3.4.3: 15% of National Land of High Potential Area (Land Productivity & Socio-economic Potential)

4. WATER RESOURCE POTENTIAL ASSESSMENT

4.1 Rainfall Analysis

(1) Selection of target stations

Amount in average of monthly rainfall for last 30 years is adopted as present potential.

Rainfall observation stations to be targeted for analysis are selected within and out of RSS respectively as shown in Figure 4.1.1.

a) 34 stations locating within the RSS are selected by following manner:

i) To exclude stations of which available data is comparatively older and having only short period; and

ii) To adopt stations of which available data is comparatively newer and having longer period, if plural number of stations are located nearby.

b) 20 stations locating out of the RSS are selected by following manner:

iii) To adopt stations of which available data is comparatively and longer; and

iv) To adopt stations which are located near the border of the RSS.

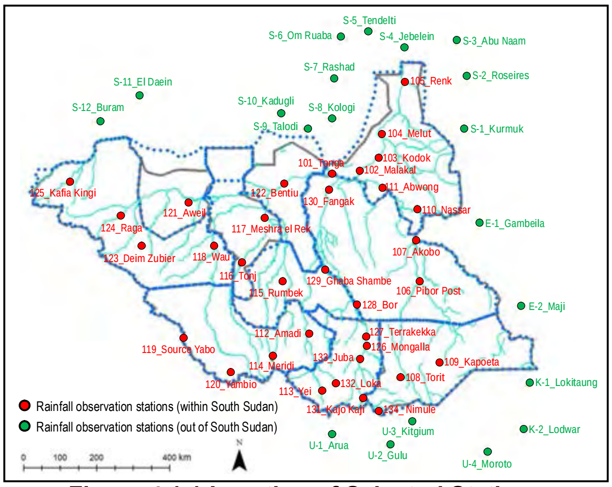


Figure 4.1.1 Location of Selected Stations

(2) Estimation of rainfall amount in average for last 30 years

Observed data collected from the several organizations were compiled for the rainfall analysis. However, due to the civil war occurred in Sudan in 1980ѕ, observation at most of the stations stopped in those periods. Stations having data for the last 30 years are only 6 stations (Malakal, Renk, Wau, Aweil, Raga and Juba). Therefore, monthly rainfall amount in average for last 30 years of the other stations are estimated by using "Normal Ratio Method". Figure 4.1.2 shows contour maps of annual rainfall amount.

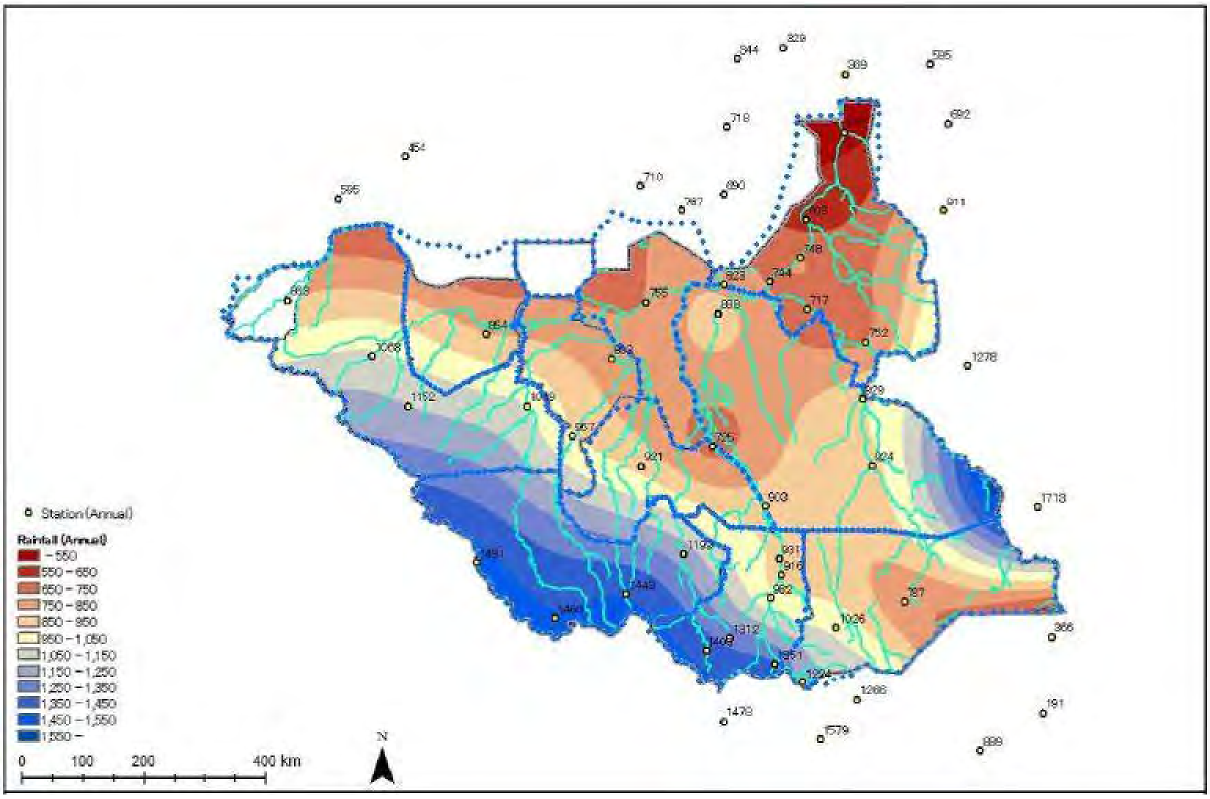


Figure 4.1.2 Rainfall Amount Contour Map (Annual)

Following trends in the country are found from the contour maps:

i) Annual rainfall decreases from south-west to north-east, however, Sudd area does not follow this trend by showing a bit higher amount; and

ii) Fewer amount of rainfall is occurring in south-east area.

And based on the results of analysis, the country can be divided into three(3) major zones which are classified by rainfall amount and moisture regimes.

i) High rainfall zone: at south-west part of the country and also far south-east and Kapoeta Hills

Most of this zone is located at Green Belt (AEZ classification) with 1,500 mm/year of rainfall. Rainfall pattern is highly variable.

ii) Medium rainfall zone: at middle part of the country, and east and west parts

The rainfall amount extends 500 to 1,000 mm/year.

iii) Low rainfall zone: at north-east part of the country

Rainfall is generally less than 500 mm/year. Rainfall pattern is highly variable.

The pattern of rainfall distribution makes the major three (3) seasons in the year: 1) dry, 2) pre-wet and pre-dry and 3)wet seasons. The dry season takes place for around 3 months (December, January and February) with range of monthly rainfall from 0 to 100 mm. The pre-dry and pre-wet seasons dominate in March, April, May, October and November with range of 100 to 250 mm. The wet season occurs on the month of June, July, August and September with monthly rainfall amount above 250 mm.

4.2 River Discharge Analysis

(1) Objectives

River discharge analysis is carried out aiming to estimate average amount of annual specific yield (SY) for last the 30 years at each catchment area as present surface water resources potential.

(2) Data availability

For calculating SY, river discharge (Q) data is essential. Table 4.2.1 shows data source and frequency of observation each data, etc.

Table 4.2.1 Source of River Discharge Data

Source	Item	Frequency	Feature	Remarks
The Nile Basin	Discharge	10 days mean and Monthly	Books published each 5 year by Egyptian Government	
	Discharge Gauge Reading	Daily		
	Gauge Reading	10 days and monthly mean		
Nile DST*	Discharge	10 days mean and Monthly	Arranged data by Nile Basin Initiative (NBI)	
Directorate of water and sanitation WBG state	Discharge Gauge Reading	Daily		Rivers located within Bahr el Ghazal Basin
	Gauge Reading			
MEDIWR	Discharge Gauge Reading	Daily		Juba and Mongalla only
Egyptian Irrigation Office in Malakal	Discharge Gauge Reading	Daily		Malakal, Melut and Hillet Doleib only

*) DST: Decision Support Tool

1) Selection of target river discharge stations

Stations to be targeted are selected by the following conditions. After the examination of all data by each station, 71 stations out of 193, are selected for the analysis.

- ➢ Location of observation station is clearly identified.
- ➢ Area of catchment is not extremely small.

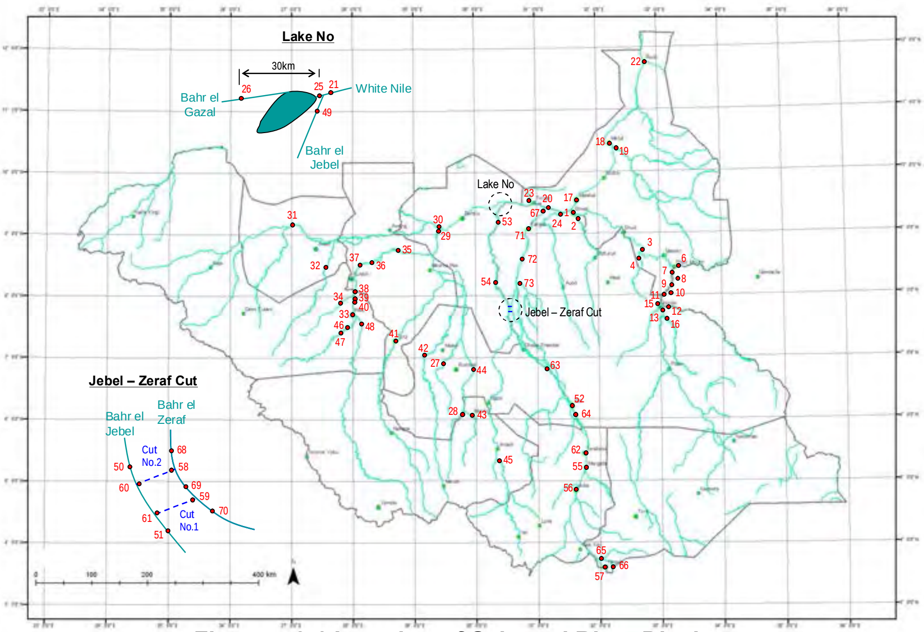
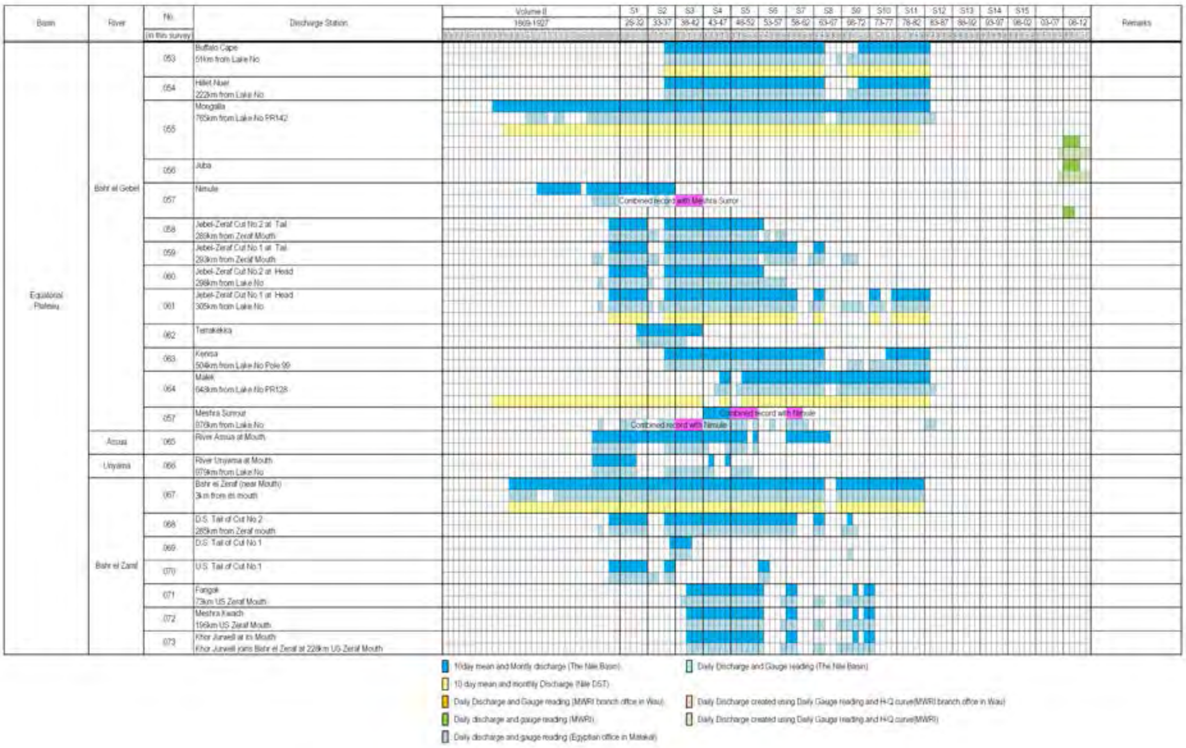


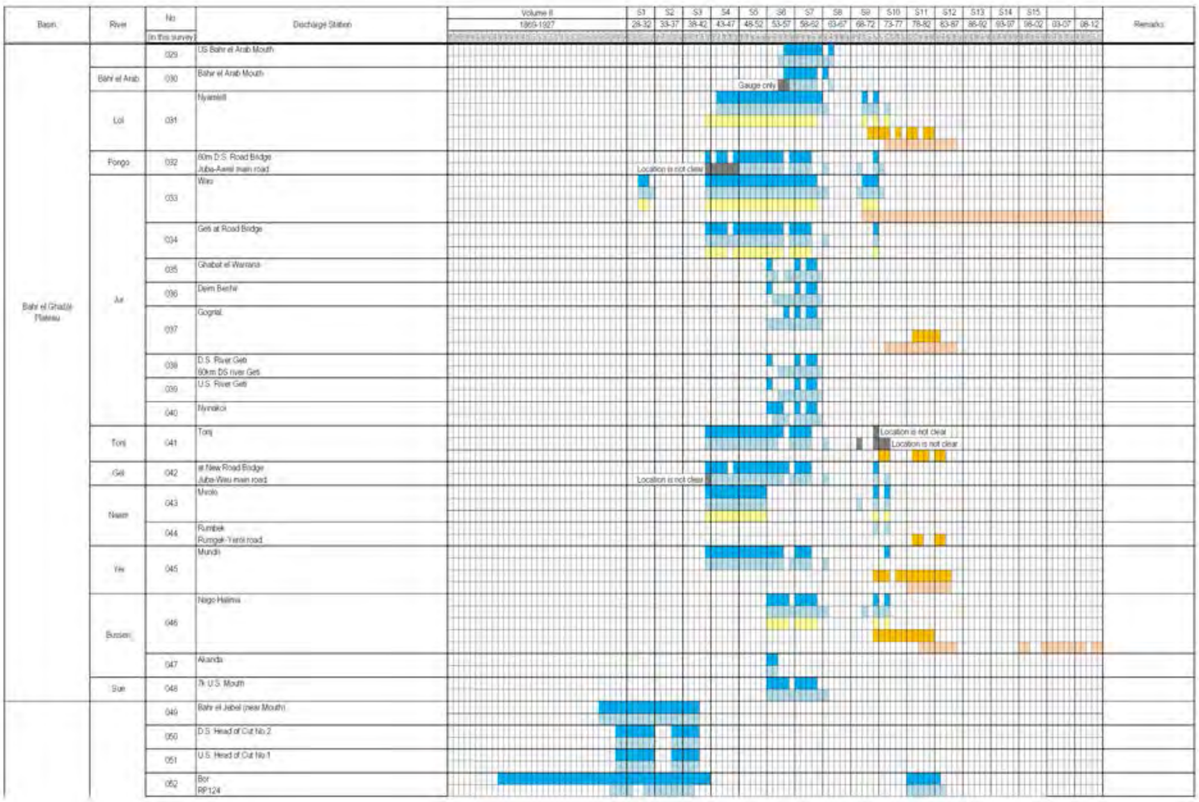
Figure 4.2.1 Location of Selected River Discharge Measurement Stations

Location of selected stations and period of available data are shown in Figure 4.2.1 and Table 4.2.2 respectively. Due to the shortage by the same reason for rainfall, discharge station of which period is more than for the 30 years, is available in Malakal only.

Table 4.2.2 Data Available Period

Basin	River	No. (in this survey)	Discharge Station	Volume II 1869-1927, S1 28-32, S2 33-37, S3 38-42, S4 43-47, S5 48-52, S6 53-57, S7 58-62, S8 63-67, S9 68-72, S10 73-77, S11 78-82, S12 83-87, S13 88-92, S14 93-97, S15 98-02, 03-07, 08-12	Remarks
Ethiopian Plateau	Sobat	001	Hillet Doleib 9km from its Sobat mouth		
		002	Khor Fullus at its mouth 15km from the mouth of river sobat		
		003	D.S. Khor Nyanding 2km D.S. Khor Nhyanding Mouth		
		004	Nyanding Mouth 239km from mouth of river Sobat		
	Baro	006	US the Baro-pipor Junction (River Baro Mouth)		
		024	Khor Attar at Mouth Khor Attar joins the White Nile 108km from Lake No "the same as 105		
	Pibor	007	US the Baro-pipor Junction		
		008	Khor Makwai at its Mouth 366km from the mouth of river Sobat		
		009	U.S. Khor Makwai 369km from the mouth of river Sobat		
		010	Gila at Mouth 401km from the mouth of river Sobat		
		011	U.S. River Gila 401km from the mouth of river Sobat		
		012	Akobo at Mouth 465km from the mouth of river Sobat		
		013	U.S. River Akobo 8km US the mouth of river Akobo, 471km from the mouth of river Sobat		
		015	Khor Geni at its Mouth		
		016	River Agwei at its Mouth		
	White Nile	017	Malakal 811km from junction of the Blue and White Nile		
		018	Melut 669km US junction of Blue and White Nile		
		019	Khor Adar 12km US Melut, 1.54km US its Mouth	Gauge only	
		020	Abu tong 6km US of the Mouth of Bahr el Zeraf		
		021	Lake No 957km from the junction of the Blue and White Nile		
		022	Renk		
		023	Tonga at Mouth Tonga cut joins the White Nile in its left bank at 62km from Lake No		
		024	Khor Attar Tail "the same as 063		
	Bahr el Ghazal	025	Bahr el Ghazal at Mouth		
		025	Exit from Lake No		
		026	D.S. Khor Doleib 29km from Ghazal mouth		
		027	River Gulmar at New Road B Juba-Wau main road		
		028	River Wokko at Road Bridge	Gauge only	


Basin
River
No.
(in this survey)
Discharge Station
Volume II
1869-1927
S1 S2 S3 S4 S5 S6 S7 S8 S9 S10 S11 S12 S13 S14 S15
28-32 33-37 38-42 43-47 48-52 53-57 58-62 63-67 68-72 73-77 78-82 83-87 88-92 93-97 98-02 03-07 08-12
Remarks
Equatorial Plateau
Bahr el Gebel
053 Buffalo Cape 51km from Lake No
054 Hillet Nuer 222km from Lake No
055 Mongalla 765km from Lake No PR142
056 Juba
057 Nimule
Combined record with Meshra Surror
058 Jebel-Zeraf Cut No.2 at Tail 289km from Zeraf Mouth
059 Jebel-Zeraf Cut No.1 at Tail 293km from Zeraf Mouth
060 Jebel-Zeraf Cut No.2 at Head 298km from Lake No
061 Jebel-Zeraf Cut No.1 at Head 305km from Lake No
062 Terrakekka
063 Kenisa 504km from Lake No Pole 99
064 Malek 643km from Lake No PR128
057 Meshra Surrour 876km from Lake No
Combined record with Nimule
Assua
065 River Assua at Mouth
Unyama
066 River Unyama at Mouth 879km from Lake No
Bahr el Zeraf
067 Bahr el Zeraf (near Mouth) 3km from its mouth
068 D.S. Tail of Cut No.2 285km from Zeraf mouth
069 D.S. Tail of Cut No.1
070 U.S. Tail of Cut No.1
071 Fangak 73km US Zeraf Mouth
072 Meshra Kwach 196km US Zeraf Mouth
073 Khor Jurwell at its Mouth
Khor Jurwell joins Bahr el Zeraf at 228km US Zeraf Mouth
10day mean and Montly discharge (The Nile Basin)
10 day mean and monthly Discharge (Nile DST)
Daily Discharge and Gauge reading (MWRI branch office in Wau)
Daily discharge and gauge reading (MWRI)
Daily discharge and gauge reading (Egyptian office in Malakal)
Daily Discharge and Gauge reading (The Nile Basin)
Daily Discharge created using Daily Gauge reading and H-Q curve(MWRI branch office in Wau)
Daily Discharge created using Daily Gauge reading and H-Q curve(MWRI)


Basin
River
No.
(in this survey)
Discharge Station
Volume II
1869-1927
S1 S2 S3 S4 S5 S6 S7 S8 S9 S10 S11 S12 S13 S14 S15
28-32 33-37 38-42 43-47 48-52 53-57 58-62 63-67 68-72 73-77 78-82 83-87 88-92 93-97 98-02 03-07 08-12
Remarks
Bahr el Ghazal Plateau
029 US Bahr el Arab Mouth
Bahr el Arab
030 Bahr el Arab Mouth
Gauge only
Lol
031 Nyamlell
Fongo
032 60m D.S. Road Bridge Juba-Aweil main road
Location is not clear
Jur
033 Wau
034 Geti at Road Bridge
035 Ghabat el Warrana
036 Deim Beshir
037 Gogrial
038 D.S. River Geti 60km DS river Geti
039 U.S. River Geti
040 Nyinakok
Tonj
041 Tonj
Location is not clear
Location is not clear
Gel
042 at New Road Bridge Juba-Wau main road
Location is not clear
Naam
043 Mvolo
044 Rumbek Rumgek-Yerol road
Yei
045 Mundri
Bussere
046 Nago Halima
047 Akanda
Sue
048 7k U.S. Mouth
049 Bahr el Jebel (near Mouth)
050 D.S. Head of Cut No.2
051 U.S. Head of Cut No.1
052 Bor RP124

(3) Data arrangement

1) Data conversion from gauge reading H to river discharge Q

As it is clearly shown in the Table 4.2.2, observed river discharge data Q are very limited while some stations have gauge reading (river depth) data H.

H can be converted into Q by using H-Q curve created with historical H and Q but this conversion can be applied under a condition that formulation of cross section when H observed is the same as that used to create H-Q curve. And generally, H-Q curve is periodically updated according to the latest formation of cross section.

As for river discharge observation stations in RSS, even if those have recent H, due to lack of recent Q, H-Q curve can be created by old data only. Additionally, some of H data are considered as wrong number due to miss reading of gauge. In these cases, accuracy of converted Q is doubtful. Therefore, in this study, Q data converted from H are judged as out of targets for the analysis.

2) Data quality check

i) Exclusion of abnormal value

There is possibility that data include abnormal number. This sometimes happens due to some trouble on measuring facilities/devices or mistyping at recording. The number having higher /less amounts than those of the other period are judged as abnormal value and excluded from the targets for analysis.

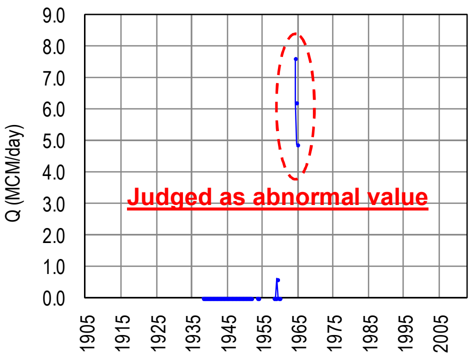


Figure 4.2.2 Judgement of Abnormal Value

ii) Exclusion of 10 days mean discharge without daily discharge

Although those have no daily Q data, some 10 days mean Q data are mentioned in some sources. By the explanation written in sources, these numbers are calculated by such as interpolation method but the details are not clear. Therefore, the accuracy of 10 days means Q data without any daily Q data are doubtful so that this kind of data are excluded from the targets for analysis.

3) Compilation of data from each source

Since available periods of data are different from sources and each source has missing period, data from each source is compiled as one historical data according to the following procedure.

i) Calculation of 10 days mean Q data from daily Q data

Daily Q data are converted into 10 days mean Q data.

ii) Prioritization of data sources

According to data accuracy, sources of data are prioritized as shown in Table 4.2.3.

Table 4.2.3 Priority of Data Sources

Source	Item	Priority
The Nile basin	Discharge (10 days mean)	1
Nile DST		2
The Nile basin	Discharge (Daily)	3
Directorate water and sanitation in the States		4
MEDIWR		
Egyptian Irrigation Office in Malakal		

iii) Data Compilation

Data of the Nile Basin (10 days mean) with highest priority is selected as the base of historical data and data from the other sources are used to fill up the missing period of this base data in prioritized order according to the following procedure mentioned in Figure 4.2.3. Compilation is done by 10 days mean Q and finally it converted into monthly Q.

Data availability period after compilation is shown in Table 4.2.4.

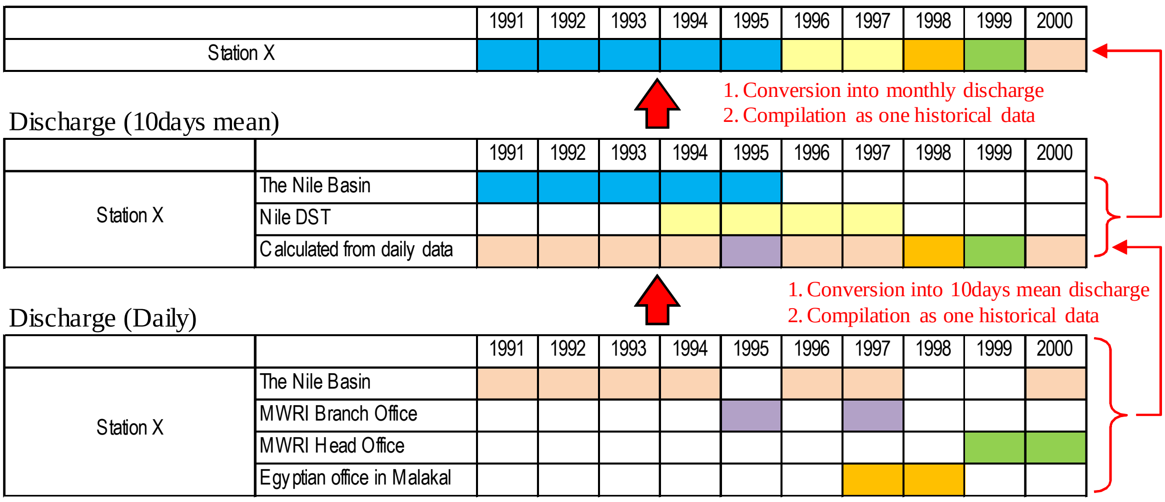
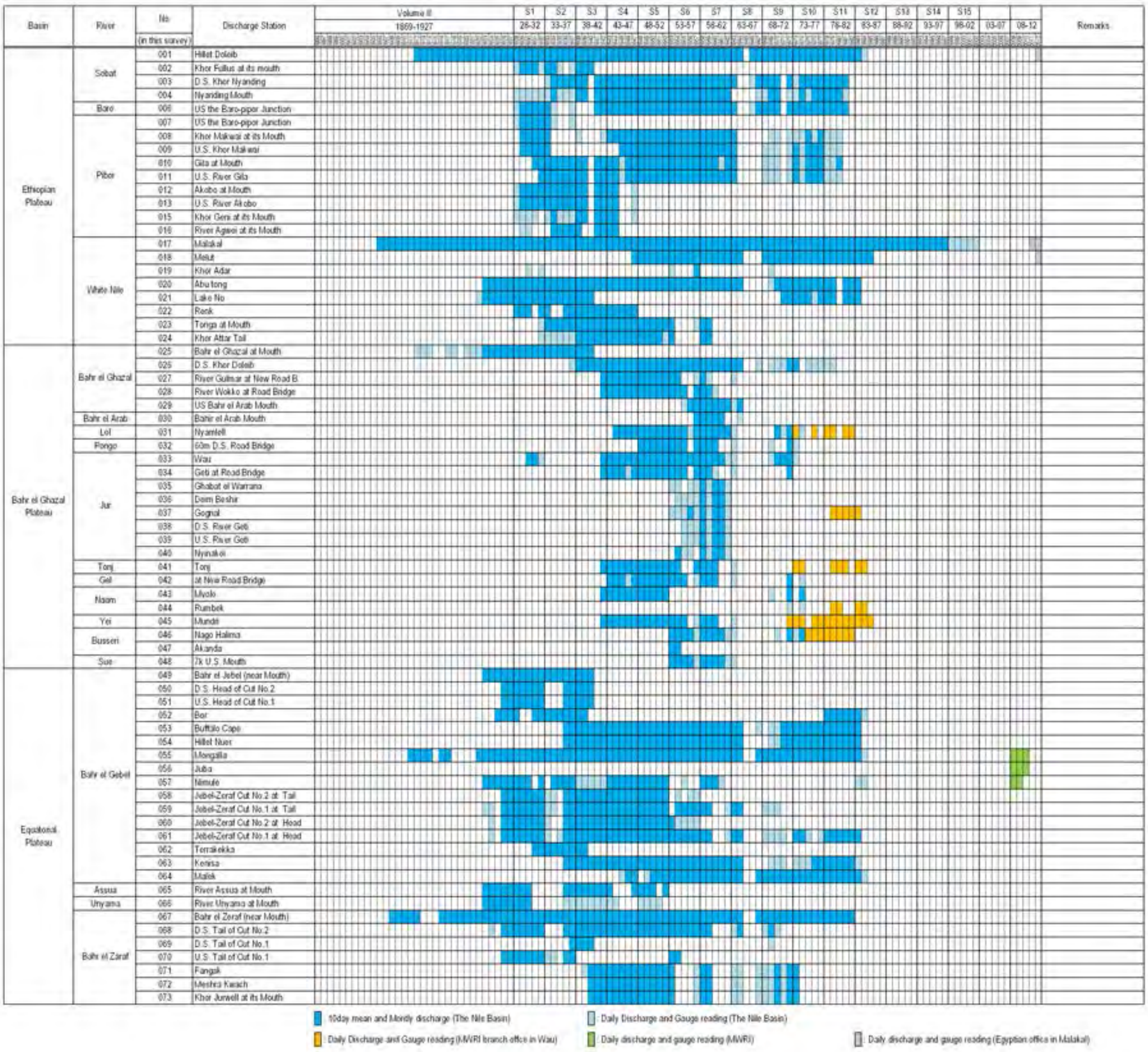


Figure 4.2.3 Example of Data Compilation

Table 4.2.4 River Discharge Data Available Period (After Compilation)



(4) Methodology and analysis

1) Methodology

Average amount of annual specific yield for last 30 years (SY_{30}) is calculated by the following formula.

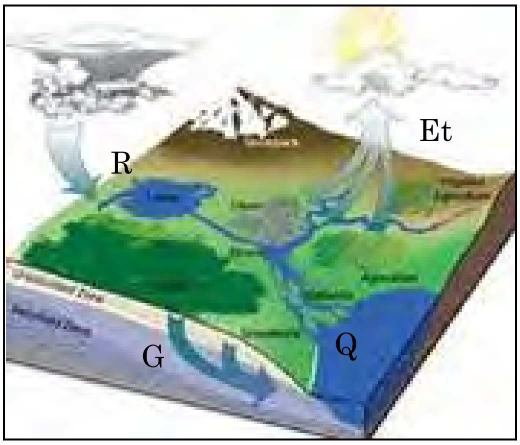
$$SY_{30} = Q_{30} / A \times 1{,}000$$

SY_{30}: Average annual specific yield for last 30 years (mm/year)
Q_{30}: Average annual river discharge for last 30 years at the exit of the catchment area (MQM/year)
A: Catchment area (km^2)

However, as already mentioned there is only one(1) station in Malakal; having river discharge data for last 30 years.

Runoff simulation model assessing the discharge in time-series is considered as a measure to estimated Q_{30} but it is judged that not only river discharge data but also rainfall data are not enough to verify the result of simulation. Therefore, in this study, ñConceptual Mathematical Modelò assessing typical discharge amount is selected to calculate Q_{30} at the other stations.

In ñConceptual Mathematic Modelò, river discharge Q is shown by the following formula.



Hydrologic Cycle

$Q = A \times (R - G - Et)$

Q: River discharge

A: Catchment area

R: Rainfall

G: groundwater recharge/flow

Et: Evapotranspiration

Since estimating G and Et are difficult, generally these values are represented with coefficient showing the ratio against rainfall amount as below;

$Q = A \times (R - G - Et)$

$= A \times (R- ŬR - ɓR)$

$= A \times R (1- Ŭ- ɓ)$

$= A \times R \times F$

$F = Q / (A \times R)$

Ŭ, ɓ: Coefficient

F: Flow ratio

In this case, SY_{30} is shown as a following formula.

$SY_{30} = Q_{30} / A \times 1{,}000$

$= A \times 1{,}000 \times R_{30} \times F / A \times 1{,}000$

$= R_{30} \times F$

R_{30}: Average annual amount of rainfall for last 30 years (mm)

Based on the concept of this method, SY_{30} is calculated according to the following procedure shown in Figure 4.2.4:

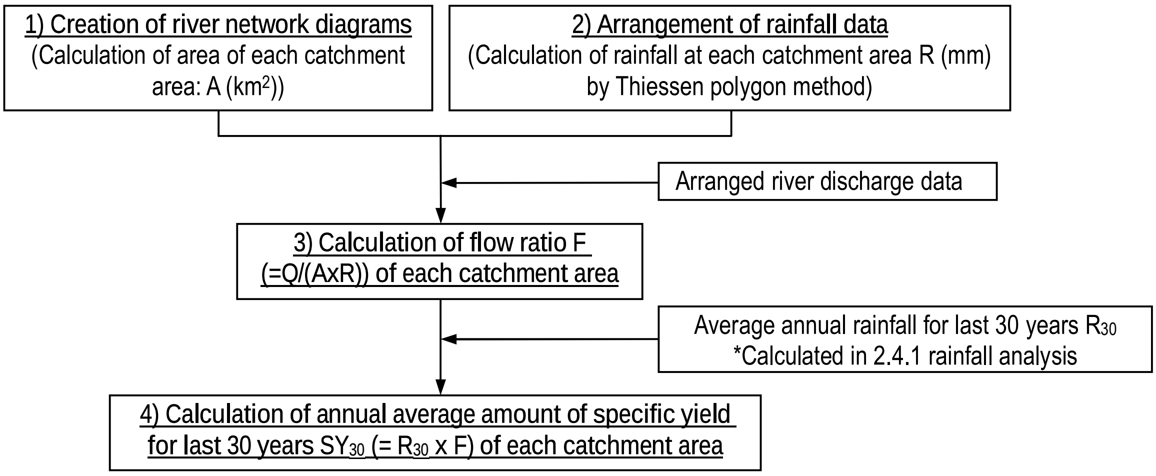


Figure 4.2.4 Procedure of SY_{30} Calculation

2) Creation of river network diagrams

To understand the river network structure in RSS, it is created based on i) river numbering tables and ii) river delineation map. Since RSS has four (4) main river basins: 1) Bahr el Ghazal, 2) Bahr el Jebel, 3) Sobat and 4)White Nile, diagrams area created by basin as shown in Figure 4.2.5 and 4.2.6.

i) River numbering tables

Based on river alignment data in Digital Atlas (produced by NBS) and topographic maps published in 2005 with scale 1:500,000, alignment and name of each river are identified and each river is numbered with initials of its belonging river basin, as shown in Table 4.2.5 to 4.2.8.

Figure 4.2.5 River Basins in the RSS

ii) River delineation map

Aiming to calculate the area of each catchment area, a river delineation map is created using SRTM-DEM (90m) and modified manually referring topographic maps with scale 1:500,000 as shown in Figure 4.2.7.

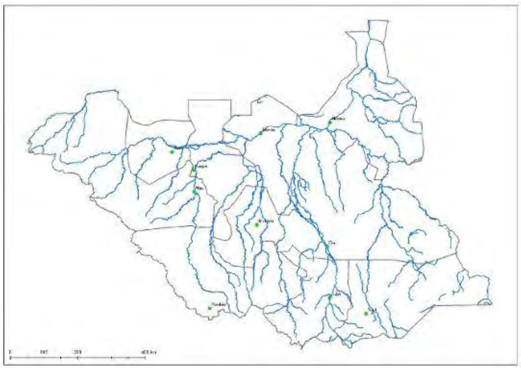


Figure 4.2.6 River Alignment produced by NBS

Catchment areas are created with its base point at the junctions of rivers or points of river discharge measurement stations, and numbered with initials of its belonging river basin same as rivers.

iii) River network diagrams

i) River numbering tables and ii) River delineation map are compiled as river network diagrams. In these diagrams, area of catchment areas (km^2), average annual discharge for the last 30 years (MCM/year) and average annual specific yield (SY) for the last 30 years (mm) are described as shown in Figure 4.2.8 to 4.2.11.

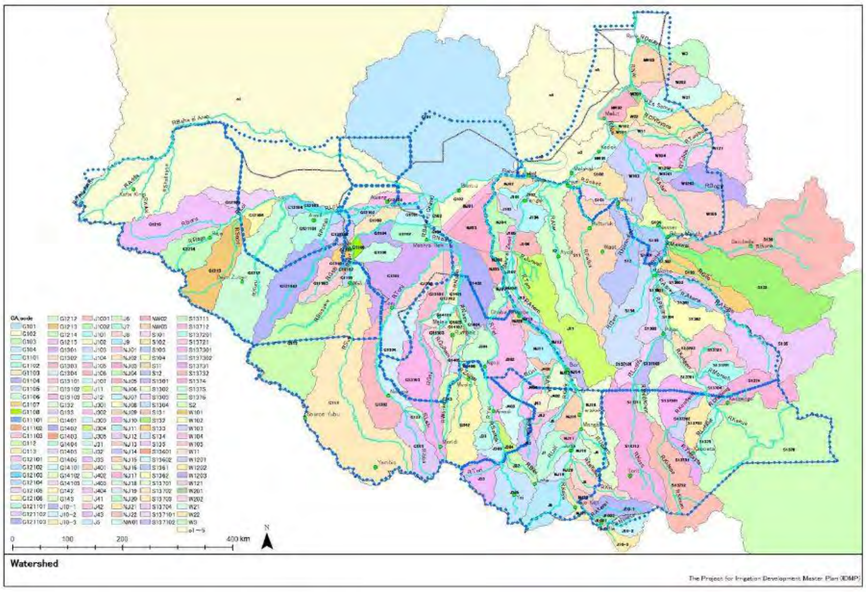


Figure 4.2.7 River Delineation Map

Table 4.2.5 River Numbering Table (Bahr el-Ghazal River Basin)

G:Bahr el Ghazal River basin

Primary tributary		2nd tributary		3rd tributary		4th tributary	
Code	Name of River	Code	Name of River	Code	Name of River	Code	Name of River
1	Bahr el Ghazal	11	Jur	111	Geti		
				112	Bussere		
				113	Sue		
		12	Bahr el Arab	121	Lol	1211	Pongo
						1212	Kuru
						1213	Sopo
						1214	Raga
						1215	Boro
		13	Tonj	131	Gel		
				132	Lesi		
				133	Ibba		
		14	Naam	141	Gulham		
				142	Zoggo		
				143	Wonko		

: All the discharge evaporate at the swamps located at the exit of river. (Not connect to any rivers)

Table 4.2.6 River Numbering Table (Bahr el-Jebel River Basin)

J:Bahr el Jebel River Basin

Primary tributary		2nd tributary		3rd tributary	
Code	Name of River	Code	Name of River	Code	Name of River
1	Bahr el Zeraf	11	Jurwell	111	Tem
		12	Magwong		
2	Atem				
3	Yei	31	Bostaki		
		32	Bibi		
		33	Tori		
4	Gal	41	Anok		
		42	Awong		
		43	Tatan		
5	Gwir				
6	Ugurro				
7	Luli				
8	Kii	81	Lefuleur		
9	Kaya				
10	Assua	10-1	Ateppi		
		10-2	Nyimur		
		10-3	Unyama		

Table 4.2.7 River Numbering Table (Sobat River Basin)

S:Sobat River Basin

Primary tributary		2nd tributary		3rd tributary		4th tributary		5th tributary	
Code	Name of River	Code	Name of River	Code	Name of River	Code	Name of River	Code	Name of River
1	Sobat	11	Fullus						
		12	Nyanding						
		13	Pibor	131	Baro				
				132	Makwai				
				133	Gilo				
				134	Geni				
				135	Akobo				
				136	Agwei	1361	Abana		
						1362	Kong kong		
				137	Kangen	1371	Lotifa	13711	Medikireit
								13712	Koss
						1372	Morech	13721	Lelazat
						1373	Kondech	13731	Tingayta
								13732	Kidepe
						1374	Chabong		
						1375	Lotilet		
						1376	Kakua		
2	Atar								

: All the discharge evaporate at the swamps located at the exit of river. (Not connect to any rivers)

Table 4.2.8 River Numbering Table (White Nile River Basin)

W:White Nile River Basin

Primary tributary		2nd tributary		3rd tributary	
Code	Name of River	Code	Name of River	Code	Name of River
1	Adar	11	Tombao		
		12	Doga	121	Yabus
2	Birbari	21	Es Samaa		
		22	Chifayaca		
3	Doleib				

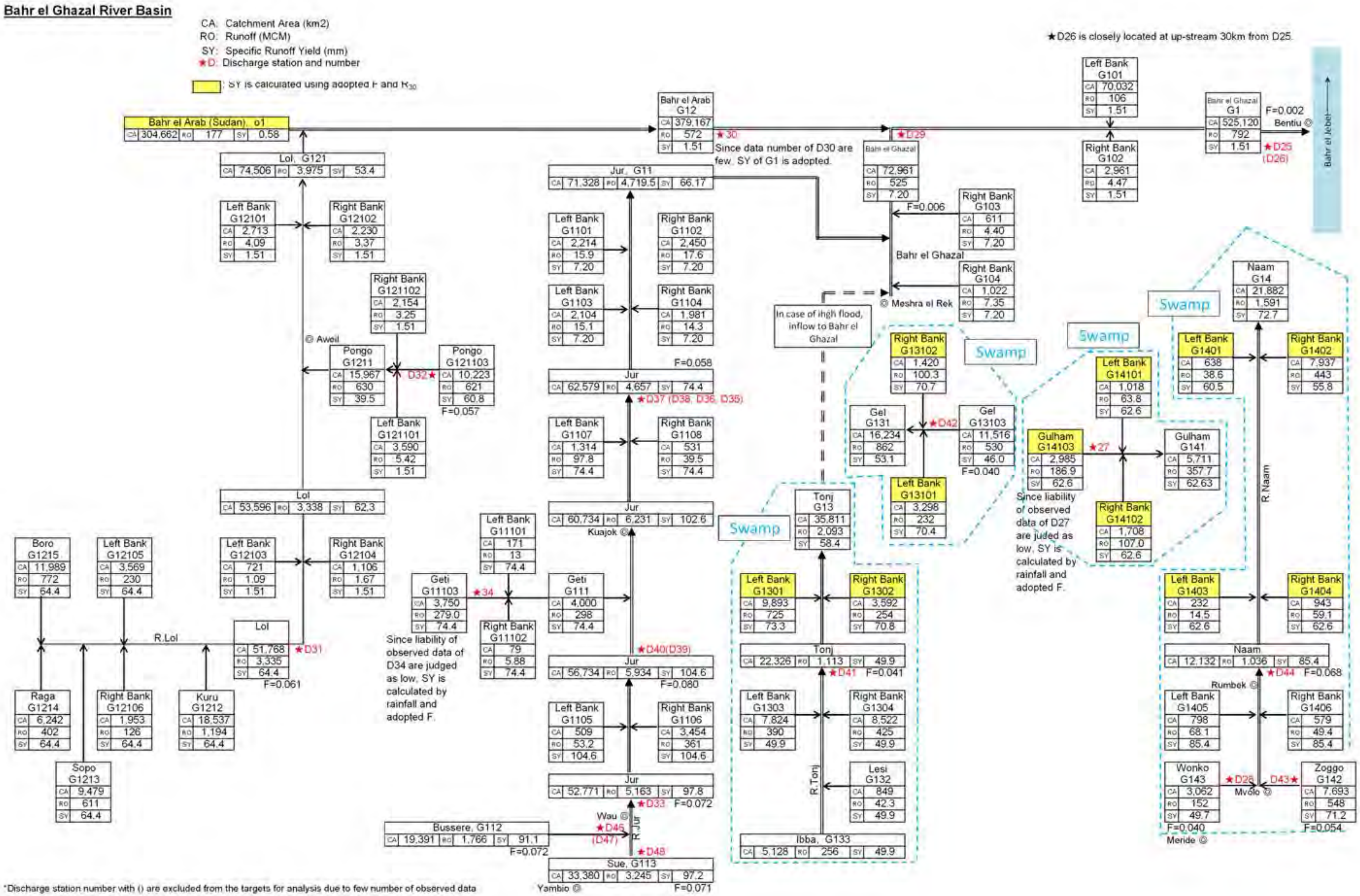


Figure 4.2.8 River Network Diagram (Bahr el-Ghazal River Basin)

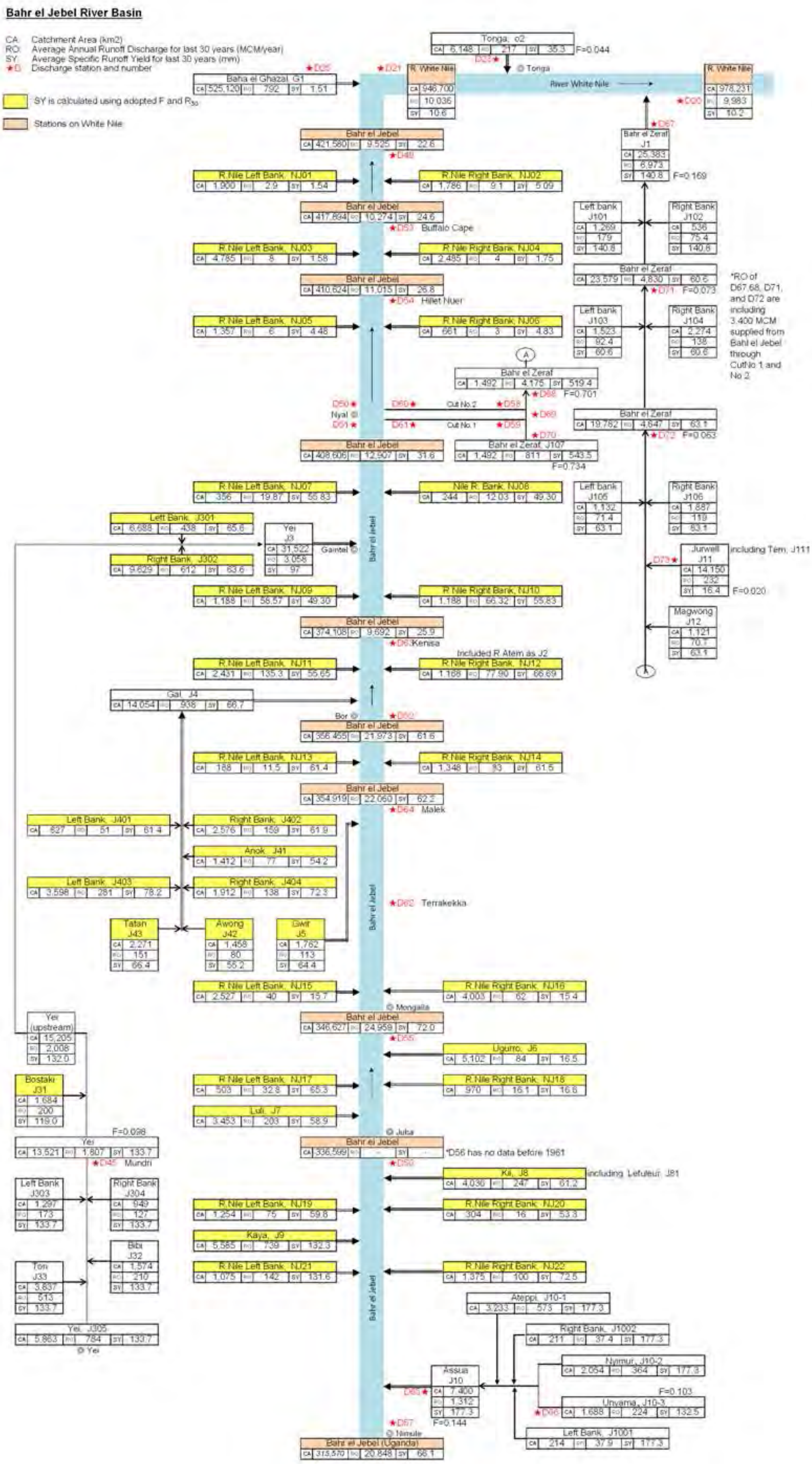


Figure 4.2.9 River Network Diagram (Bahr el-Jebel River Basin)

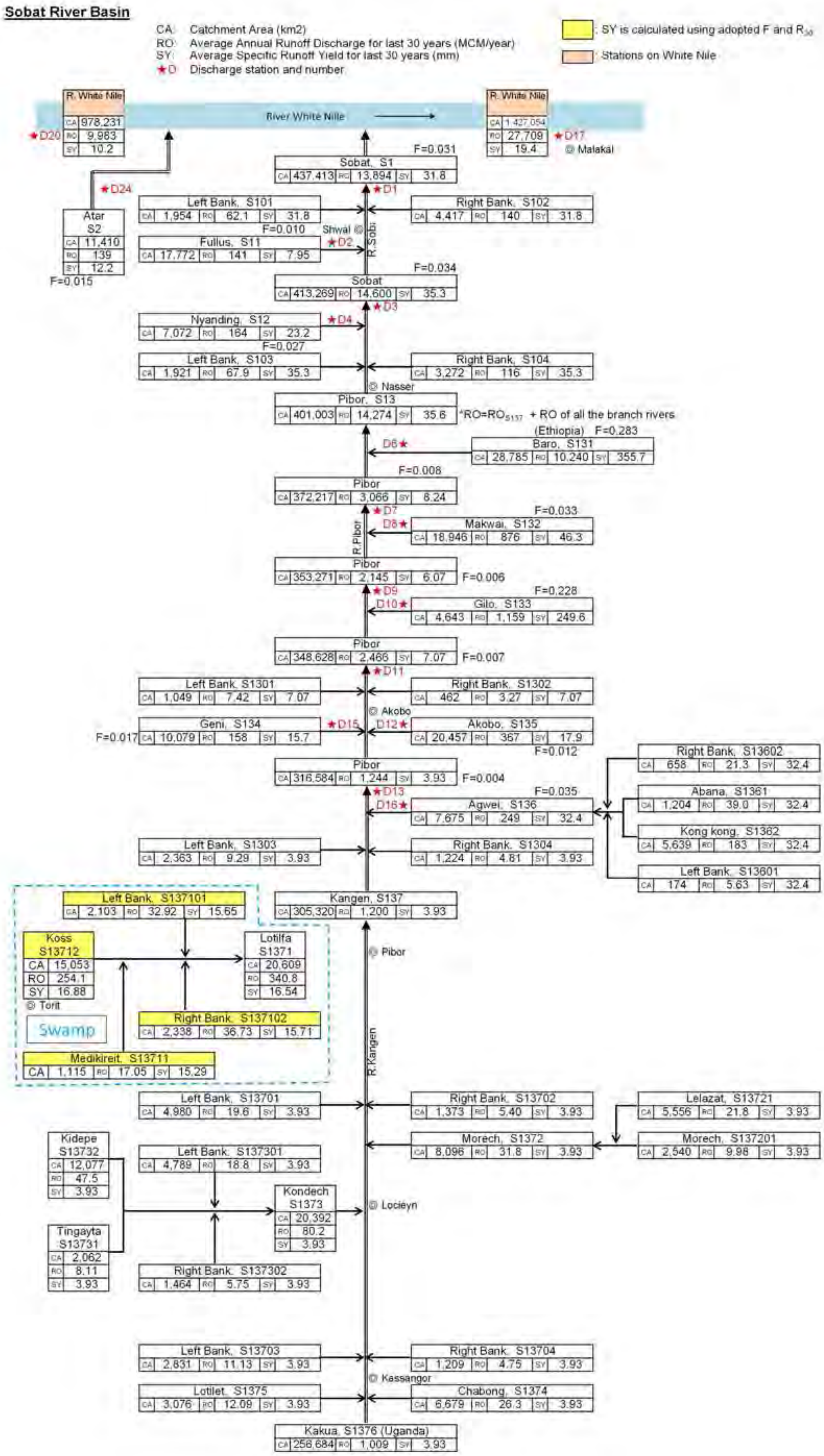


Figure 4.2.10 River Network Diagram (Sobat River Basin)

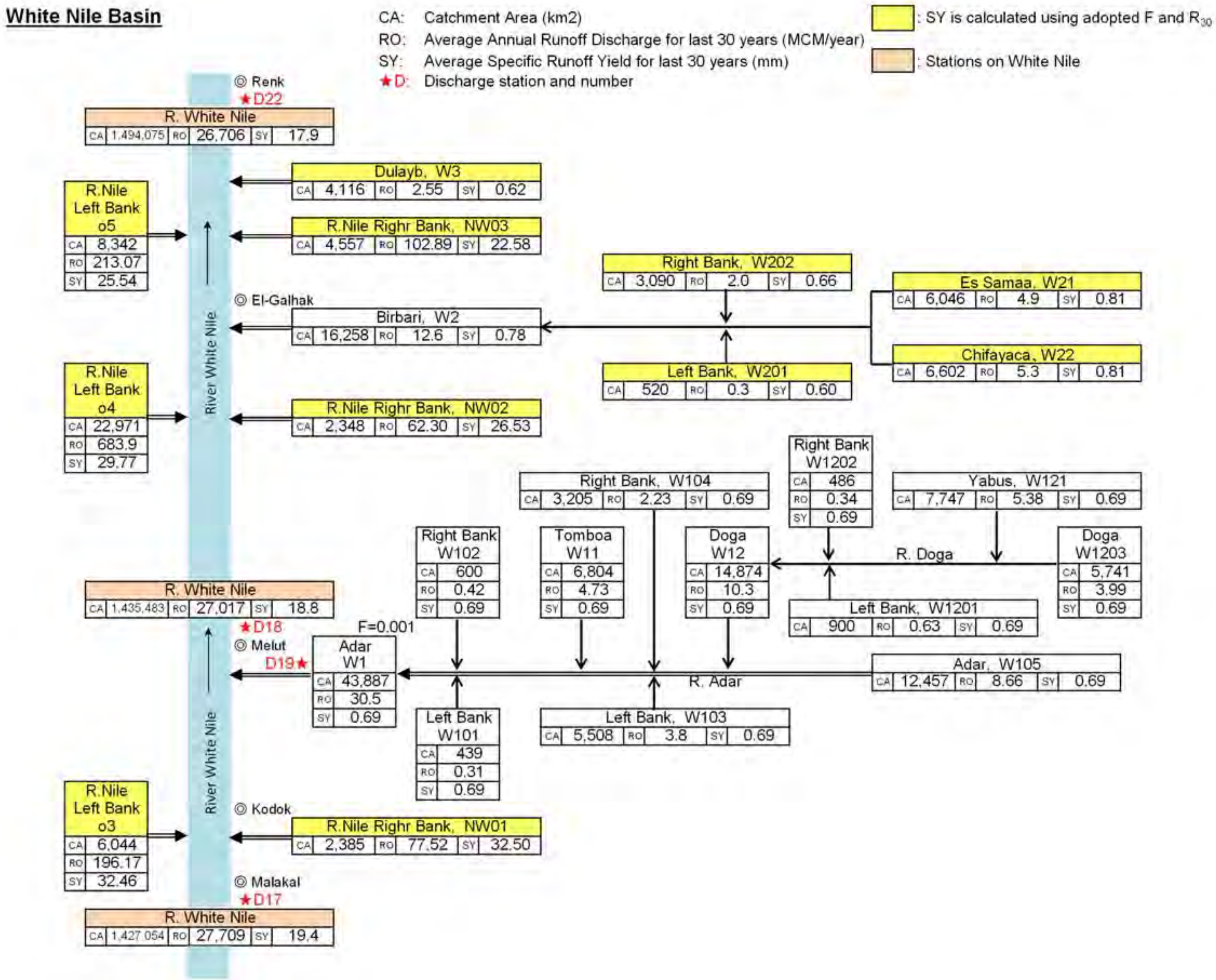
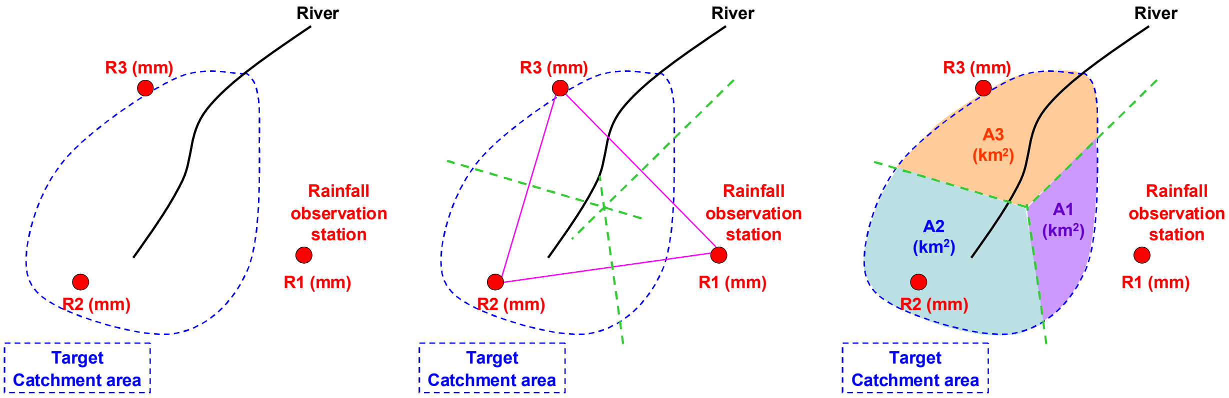


Figure 4.2.11 River Network Diagram (White Nile River Basin)

3) Arrangement of rainfall data R

In case that rainfall observation stations are settled within every catchment area and those observed amount shows typical, observed amount can be typical amount of the catchment area. However, in RSS, the number of rainfall observation stations is limited and not settled within every catchment area. Therefore, typical rainfall amount of each catchment area is calculated by Thiessen polygon method as shown in Figure 4.2.12 and 4.2.13.



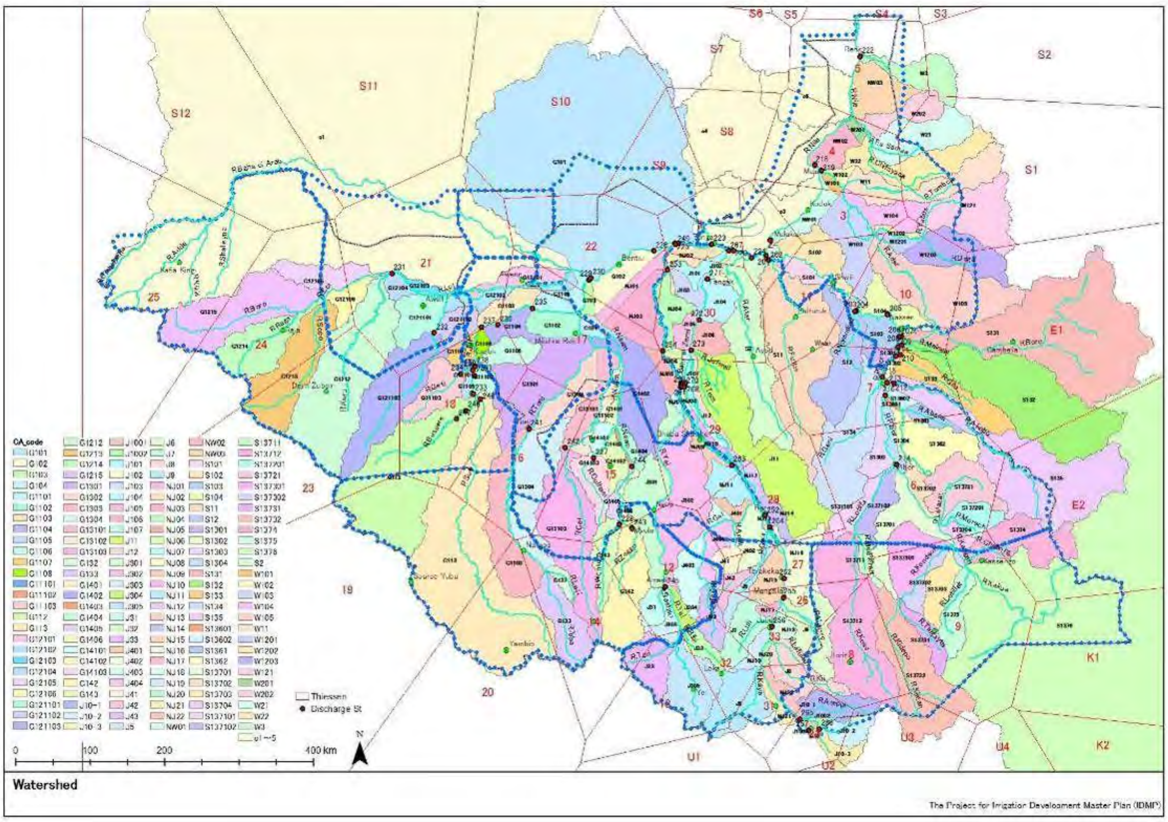
1. Selection of rainfall observation stations within/around a target catchment area and collection of observed data

2. Creation of lines connecting each rainfall station (pink line) and lines at the center of each pink line with right angle (green line)

3. Calculation of areas affected by each rainfall observation station

(Rainfall amount of target catchment area R (mm))= (A1 x R1 + A2 x R2 + A3 x R3) / (A1 + A2 + A3) x 1,000

Figure 4.2.12 Outline of Thiessen Polygon Method



4) Calculation of flow ratio

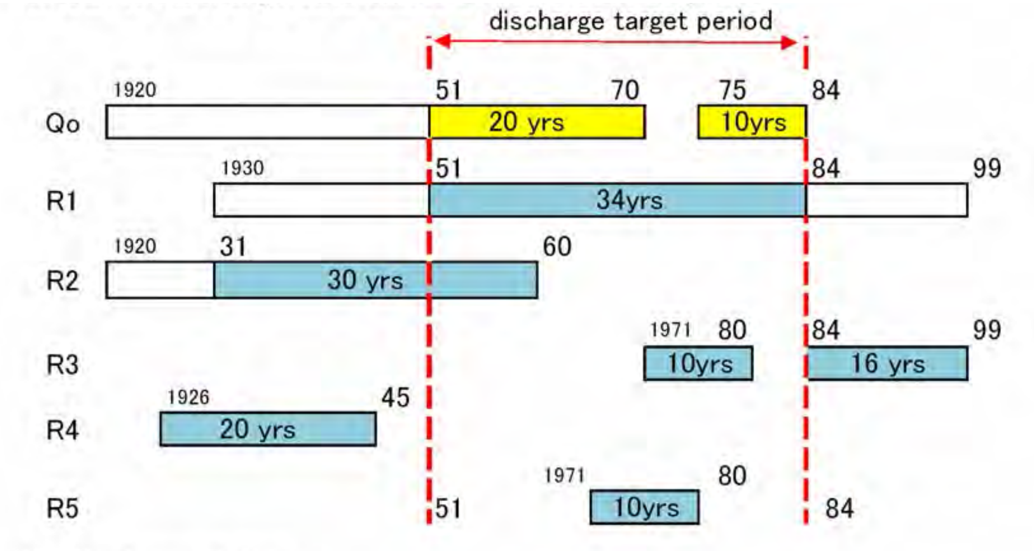
As mentioned before, flow ratio F is shown by the following formula;

$F = Q / (R \times A)$

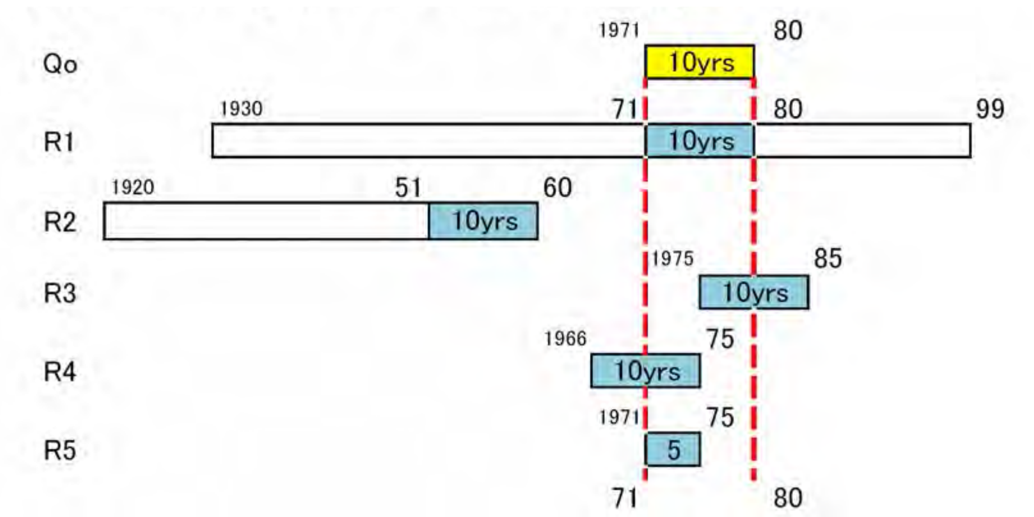
Although data of Q and R which affect to flow ratio of the target catchment area should be occurred at the period, those cases are very rare. Then in this study, by using latest 30 years data of both Q and R of each station, typical F is evaluated.

However, data available periods of each rainfall station are not same so that rainfall data are selected according to the followings rules.

i) Case-1: River discharge data is available more than 30 years.



ii) Case-2: River discharge data is available less than 30 years.



*1: Concept of F at catchment area of river having more than 2 river discharge observation stations

In the case that the river has more than two(2) discharge observation stations, F is calculated by the following formula;

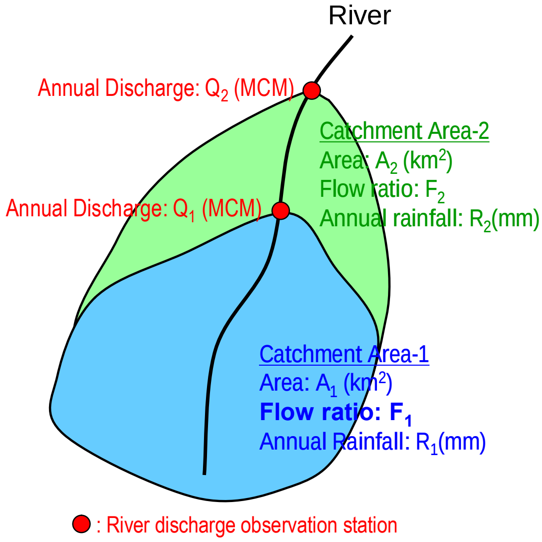
$F1 = Q_1 / (R_1 \times A_1 \times 1{,}000)$

$F2 = (Q_2 - Q_1) / (R_2 \times A_2 \times 1{,}000)$

When discharge of river decreases at downstream (which is happened in RSS), Q_2-Q_1 becomes negative value (-) and it becomes difficult to grasp the run off specification of target catchment area. For the above case, minimum number of F should be 0 so that the following formula is adopted in this study;

$F1 = Q_1 / (R_1 \times A_1 \times 1{,}000)$

$F2 = Q_2 / (R_1 \times A_1 \times 1{,}000 + R_2 \times A_2 \times 1{,}000)$



*2: Estimation of F value of catchment areas without discharge observation stations

At catchment areas where river discharge observation stations (hereinafter referred to as un-known CA), number of F is adopted from that of another catchment area having F calculated by observed Q and R (hereinafter referred to as known CA), located nearby with similar natural condition as a target un-known CA.

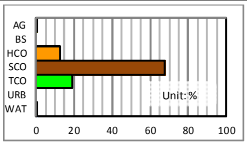
Similarity of natural condition is evaluated comprehensively with condition of 1) Rainfall, 2) Topography and 3) Land cover.

1) Rainfall: Similarity is evaluated by using range of annual rainfall amount within catchment area.

2) Topography: National land is classified into flood plain (FP), Connection zone (CN), mountain area (MT) and topographic specification of each catchment area is selected from them. In case that it is difficult to select one from them, two are selected. Similarity is judged by using selected specification.

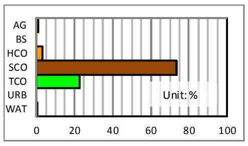
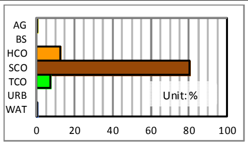
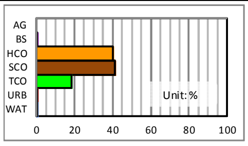
3) Land cover: National land is classified into AG (Agriculture), TCO (Trees), SCO (Shrubs), HCO (Herbaceous), URB (Urban areas), BS (Bare rock and Soil) and WAT (Water-bodies) and covering ratio of each classified item within each catchment area is calculated. Then, difference of each covering ratio between target un-known CA and known CA and summed number of differences are calculated. The known CA having minimum summed number is judged as having most similar natural condition to un-known CA as shown in Figure 4.2.14.

Target un-known CA

			Covering Ratio (%)
138		AG	0.45
		BS	0.00
		HCO	12.59
		SCO	67.77
		TCO	19.11
		URB	0.00
		WAT	0.08

Calculate the difference

Known CAs nearby Target un-known CA

			Covering Ratio (%)	Differences between Target CA	Summed differences
54		AG	1.22	0.77	**19.01**
		BS	0.00	0.00	
		HCO	3.16	9.43	
		SCO	73.20	5.43	
		TCO	22.41	3.30	
		URB	0.00	0.00	
		WAT	0.01	0.07	
128		AG	0.08	0.37	25.23
		BS	0.00	0.00	
		HCO	12.39	0.20	
		SCO	80.38	12.61	
		TCO	7.09	12.03	
		URB	0.00	0.00	
		WAT	0.06	0.02	
133		AG	0.00	0.45	55.12
		BS	0.00	0.00	
		HCO	40.13	27.54	
		SCO	41.14	26.62	
		TCO	18.63	0.48	
		URB	0.02	0.02	
		WAT	0.07	0.01	

←Minimum =Most similar to target SY-Unknow CA

Figure 4.2.14 Similarity of Land Cover

5) Calculation of average amount of specific yield for last 30 years SY_{30}

As mentioned before, SY_{30} is calculated by using calculated F and R_{30} by the following formula and a SY_{30} map is created. Each watershed is coloured according to the amount of SY_{30} as shouwn in Figure 4.2.15.

$$SY_{30} = Q_{30} \times F / A \times 1{,}000$$

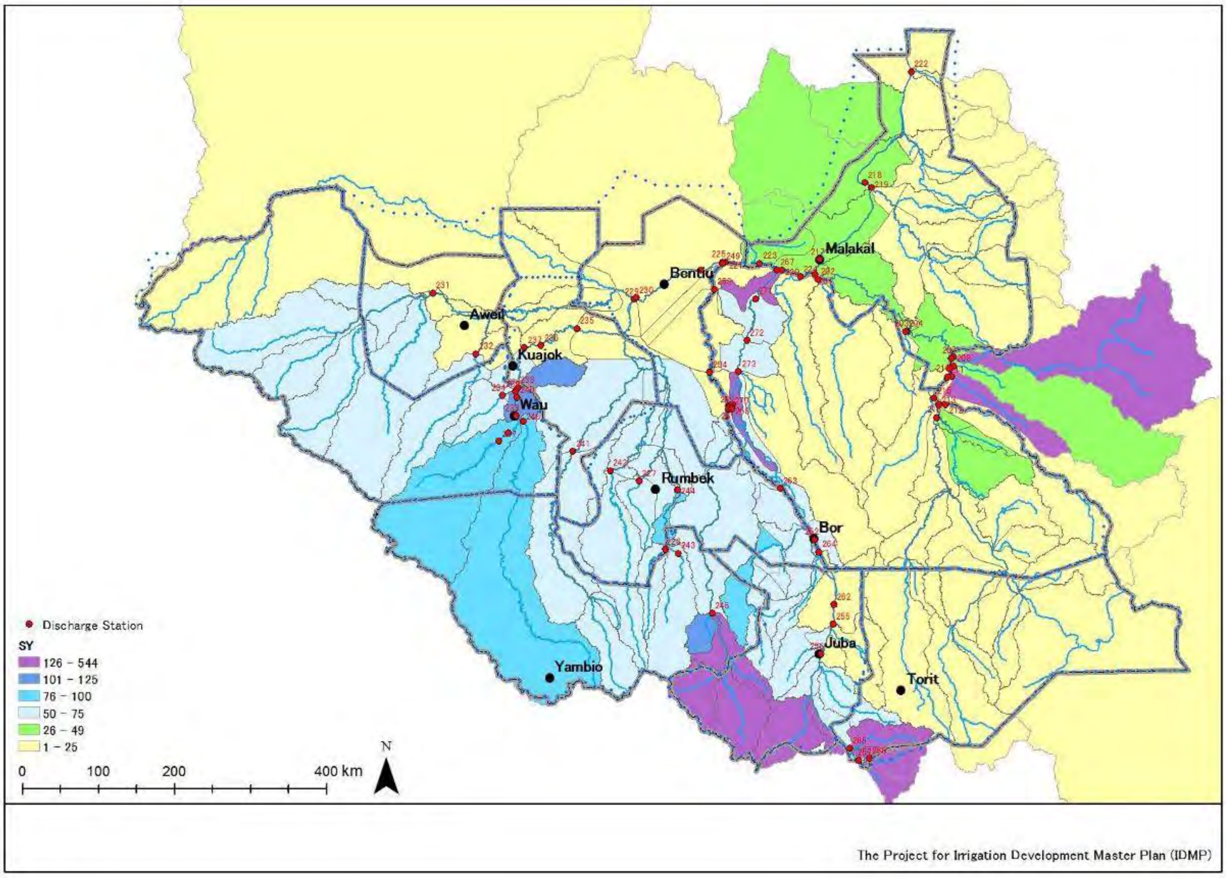


Figure 4.2.15 Specific Yield for Last 30 Years (SY_{30}) Map

(5) Results of evaluation

By created SY map, catchment area having high SY (= high surface water potential) can be identified. For perennial rivers, i.e. White Nile (incl. Bahr el Jebel) and Sobat Rivers, even those SYs are small, plenty of river water is available for irrigation. Therefore, a map overlaying with SY and Q is created as a surface water potential map, by showing with circle in blue for perennial and red for seasonal rivers on the SY map. The scale of circles shows the mean annual amount of river discharge for the last 30 years as shown in Figure 4.2.16.

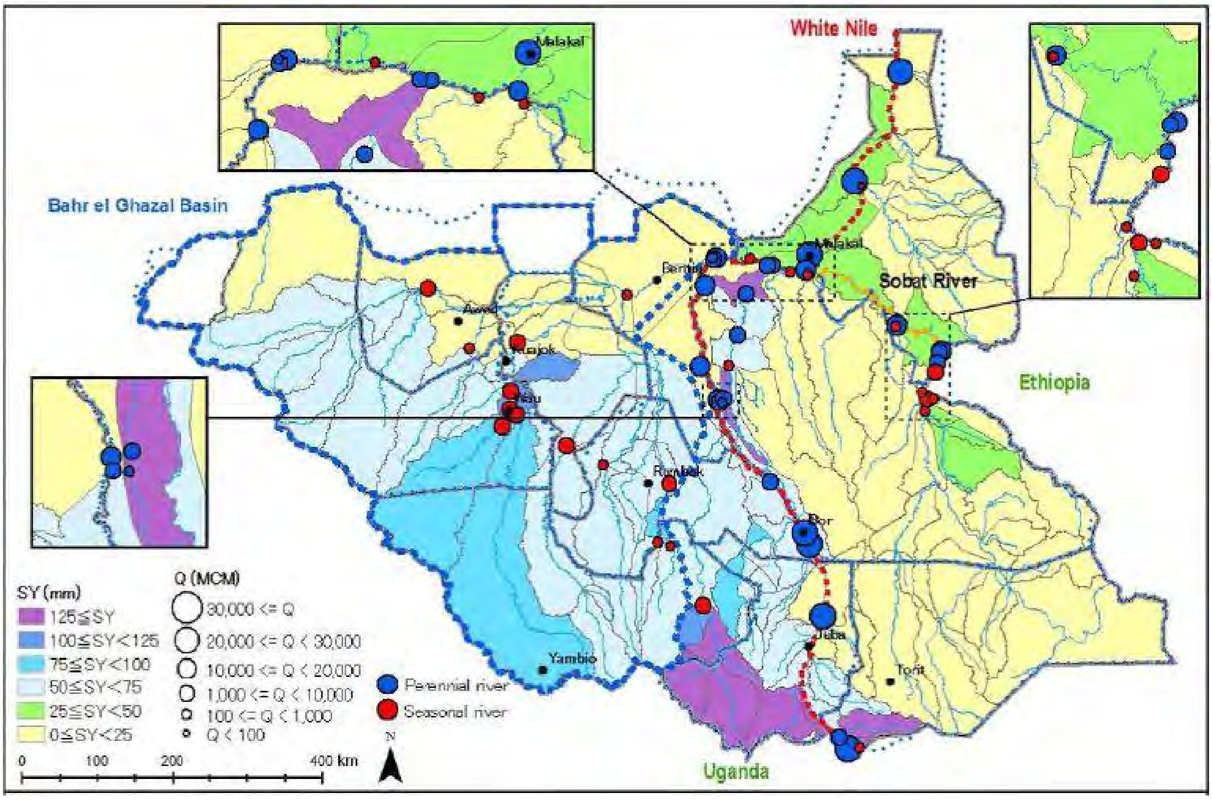


Figure 4.2.16 SY_{30}+Q_{30} Map (Surface Water Potential Map)

It is noted that the discharge of White Nile suddenly changed in 1961 by increasing with approx. 1.5 times and the amount has still been decreasing as shown in Figure 4.2.17. This change happened due to unexpected rainfall during 1961 ï 1964 at upstream of the Victoria lake (Water level of the lake raised approx. 2 m).

Since the discharge volume is considered to become near amount of before 1961 in future, it can be said that discharge after 1961 are under abnormal condition. Under this condition, discharge data before 1961 are adopted as potential on SY + Q map and for river network diagrams of White Nile, not average of the last 30 years after 1961.

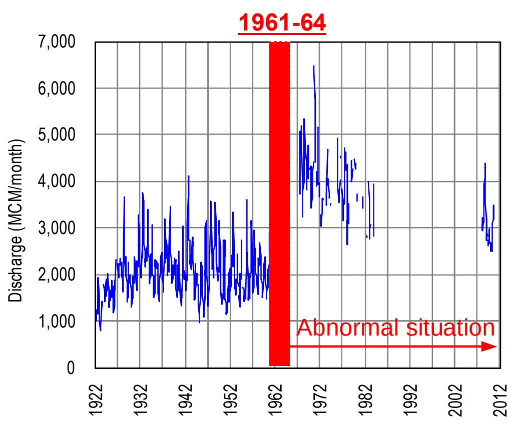


Figure 4.2.17 Record of Monthly Discharge (Mongalla Station)

Followings are summarized from the Figure 4.2.16:

1) SY of Bahr el Ghazal basin is higher than the other river basins. Especially catchment areas of

Sue and Busseri river have high SY;

2) SYs of catchment areas located near the border of Uganda are comparatively high;

3) Approx. 12,300 MCM/year of discharge of White Nile decreases between Bor (21,973 MCM/year) and Kenisa (9,692 MCM/year), which is assumed occurring due to not only high evaporation but also recharging for groundwater; and

4) River Sobat is perennial river of which discharge is mostly supplied from Ethiopia. Land development at upstream of Sobat within Ethiopia will affect to the discharge volume of Sobat River.

4.3 Groundwater Analysis

(1) Hydro-geological and geological condition of the RSS

By reviewing the results of existing documents and reports, the followings are identified.

i) Condition of ground water basin

In the RSS, there is only one (1) huge and closed groundwater basin named Sudd Basin. And the basin consists of four (4) major aquifers: namely, 1) Alluvium, 2) Umm Ruwaba Formation, 3) Nubian Sandstone and 4) Basement Complex.

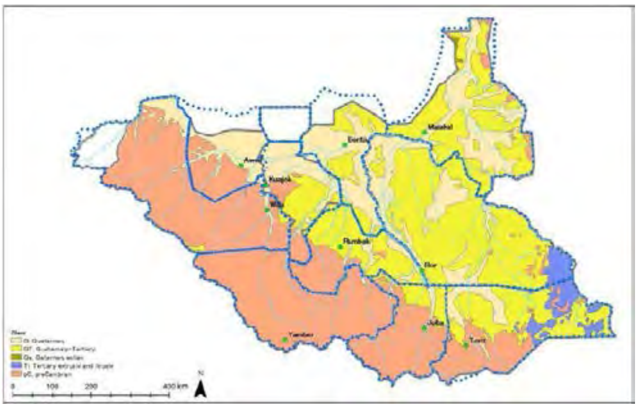


Figure 4.3.1 Geological Map

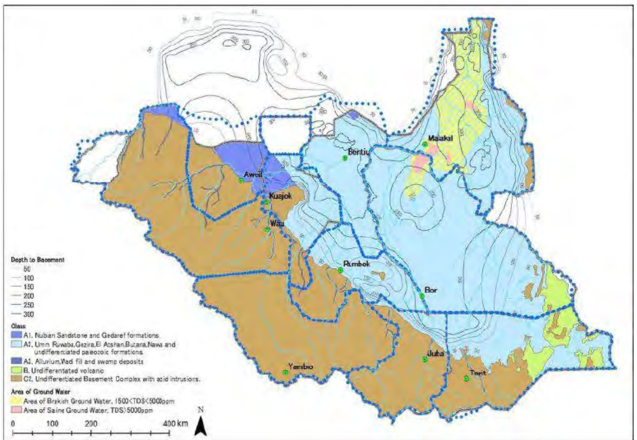


Figure 4.3.2 Hydro-geological Map

ii) Geological setting

Pre-Cambrian Basement Complex mainly consisting of Granites and Gneiss occupies throughout the country. This basement is overlaid by Nubian Sandstone partially and Umm Ruwaba Formation at Sudd Basin, and covered by alluvial deposits along with major river routes.

iii) Hydrological setting

Hydro-geologically, Basement Complex aquifer forms a small aquifer system with an impervious base (bottom) of all other aquifers. And Sudd Basin is an enormous depression of the basement filled back by unconsolidated sediments through Tertiary and Quaternary. Thus, the Sudd Basin is huge with closed individual groundwater basin, only one (1) in the country.

(2) Groundwater storage

To estimate the water storage volume, Sudd Basin is conceptually modelled by Synthetic Storage Model. Total area of Sudd Basin is as large as nearly 433,000 km^2. Because of the hugeness of the basin, groundwater storage in the Sudd Groundwater Basin has also huge volume. In case, the depth of

Alluvial deposits is estimated as 50 m, and that of Umm Ruwaba formation is around 350m, around $9.77\text{x}10^{13}$ m^3 is estimated as total volume of the aquifer, and $1.151\text{x}10^{13}$ m^3 as groundwater storage volume. Yields of groundwater are estimated as total $7.35\text{x}10^{11}$ m^3. Since some of important information/record for analysis is not described in inventory, these estimations are carried out under assumptions on transmissibility, storability and radius of influence.

(3) Groundwater development potential

Groundwater development potential is basically depending on the groundwater storage, and the storage depends on the depth of aquifer. Isobathic contour map on Sudd Basin is classified into three (3) zones (at 150 m and 250 m), and each zone is given potential ranking depending on its depth class (II to IV). Nubian Sandstone is given highest rank because of its excellent aquifer property and consequently accompanied Umm Ruwaba formation (V).

Remained wide area of the country underlain by Basement Complex is given the lowest potential as ñIò of which yield of groundwater is only enough for rural or urban water supply.

And, new volcanic intrusive rocks distributing eastern hedge of the basin is evaluated as no development potential (0). Then, brackish water body existing in the northern branch of the basin is given minus potential because of its dangerous salinity level (-I).

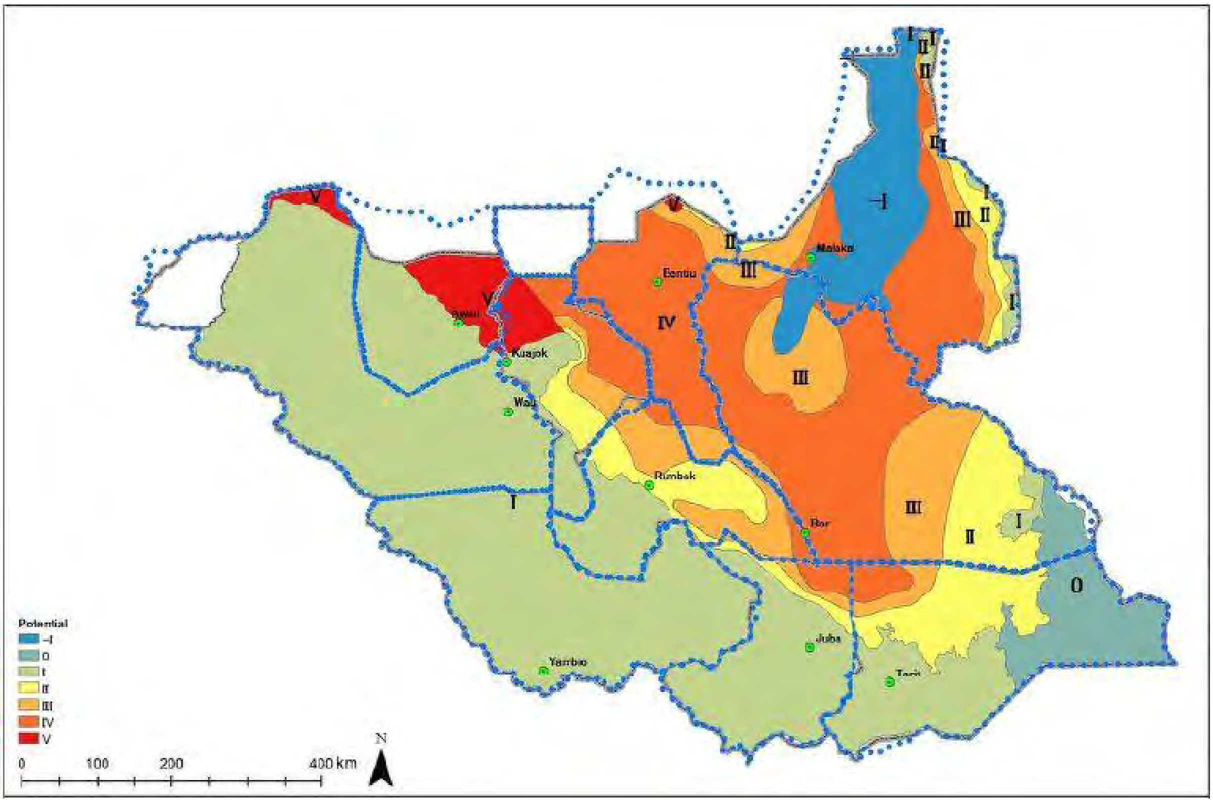


Figure 4.3.3 Groundwater Potential Map

5. IRRIGATION DEVELOPMENT POTENTIAL MAP

In the basis of results of assessments for 1) Land productivity, 2) Socio-economic and 3) Water resources potentials, three (3) maps are combined as one (1): namely, "Irrigation development potential map".

Given conditions that unused plenty of river water is available in RSS, surface water is the main source for irrigation development, while it is costly for the development of groundwater. And groundwater will be supplemental source. In considerations of the above, following two (2) kinds of irrigation development potential maps have been created as shown in Figure 5.1 and 5.2 respectively.

Map 1) Land productivity potential + Socio-economic potential + Surface water potential
Map 2) Land productivity potential + Socio-economic potential + Ground water potential

(1) Land productivity potential + Socio-economic potential + Surface water potential (Map 1)

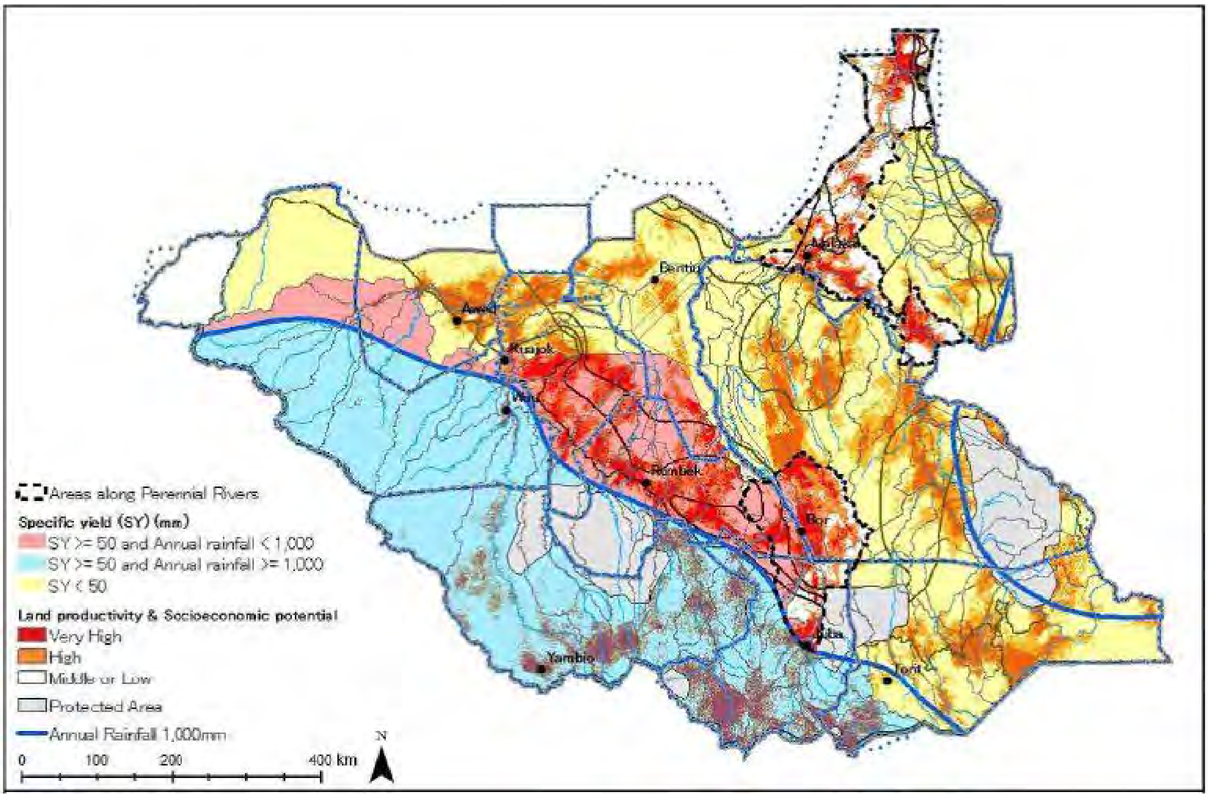


Figure 5.1 Irrigation Development Potential Map (with Surface Water Potential)

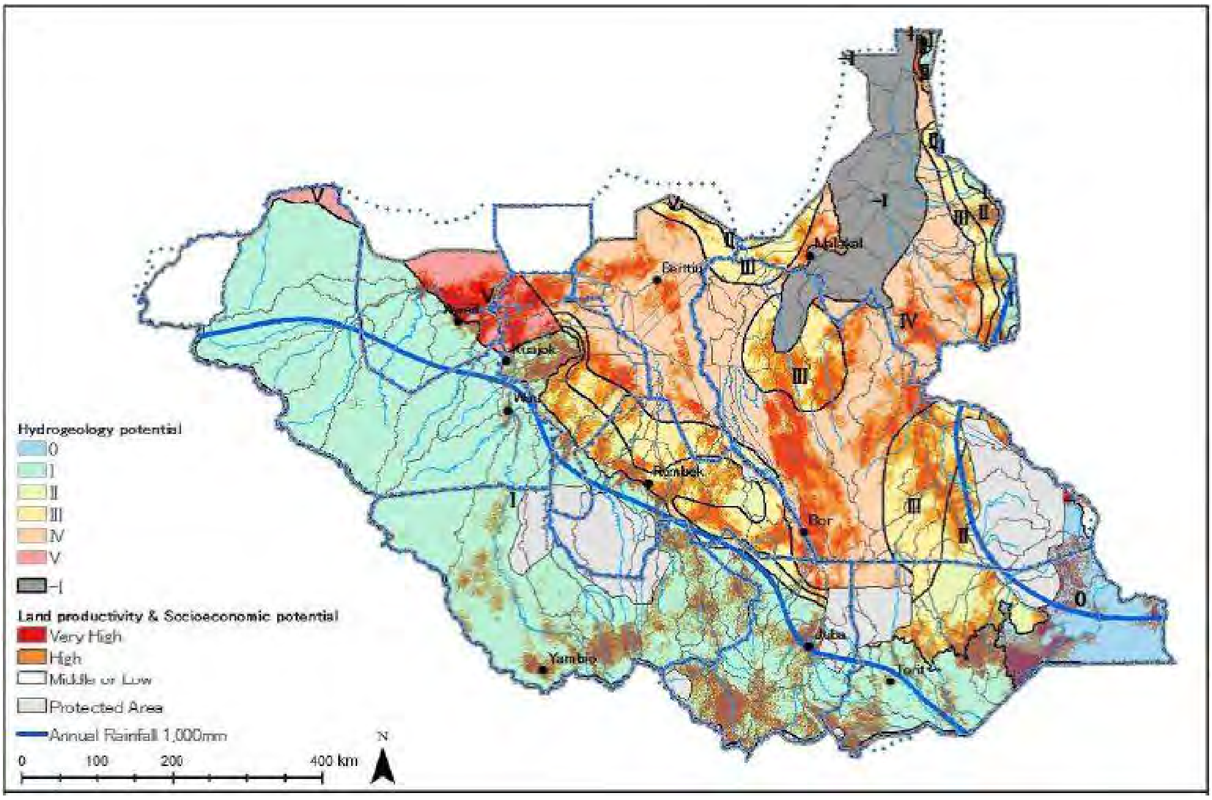
In view of irrigation development, ranking of potential areas are categorized by surface water potential as SY in consideration with annual rainfall which can irrigate for farming with ranging more or less than 1,000 mm/year as follows;

Area-1) Middle /Low potential in yellow: SY < 50 mm
Area-2) High potential in blue: SY > 50 mm with annual rainfall > 1,000 mm
Area-3) Very high potential in red: SY > 50 mm with annual rainfall < 1,000 mm

And each area is coloured according to its ranking with overlaying higher Land productivity potential and Socio-economic potential maps where are shown in dark red, while protected areas shown in grey are excluded due to restriction of land development.

In addition, catchment area along the perennial rivers where the water is available even during dry season, should be given higher potential though SY is low, except within/around the areas difficult for land development.

(2) Land productivity potential + Socio-economic potential + <u>Ground water</u> potential (Map 2)



<u>Figure 5.2 Irrigation Development Potential Map (with Groundwater Potential)</u>

Groundwater can be the supplemental source at the areas near rivers or main source at areas far from rivers.

Each area is coloured according to ranking of groundwater potential with overlaying higher Land productivity potential and Socio-economic potential maps which are shown in dark red, while protected areas shown in grey are excluded due to restriction of land development.

6. SELECTION OF HIGH POTENTIAL AREAS FOR THE DETAILED ASSESSMENT (HIGH RESOLUTION AREAS)

The high potential areas for the detailed assessment to be target for priority and/or short-term projects was narrowed at approx. 10% of national land, while they are selected by the following procedures (Stage-1 to Stage-5) in consideration of the results of the rapid assessment including water resources potential, land productivity and socio-economic potentials.

Stage-1: To select watersheds which have equal or more than 50 mm of specific runoff yield (SY) along seasonal rivers, and area of five (5) km both sides of perennial river[2] (Refer to Figure 6.2);

Stage-2: To exclude areas which are located outside of RSS and in Sudd area (Refer to Figure 6.3);

Stage-3: To exclude the areas which have more than 1,000 mm annual rainfall in consideration of the necessity[3] of the irrigation (Refer to Figure 6.4 and 6.5);

Stage-4: To exclude the areas which have low land productivity and socio-economic potentials (Refer to Figure 6.6 and 6.7);

Stage-5: To exclude the areas which are designated as the national park. (Refer to Figure 6.8 and 6.9)

Through the above procedures, 10.9% of national land has been identified as high potential areas for the detailed assessment.

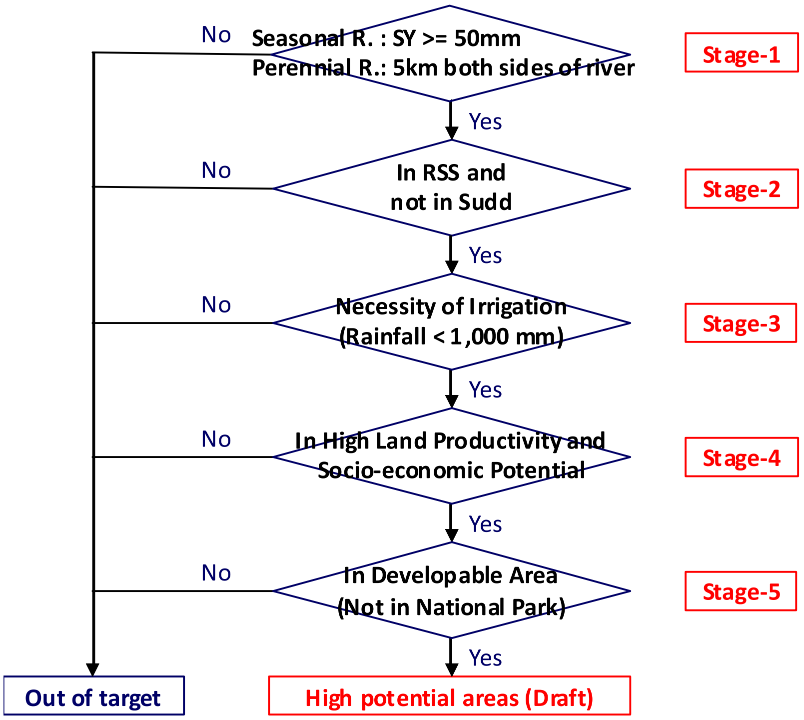


Figure 6.1 Flow of Selection of High Potential Areas for the Detailed Assessment

[2] Perennial river in South Sudan: White Nile Bahr el Jebel, Bahr el Zeraf and Sobat River.
[3] Generally, irrigation is not necessary in the area which has more than 1,000 mm of annual rainfall.

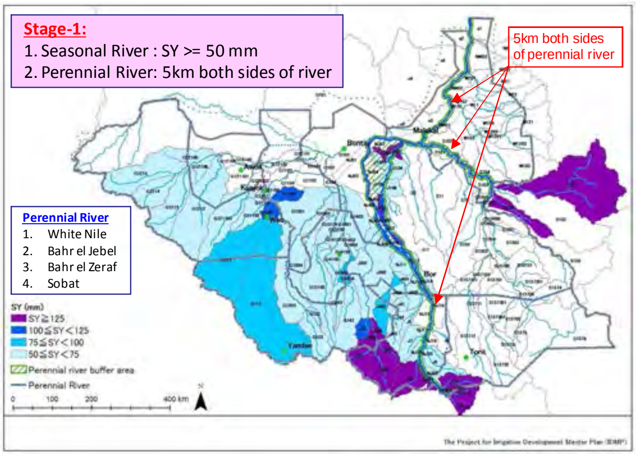


Figure 6.2 Selection of High Potential Areas: Stage-1

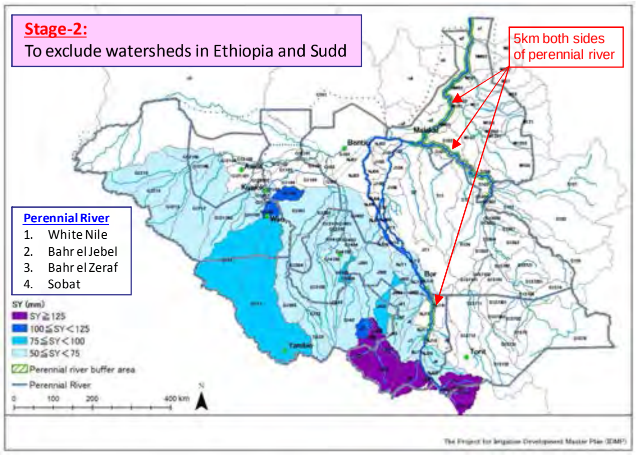


Figure 6.3 Selection of High Potential Areas: Stage-2

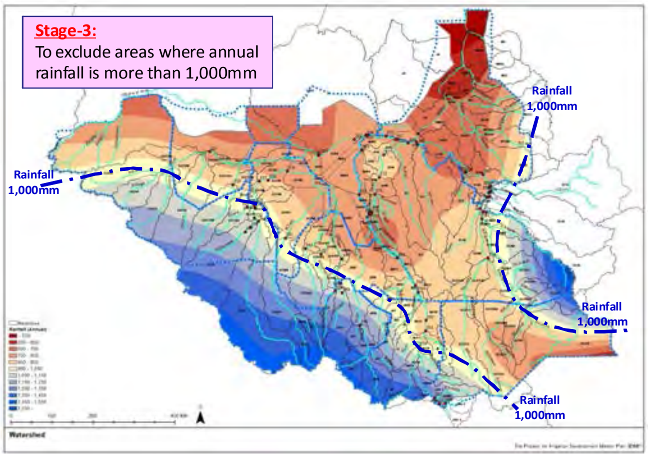


Figure 6.4 Selection of High Potential Areas: Stage-3 (Rainfall Contour)

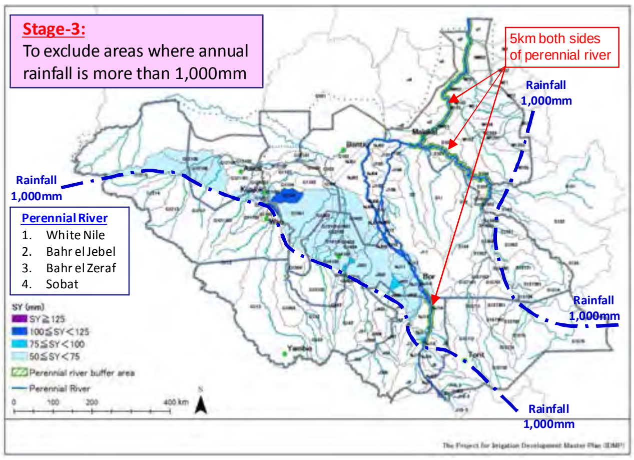


Figure 6.5 Selection of High Potential Areas: Stage-3

Figure 6.6 Selection of High Potential Areas: Stage-4 (Land Productivity & Socio-economic Potentials)

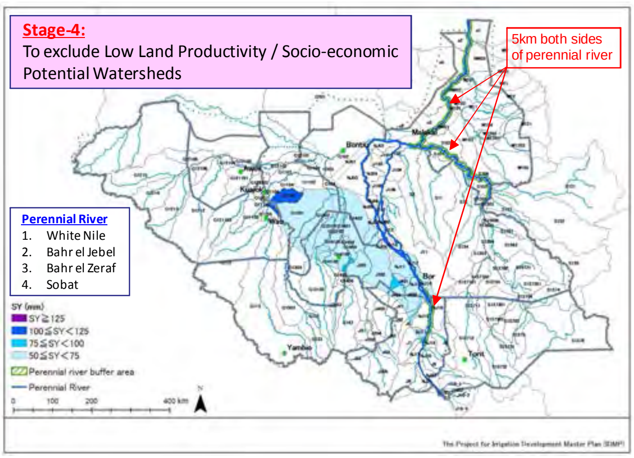


Figure 6.7 Selection of Potential Areas: Stage-4

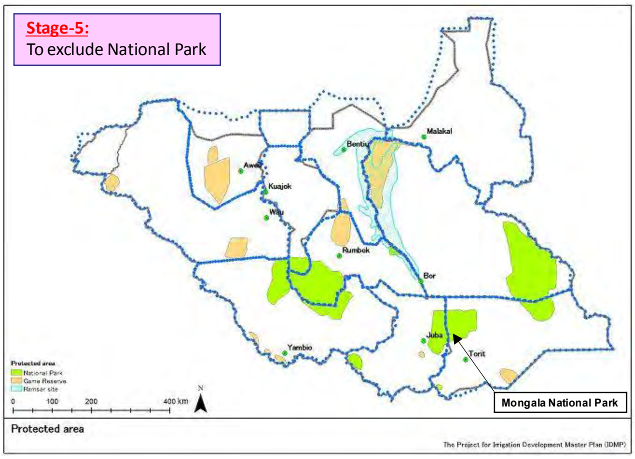


Figure 6.8 Selection of High Potential Areas: Stage-5 (Protected Area/Nature Reserve)

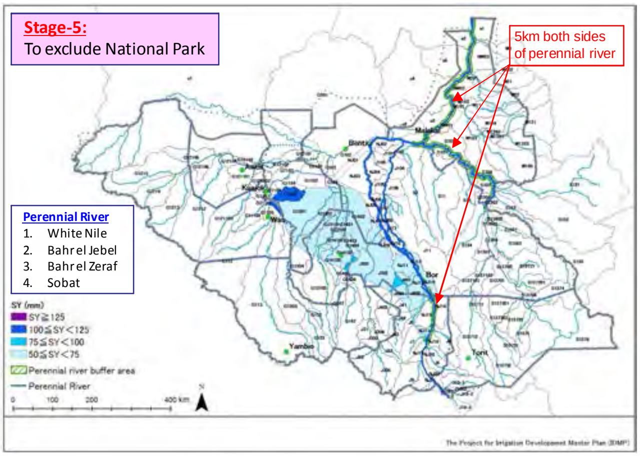


Figure 6.9 Selection of High Potential Areas: Stage-5 (10.9% of National Land)

In addition to the above procedures and evaluations, following considerations were pointed out to arrive the final decision of selecting the high potential areas:

1) Utilization of seasonal river as source of irrigation is limited in dry season due to fluctuations of discharge volume. Taking irrigation development into consideration of perennial rivers for the irrigation source, watersheds along the perennial rivers should be given higher priority in comparison with ones along the seasonal rivers;

By the above consideration,

2) The first higher potential areas in watershed along the perennial rivers should cover higher land productivity and socio-economic potentials, but not in Sudd area;

3) The second higher potential areas in watershed along the seasonal rivers should also cover higher land productivity and socio-economic potentials, but not in swamp areas; and

4) Total area of high potential areas for the detailed assessment in consideration of the above should be within 10% of national land.

In the response to the above considerations, high potential areas for the detailed assessment were reviewed/re-selected through the following stages in addition to previous five (5) stages:

Stage-6: To add high potential watershed along perennial river to the mentioned stage-5 (Refer to Figure 6.12);

Stage-7: To exclude i)Sudd and its surrounding areas, ii)areas more than 30 km from the perennial river. (Refer to Figure 6.13);

Stage-8: To exclude swamp area from the high potential watershed along the seasonal river (Refer to Figure 6.14);

Stage-9: To exclude the areas located at low land productivity and low socio-economic potentials along seasonal river (Refer to Figure 6.15); and

Stage-10: To exclude the areas where there is no observation station by taking into consideration future irrigation development (Refer to Figure 6.16).

Through the above-mentioned stages, 10% of national land is reselected as high potential areas for the detailed assessment as shown in Figure 6.17.

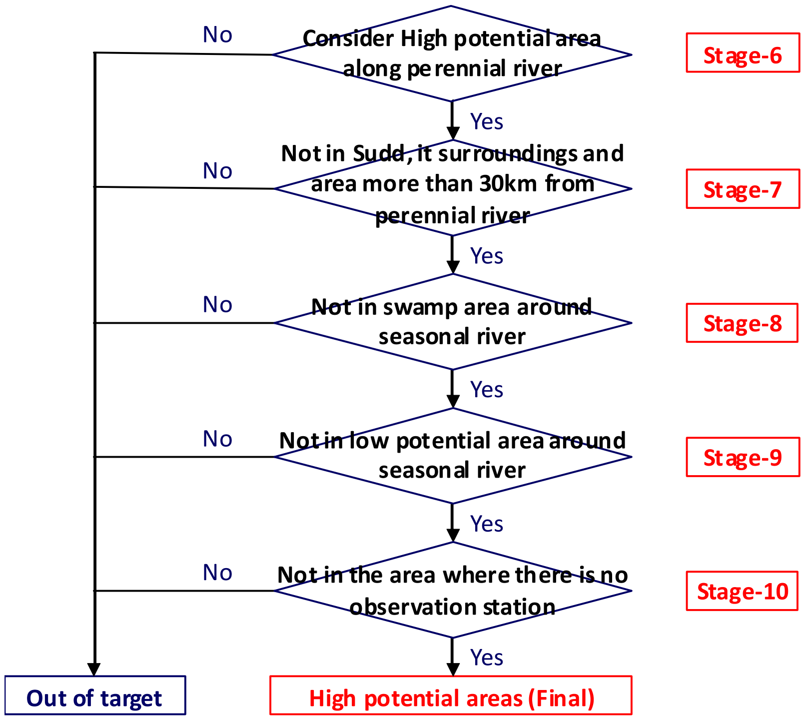


Figure 6.10 Flow of Selection of High Potential Areas for the Detailed Assessment

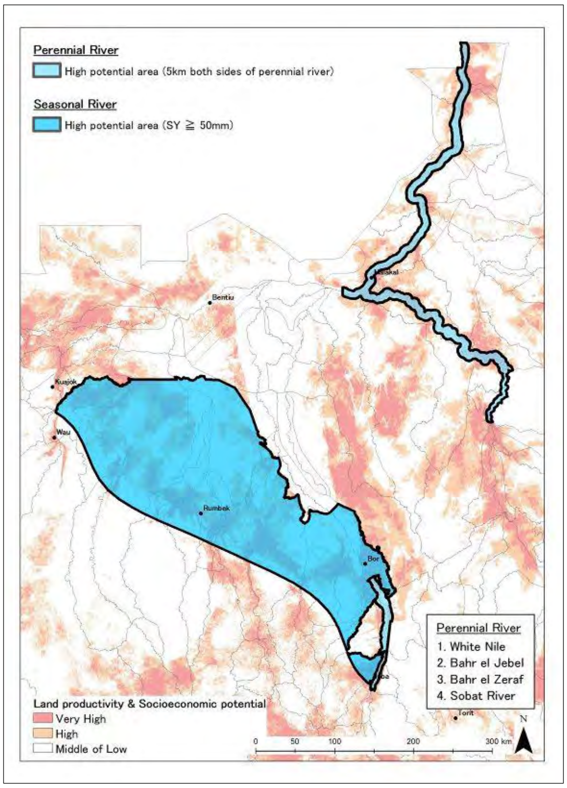


Figure 6.11 Selection of High Potential Areas : Stage-5 (Enlarged View)

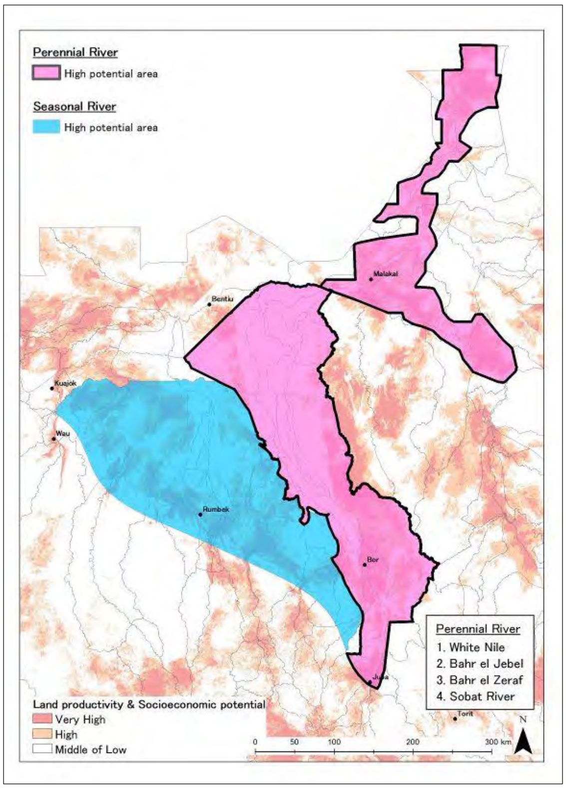


Figure 6.12 Selection of High Potential Areas : Stage-6

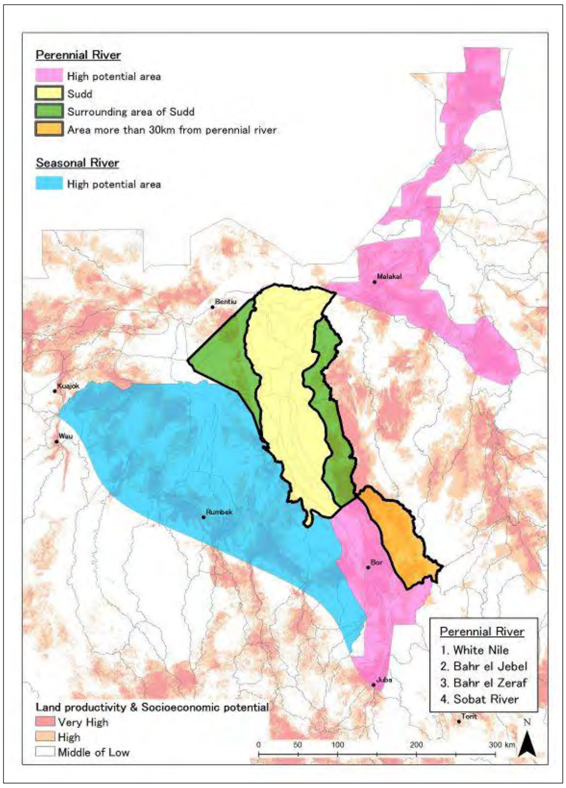


Figure 6.13 Selection of High Potential Areas : Stage-7

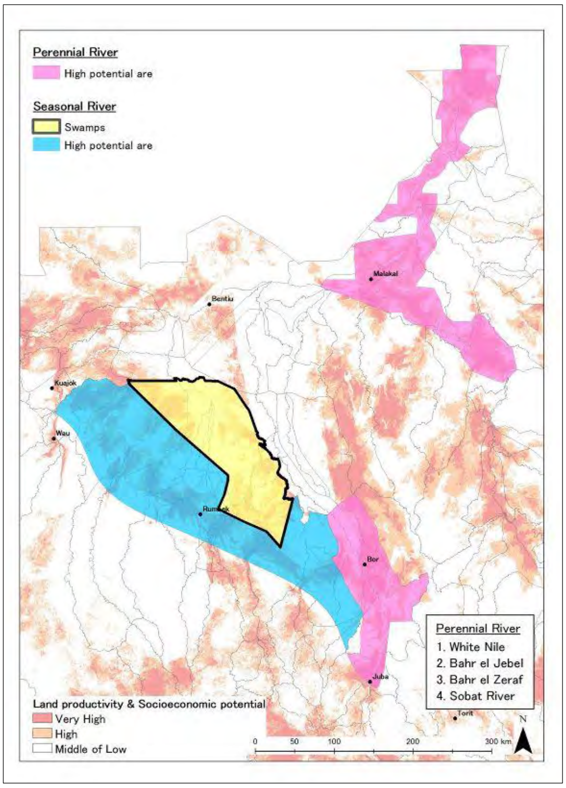


Figure 6.14 Selection of High Potential Areas : Stage-8

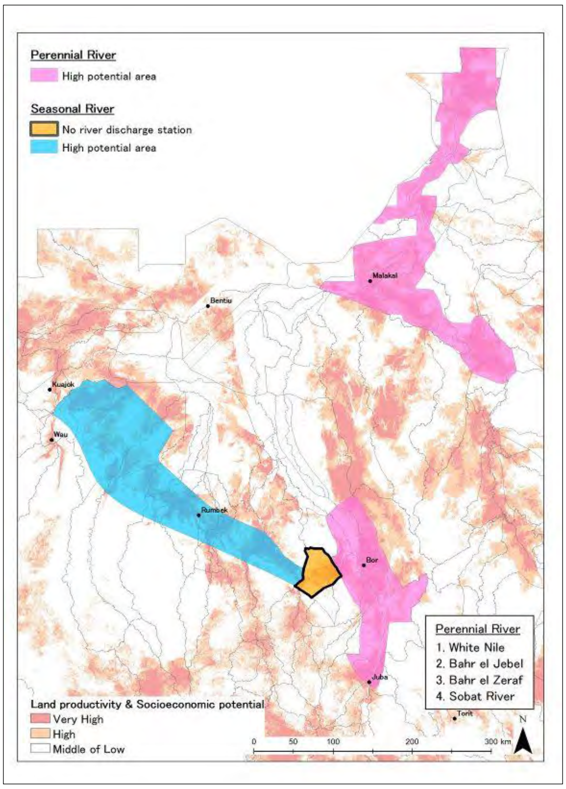


Figure 6.15 Selection of High Potential Areas : Stage-9

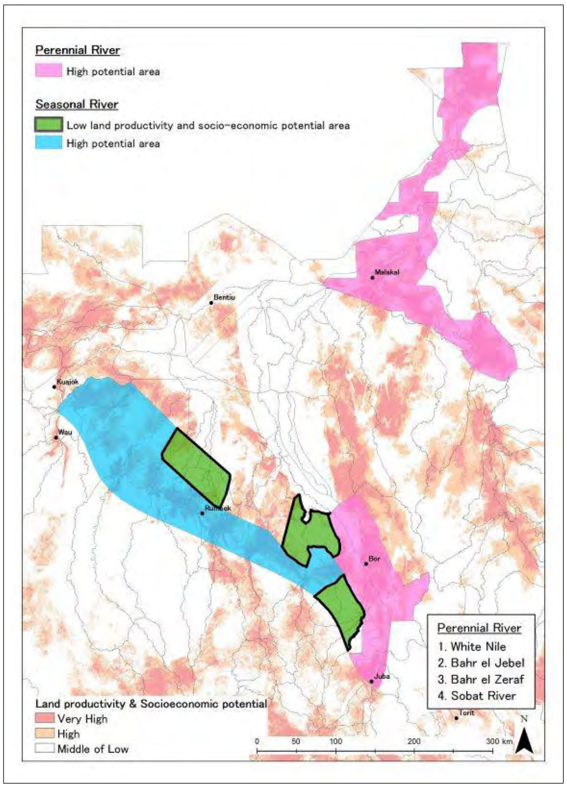


Figure 6.16 Selection of High Potential Areas : Stage-10

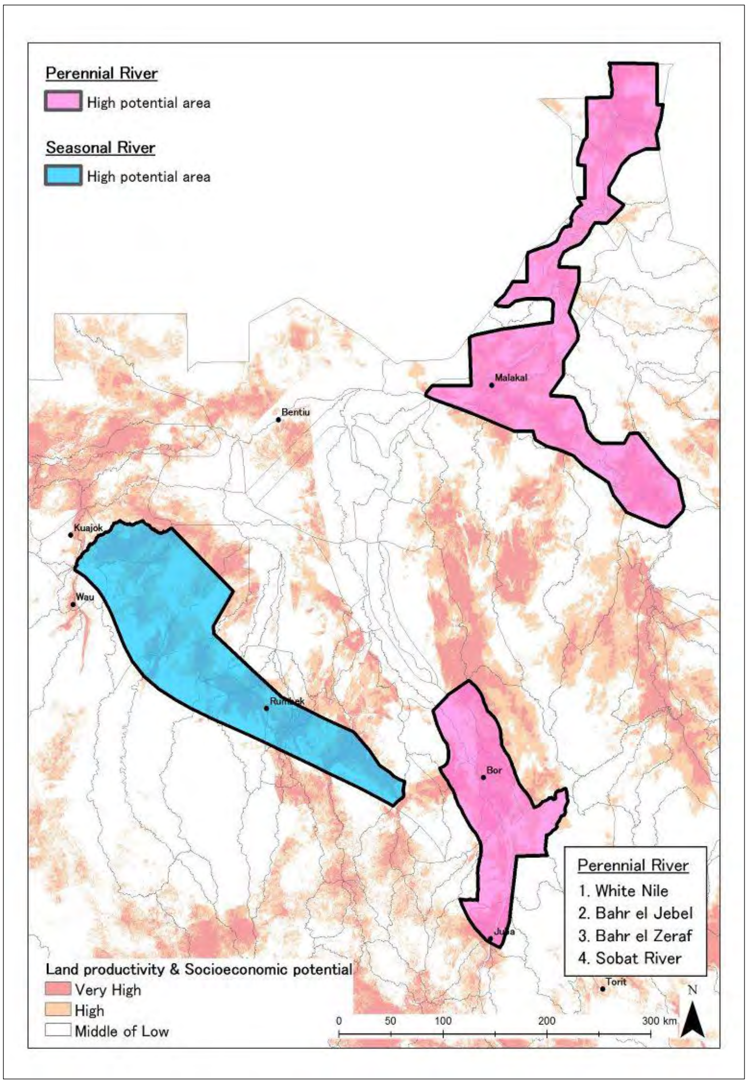


Figure 6.17 Selected High Potential Areas for the Detailed Assessment

ANNEX 3-2

GROUND WATER ANALYSIS
(GROUNDWATER DEVELOPMENT POTENTIAL)

1. APPROACH ON THE STUDY

1.1. General

There have been number of geological and hydrogeological studies in South Sudan. These were ñAssessment of the Irrigation Potential in Burundi, Eastern DRC, Kenya, Rwanda, South Sudan, Tanzania and Ugandaò so called as ñNBI Reportò, ñPreliminary Water Resources Assessment Study, Final Reportò, ñYei Town Water Supplyò, ñWater Supply in Jongley Areaò, ñWater Points Inventory by WIMS (Water Information Management System)ò, ñWell Inventory by PACT (Program Agency Collaborate Together)ò, some Geological Maps of Sudan and RSS, and also some Hydrogeological Maps of Sudan and RSS, and so-on. And in RSS, updated documents, data and information were collected and reviewed, and a field reconnaissance survey was conducted together with RSS-TT. Then, based on the reviews and the site observation, groundwater resources potential was finally evaluated.

Among these documents and data, three of the most reliable and comprehensive study reports were, especially, reviewed and assessed, and the groundwater resources potential of RSS was evaluated based on the results; these were 1) NBI Reports and its Appendix; South Sudan, 2) Preliminary Water Resources Assessment Study, and 3) DRAFT Water Resources Assessment Study Reports (for 7 Towns of Bentiu, Bor, Torit, Yambio, Aweil, Kuajok, and Rumbek) which was newly collected in RSS.

In the following three sections, the results of reviewing on theses study reports are simply summarized.

1.2. NBI Reports and its Appendix: South Sudan (NBI, 2012)

Formally the report title is rather long as shown above, so it is usually called as ñNBI Reportò. Itôs consisted of the main report and eight appendixes for each target country along with the Nile River. Appendix; South Sudan is one of them.

This report made a study on comprehensive irrigation potential in the each country through data collection, field reconnaissance, and analysis using modern remote sensing technique and model simulation. As a unique feature, it applied the same survey and analysis technique to all countries, and estimated the irrigation potential of each country by percentage between 0 to 100%.

For the estimation of water resources, the report applied ñNFLmodò model for analyses on both surface and groundwater. Remarkably, the study used modern satellite data (by GRACE) to complement the absolute shortage of raw data on groundwater and analyzed groundwater movement trend. However, the quite regular groundwater fluctuation was not caused by recharging but caused by a tidal mechanism of Earth. Irregular movements in the graph, pointing too low or high values, were just come from meteorological phenomena (by rainfall and evapotranspiration). Such tidal phenomena is easily confirmed or probed setting an AWLR (Automatic Water Level Recorder) with one millimeter accuracy in any monitoring well and continuing observation for around one year.

In the Appendix: South Sudan, the report indicated the referential tables of the surface flow through the Nile and groundwater volumes in Sudd (and Baggara) Basins (refer to Table 1.1.). The report said the huge difference of the figures in the table, for the recharging and the abstraction, should come from the difference of knowledge and understanding on groundwater recharge and discharge. As a result, the report showed a groundwater recharge map and a potential map indexed by percentage from 0 to 100%.

Table 1.1 Storage, Annual recharge and annual abstraction of the Sudd and Baggara acuifers In billion cubic meters (BCM)

	Sudd			Baggara		
Souce	Stor.	Rech.	Abstr.	Stor.	Rech.	Abstr.
Yousif & Abdalla (2010)	1.8	0.034	0.003	1.7	0.03	0.028
Madani (2009)	4.5	0.08	–	5.4	0.04	–
Omer (2008)	–	0.341	0.0018	–	0.155	0.012

1.3. Preliminary Water Resources Assessment Study, Final Report (MWRI / WB, 2010)

The report describes, in its general assessment on current status of water resources, groundwater information in RSS as in quite poor condition or lacking of important data or information for both surface and groundwater, for examples, meteorological data, hydrological measurement data, and groundwater data/information such as depth, yield, lithological description, results of pumping test, etc. It strongly expressed the importance to secure accurate and complete database.

For the groundwater aspect, the report noted severe shortage on the data or studies for groundwater basin in the case of RSS. There are some but they are not enough, not exact, not new, and not comprehensive. It said also such kinds of total and complete data base should be constructed urgently, just as agreeable.

The report summarized a geological condition of RSS at first, then, described clearly four major hydrological units in RSS as 1) Alluvial Deposits, 2) Umm Ruwaba Formation, 3) Nubian Sandstone, and 4) Basement Complex. Then, it described the situation of ñSudd Basinò as the only one and the number one groundwater basin in RSS, consisted of above mentioned four hydrogeological units (or aquifers). The study tried to estimate the groundwater development potential but it can said the potential should be so large but could not say how-much because of too short of available data/information.

Significantly, the study report provided quite exact hydrogeological map in it. The map indicated the distribution of each aquifer, depth contours of Umm Ruwaba formation, supposed groundwater flow in the Sudd Basin, and distribution of brackish water in the basin. The hydrogeological map is quite available for our study.

On the groundwater quality, the report noted that the groundwater quality should be good or permissible for human beings, but it is not sure in this moment because too small information.

1.4. DRAFT Water Resources Assessment Study Report (MWRI, 2012)

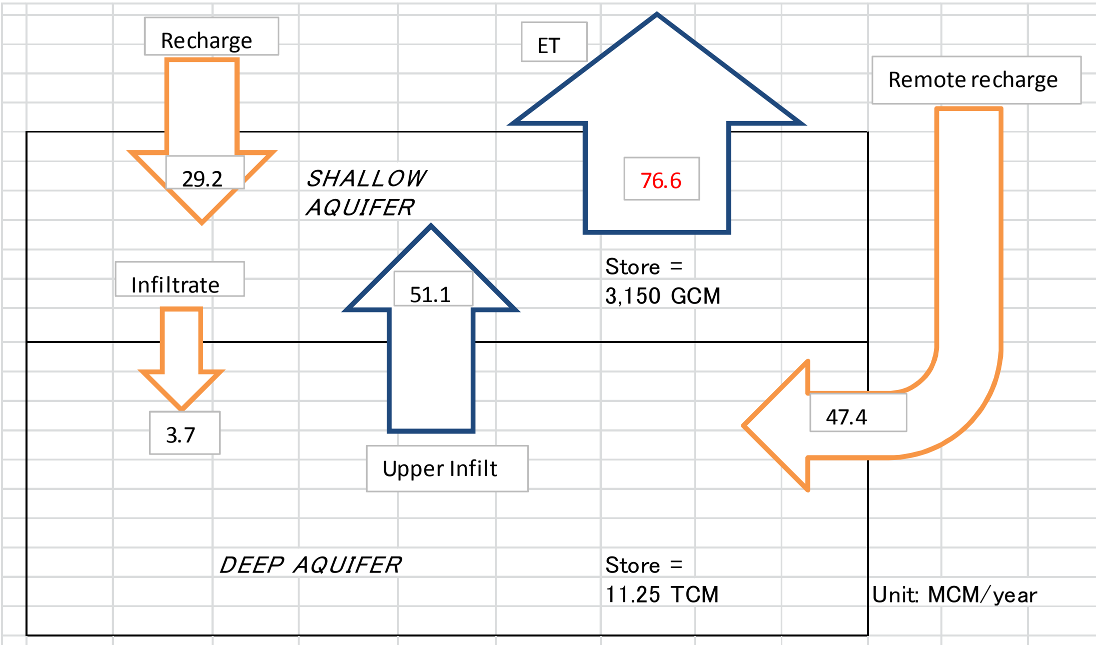
(Bentiu: Unity State, Bor; Jonglei State, Torit; Eastern Equatoria State, Yambio; Western Equatoria State, Aweil; Northern Bahr el Ghazal State, Kuajok; Warrap State, and Rumbek; Lake State)

This study reports were obtained recently. Purpose of the study was making up urban water supply plans in the seven local cities except the capital of Juba. For the purpose, the studies sought both surface and groundwater resources potential in and around each city.

The reports described out the natural and social conditions of seven target cities, including geology and hydrogeology of RSS in their common description parts. Six cities out of seven (excepting Yambio) were in or along with the Sudd Basin, and therefore, the groundwater studies must focus to the Sudd Basin, only one groundwater basin in RSS. Four of the major aquifers (Alluvial, Umm

Ruwaba, Nubian, and Basement) in Sudd Basin were described as a general in every city but not so in detail because of shortage of data/information.

Remarkably, in these six cities along with the Sudd Basin, groundwater volume contained in Sudd Basin was roughly calculated as around 2.3 x 10^{11} m^3. And in the Appendix of Volume Aweil, groundwater balance of Sudd Basin, applying MODFLOW, was conducted and resulted as shown in th following figure (original was in bar chart but the author revised into a concept chart). Along with the graph, yearly recharge in the basin was 29.2 MCM, evapotranspiration was 76.6 MCM, and around 51.1 MCM of groundwater in the lower aquifer was infiltrating upward to the shallow aquifer.



In the report, aquifers in Sudd Basin except Nubian Sandstone and the Basement Complex (it means a combination with Alluvial Aquifer and Umm Ruwaba Formation) was separated into two aquifers of the shallow (0 to 150m depth) and the deep aquifers (lower than 150m), and the isobathic line map of both aquifers were provided. Thus, our study shall be continued mainly applying the data/information in this òDRAFT Water Resources Assessment Study Reports (for 7 Towns of Bentiu, Bor, Torit, Yambio, Aweil, Kuajok, and Rumbek)ò.

2. GEOLOGIC AND HYDROGEOLOGIC SETTINGS OF RSS

2.1. Geological Setting of RSS

Geological setting of RSS is rather simple, especially its surface geology is consisted of only two major units basically; Basement Complex of mainly Pre-Cambrian age including several intrusive rock bodies from Pre-Cambrian to Tertiary, and some unconsolidated sediments filling up the vast Sudd Basin.

Pre-Cambrian Basement Complex associated with some young intrusive rocks expose in the southwest, south, southeast and east to northeast hedge of the country just surrounding the Sudd Basin occupying around one thirds of the territory. Basement Complex is consisted of mainly ñGranitesò and Granitic Gneissò, normally massive and hard. However, the Granites form weathered zone on its surface, and regular joints and fissures inside. Intrusive rocks associated with the basement are mainly Basalt, very hard and impervious. Unconsolidated sediments occupy remaining two thirds of the country area, and the Nile run through the basin from south to north. The sediments are classified into two formations; old sediments formed through Tertiary to Quaternary, and young one of recent. The old sediments are called as ñUmm Ruwaba Formationò, the most famous aquifer in RSS.

In the country, there is another important geological unit, which is not exposed anywhere though. It is so-called ñNubian Sandstoneò, sedimentary rock formation formed through Paleozoic to Mesozoic era and one of the largest aquifer in Africa but its groundwater is ñfossil waterò. The Nubian Sandstone distributes in the northwest corner of the Sudd Basin, at the northwest of Aweil, State capital of Northern Bahr el-Ghazal.

Thus geological setting of RSS is summarized as Table 2.1 shown below, and a geological map of RSS is shown in Figure 2.1.

Table 2.1 Geological Setting of South Sudan

Era	Period	Common Name in Africa	Local Name
Ceozoic	Quaternary	Alluvium	Alluvium
	Tertiary	Continental Terminal	Umm Ruwaba Formation
Mesozoic Paleozoic		Continental Intercalary	Nubian Sandstone
Proterozoic	Pre-Cambrian	Basement Complex	Basement Complex

2.2. Hydrogeological Setting

In the country, there are four major aquifers, namely; Alluvial Aquifer, Umm Ruwaba Aquifer, Nubian Sandstone Aquifer, and Basement Complex Aquifer, from upper to lower. Basement Complex is a kind of important aquifer but, in the same time, it is completely impervious basement to the other aquifers overlying it. The basement outcrops in southwest 1/3 of the country and along northeast hedge of the territory, forming a vast concave like a ship bottom in WNW-ESE direction between the both outcrops. The concave was formed through geo-technical movement in very old time, and then, the trough was

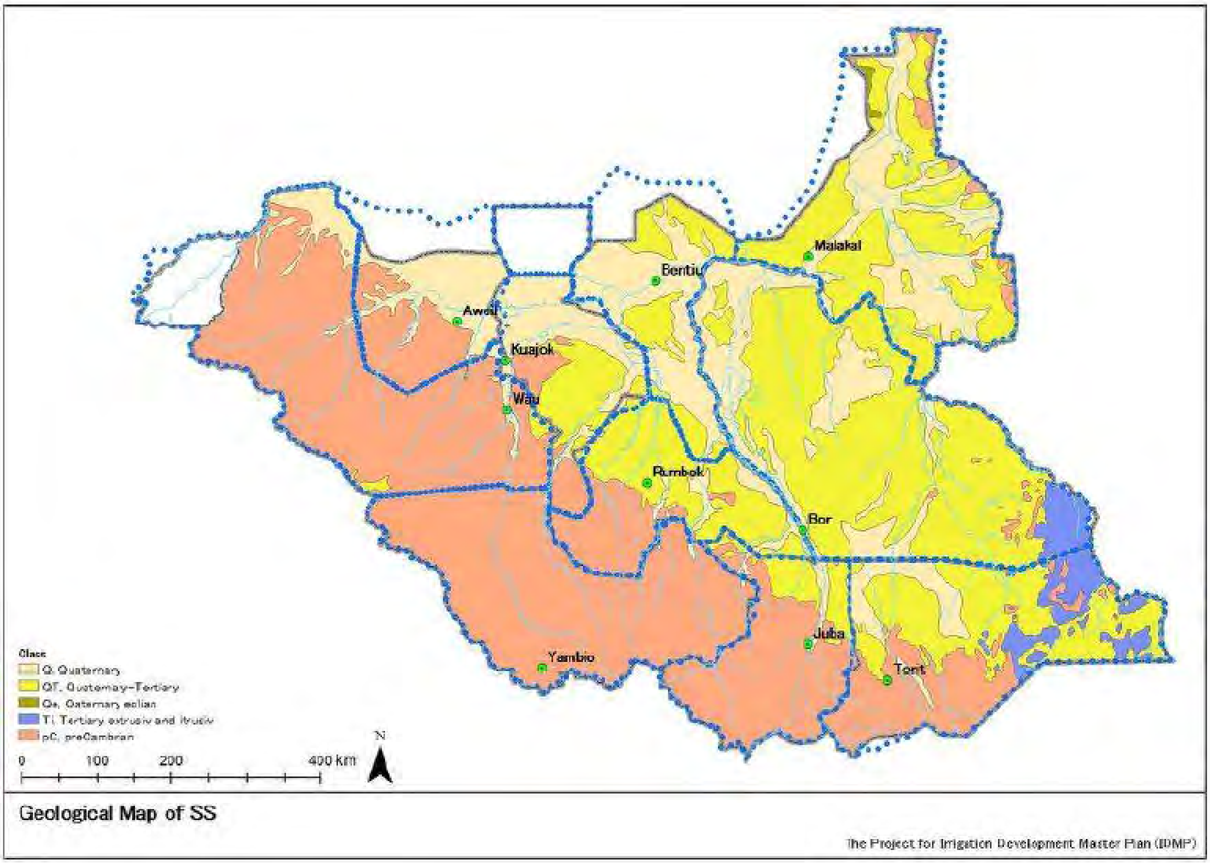


Figure 2.1 Geological Map of RSS

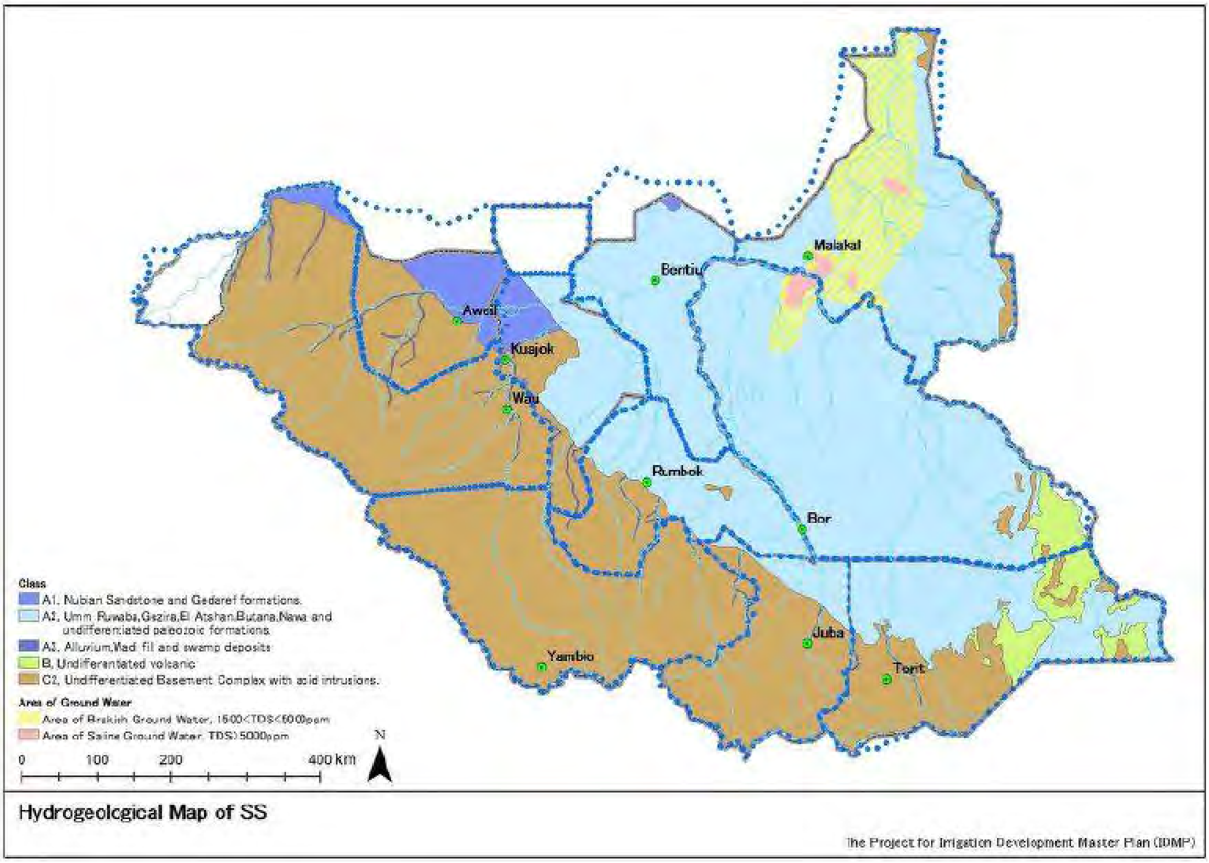


Figure 2.2 Hydrogeological Map of RSS

filled by huge volumes of sediments through long geological time, at first by Nubian Sandstone at NW end, then by Umm Ruwaba formation almost full of the basin, and alluvial deposits are now covering the Umm Ruwaba formation along with the main river routes. This is the hydrogeological explanation of Sudd Basin, as the only one and the number one groundwater basin in RSS. A hydrogeological Map is attached as Figure 2.2.

Basement Complex Aquifer

Basement Complex is mainly consisted of granitic rocks, and these rocks are easily weathered its surface forming a coarse sand like zone. Farther, they form rather regular joints inside, and many fissures develop along with the joints. These weathered zones and fissures can keep groundwater inside, and form aquifer. Scale of the aquifers are not so large but water quality is usually good for drinking, so the Basement Aquifer shall be one of important water resources for rural or small scale urban water supply.

Associated with the weathered zone of Basement Complex, Laterite cover is commonly observed in the areas where the Basement crops out. Laterite cover is from 3.0 to 5.0m in thickness, and usually hard to very hard. However, Laterite layer is permeable and easily forms small scale aquifer just enough to withdraw by a hand-pump.

Nubian Sandstone Aquifer

Nubian Sandstone Aquifer is a quite famous aquifer in the world, for its enormous volume (spreading from Libya to Egypt and Sudan), quite high yield (22,520 m^3/day in artesian, sometimes), very high confined pressure (more than 40m above ground surface), high groundwater temperature (more than 75 sometimes), and by its nature of fossil aquifer. As the name shows it is massive and hard sandstone but it has very high porosity can contain enough groundwater in it. Nubian Sandstone is a major aquifer in the north Sudan, however, it distributes only at northwest corner of the Sudd Basin, in the north of Aweil, in the case of RSS. Based on the existing report (Preliminary Water Resources Assessment Study), it distributes at the depths from 283 to 341m, below the thick Umm Ruwaba Formation. There is not enough information on the hydrogeological condition on its but it can be expected the high yield.

Umm Ruwaba Formation

This is another famous aquifer but in the north and south Sudan. It filled up the most of the vast Sudd Basin, supposedly more than 350m from the ground surface (refer to the above sentence), so that the volume of the sediments filled up the Basin are quite huge. Basically, the formation is consisted of fluvial deposits, mainly coarse grain sediments such as gravel, sand and sandy silt. However, it was believed to be deposited in the basin as the condition of ñinland deltaò repeatedly and from every direction, therefore, the qualities of sediments are not widely continuous in vertically and horizontally also. Thus, the aquifer quality of the Umm Ruwaba was not steady, some showed quite good yield but another well drilled near the one showed not prefer yield. An existing report said the Umm Ruwaba formation is an aquifer with medium quality as a total. One of the data showed the Transmissivity of the formation should be ranging from 100 to 3,000 m^2/day. However, the volume of the sediments is enormous and it is totally consisted of fluvial deposits, so that the groundwater volume contained in the Sudd Basin (Groundwater Storage) is also enormous. ñWater Resources Assessment Study Report for 7 Townsò said the total volume of the aquifer should be 14.7 x 10^{11} m^3, and the groundwater storage in the Sudd Basin should be 2.3 x 10^{11} m^3. Groundwater quality of the Umm Ruwaba

Formation is almost good for drinking, excepting the center to the north branch of the basin which indicates high salinity from 500 to 5,000 ppm of TDS.

The Sudd Basin is considered as a closed groundwater basin, as a matter of fact. The groundwater flow within the basin itself is towards its central part. In the central part, where groundwater levels intersect the ground surface of lower elevation, groundwater may discharge to the ground surface forming wetlands or lakes, seasonal or permanent.

Alluvial Aquifer

Alluvial aquifers cover the areas only along with large rivers or seasonal Wadis. Alluvial aquifers are conformed by fluvial deposits mainly sand and gravel, associated by some silty and clayey deposits. Depth of Alluvial deposits is usually less than 50m and groundwater quality of the aquifer is mostly excellent.

Alluvial Aquifer is, thus, easily drilled, shallow depth, and excellent water quality, nevertheless, the aquifer is not so much developed in RSS. Only a few data and information on Alluvial Aquifer is available right now. One of the reasons was that the alluvial deposits were hardly distinguished from the Umm Ruwaba Formation because the both were unconsolidated fluvial deposits. To develop Alluvial Aquifer actively and to accumulate the data and information on it is urgently required in near future.

Finally, the major aquifers in RSS are summarized in a table together with geological setting, as Table 2.2.

Table 2.2 Major Aquifers in RSS

Age	Common	Aquifer	Character	Advantage	Disadvantage	Note
Quataernary	Alluvial	Alluvial Aquifer	・Unconsolidated sand & gravel ・Unconfined aquifer.	・Excellent water quality ・Shallow well depth	・Abundant when surface water is abundant	Filtered river water
Tertiary	Continental Terminal	Umm Ruwaba Aquifer	・Unconsolidated sand & gravel ・Confined aquifer.	・Good water quality ・Medium yield	・Unstable aquifer condition ・Saline water in somewhere	Around 350m thickness
Paleozoic to Mesozoic	Continental Intercalary	Nubian Sandstone Aquifer	・Sandstone with shale and clay intercalation ・World's largest fossil water aquifer ・Highly confined ・High water temperature	・Containing huge volume of groundwater ・Artesian condition mostly	・Need a deep drilling ・Need hard rock drilling ・Very high water tempereture sometime	500m～3000m thickness
Pre-Cambrian	Basement Complex	Basement Aquifer	・Weatherd zone or fissured aquifer ・Unconfined aquifer	・Easy to drill ・Good water quality	・High local varaiety ・Low driing successful rate	Occupy 1/3 of SS teritory

3. GROUNDWATER RESOURCES

3.1. Groundwater Basin in RSS

As explained so far, there are four major aquifers in South Sudan, however, there is only one but huge groundwater basin called as the Sudd Basin. And, the basin is consisted of all the four major aquifer units. The Basement Complex forms its impervious bottom, Nubian Sandstone fills its north-western corner, Umm Ruwaba Formation fills up the most of the basin by fluvial deposits, and the surface is covered and now covering by Alluvial deposits (Alluvial Aquifer).

Still now there is few information on the basin, for example, no one knows its exact depth and hydrogeological properties such as Transmissivity, Storativity, Specific Yield, and groundwater quality. However, based on reviews to existing study reports, examining on several geological and hydrogeological maps, and through a field reconnaissance, the total shape of Sudd Basin was roughly drawn up. The total area was sought from the geological map, as the area distributing Alluvium and Umm Ruwaba Formation (including other Tertiary Deposits) as shown in Figure 3.1. Unconsolidated sediments in the basin were divided into three layers as Alluvial deposits, Umm Ruwaba (the shallow) and Umm Ruwaba (the deep) aquifers by the depths of 50m and 150m. Division of Umm Ruwaba was in accordance with the MODFLOW model in the 7 town report. Isobathic contours of the shallow and the deep aquifer are also taken from the report supposition.

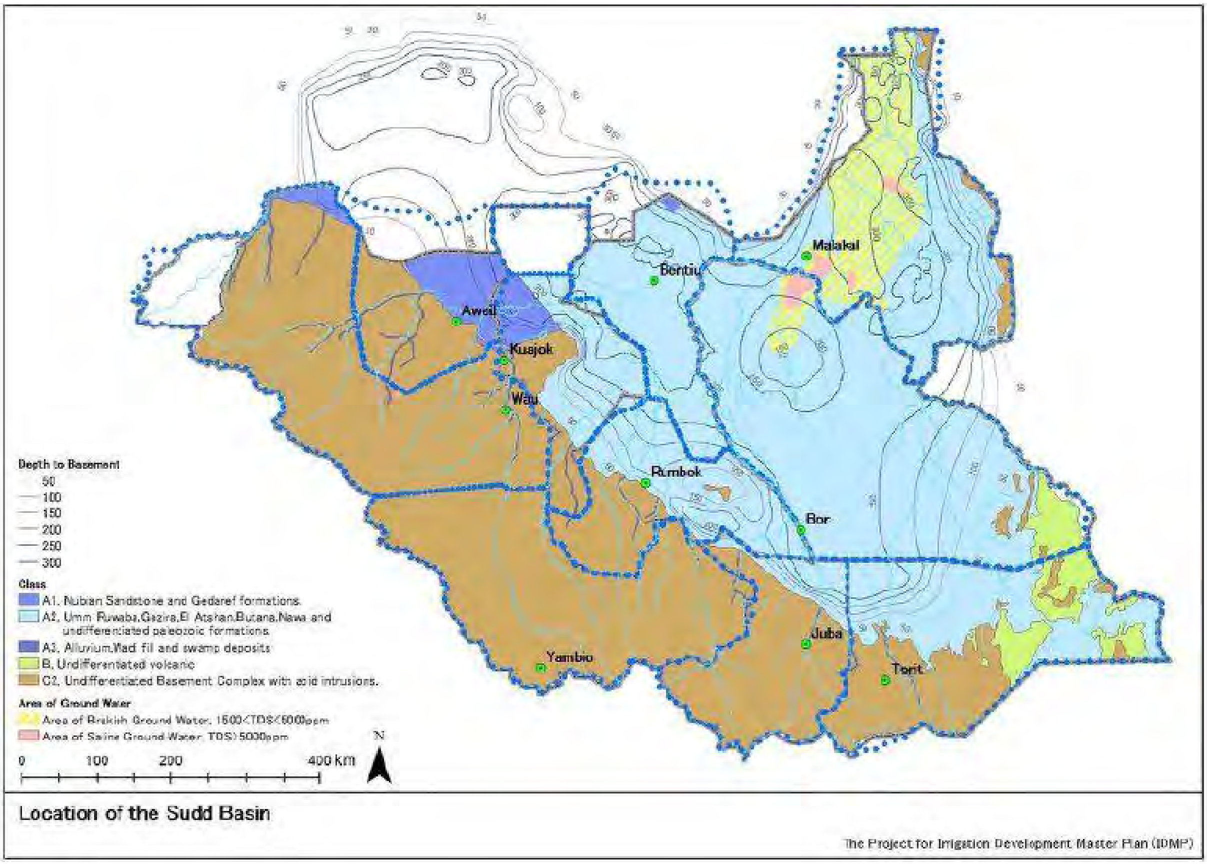


Figure 3.1 Location of the Sudd Basin

Then, major figures were supposed as follows:

- Total area: approx.. 432.7 (1,000 km^2)
- In territory: approx.. 365 (1,000km^2)
- Area brackish water approx.. 3.6 (1,000km^2)
- Aquifer Volume (Alluvial aquifer): approx.. 1.947 x 10^{13} m^3
- Aquifer Volume (Umm Ruwaba: shallow): approx. 3.843 x 10^{13} m^3.
- Aquifer Volume (Umm Ruwaba: deep): approx..3.989 x 10^{13} m^3

Total area of Sudd Basin was estimated as 432,700 km^2, and around 85% of it is in the territory of RSS. However, there is no barrier in groundwater body, so the following consideration shall go on using the total area. Thus, the volumes of Alluvial, Umm Ruwaba (the shallow) and Umm Ruwaba (the deep) aquifers were 19.47, 38.43 and 39.89 TCM (Tera: 10^{12} Cubic Meter), respectively. Farther, there was rather large area where brackish water was distributing in the northern branch of the basin, and this area was already omitted from the figure of the areas.

3.2. Groundwater Storage and Yields

3.2.1 Groundwater Storage Model

As explained so far, the volume of each aquifer was quite huge as counted by TCM, and therefore, groundwater volumes contained in each aquifer, ñGroundwater Storageò in other words, was also huge. The groundwater storage means simply a water volume contained in aquifer, and must be distinguished from ñGroundwater Yieldò which means the groundwater volume yielded from the aquifer when groundwater table (in the case of unconfined aquifer) or piezometric head (in the case of confined aquifer) was reduced for a certain depth.

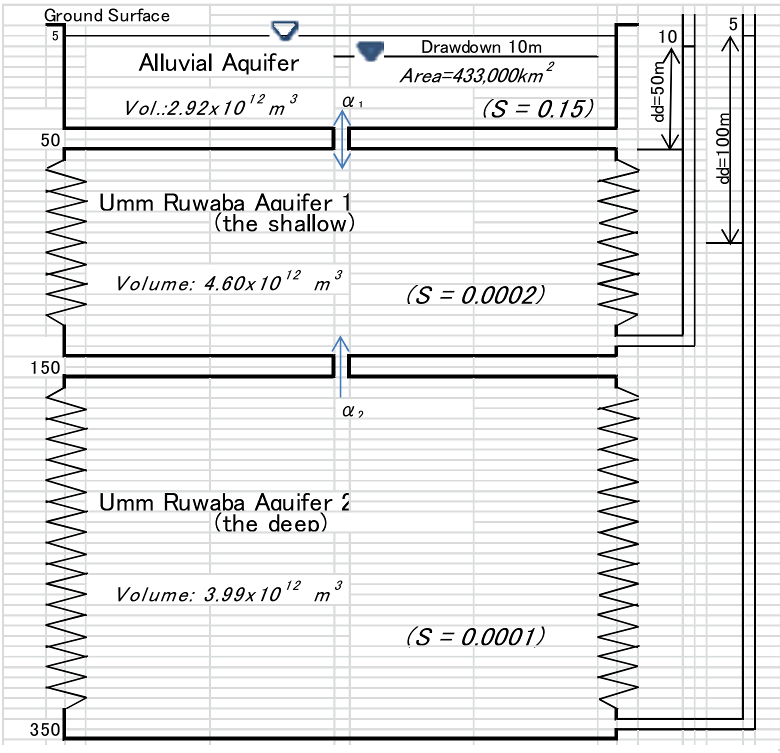


Figure 3.2 Storage Model of Sudd Basin

In the study, only Alluvial aquifer is accounted as unconfined aquifer and both Umm Ruwaba aquifers are classified to confined aquifer. Thus, the Sudd Basin was modeled up as shown Figure 3.2. The model was one of the concept model: Synthetic Storage Model (SSM)ò developed by Sanyu Consultants Inc., for analyzing both surface and groundwater balance. The model was applied for groundwater analysis on several underground dam schemes in Japan. Although Sudd Basin was roughly modeled under the concept of SSM but actual analysis could not be done because of lacking of input data, e.g. Permeability, Storativity, and groundwater hydrograph of each aquifer.

Sudd Basin was modeled into three stories tanks meaning Alluvial, Umm Ruwaba upper, and Umm

Ruwaba lower aquifers respectively. The uppermost, Alluvial aquifer, has 50m depth and open groundwater table. The lower two aquifers are drawn as closed tank with spring which means piezometric pressure. Total depth was estimated at around 350m. All of the tanks were connected by small pipes with any leakage coefficients; Ŭ$_1$ andŬ$_2$. Groundwater table of Alluvial aquifer was assumed as 5.0m below the ground surface in average. The second and the third aquifers are highly confined, having high piezometric head nearly same with Alluvial aquiferôs one, and water comes up or down depending upon the depths of water table and the head. The second tank and the third tanks are also connected by small pipe, and water may come up from the lower to upper aquifer because of the deference of heads.

3.2.2 Groundwater Storage

In the case of unconfined aquifer, groundwater storage can easily be calculated through ñthe aquifer volume x Storativityò, if the Storativity is known. Storativity is a ration of groundwater volume released from an aquifer through unit drawdown (no dimension), which is obtained though pumping test with at least an observation well(s). Unfortunately, there was no reliable pumping test data for Alluvial aquifer, a common value of 0.15 is adopted as a Storativity and Specific Yield of Alluvial deposits. Then, supposed groundwater table of Alluvial aquifer in Sudd Basin was set at 5.0m below the ground surface.

The case of confined aquifer is a little deferent from the unconfined aquifer. Confined aquifer has no groundwater table, having only a piezometric head; a pressure groundwater shall go up when a drilling touched to the aquifer. Groundwater in a confined aquifer is pressed into the fixed certain space elastically, and the elasticity is Storativity in the case of confined aquifer. In this case of confined aquifer, an effective porosity in where groundwater contained was considered a little smaller than the case of unconfined aquifer because of their accumulated depth. In the study, the values of 0.12 and 0.10 were taken for effective porosities to estimate the groundwater storage.

Because of the huge volumes of aquifers, groundwater storages in each aquifer were also so huge, as shown in Table 3.1. As a result, total groundwater storage in Sudd Basin was estimated as 1.151 x 10^{13} m^3, 11.51 TCM (Tera Cubic Meter) indeed.

Table 3.1 Estimation of Groundwater Storage and Yields

Depth (m)	Area(km^2)	Vol in Dep.	Aq. Vol. (m^3)	Storage Vol.	Yield (m^3)	Note
0m	432748.8				*Sy=0.15*	Alluvial Aquifer
<25	432743.3	8.655E+12		*S=0.15*	*dd=10m*	
<50	432410.4	1.081E+13	1.947E+13	2.920E+12	6.491E+11	
<75	412569.5	1.056E+13				Umm Ruwaba (Shallow)
<100	378665.3	9.890E+12			*dd=50m*	
<125	357875.8	9.207E+12		*S=0.12*	*Sy=0.0002*	
<150	336758.3	8.683E+12	3.834E+13	4.601E+12	4.601E+10	
<175	313324.2	8.126E+12		(↑= q_0)		Umm Ruwaba (Deep)
<200	287628.6	7.512E+12				
<225	259140.9	6.835E+12				
<250	227873.3	6.088E+12				
<275	180595.2	5.106E+12				
<300	123813.4	3.805E+12			*dd=100m*	
<325	34700.4	1.981E+12		*S=0.10*	*Sy=0.0001*	
<350	0	4.338E+11	3.989E+13	3.989E+12	3.989E+10	
Total		9.770E+13	9.770E+13	1.151E+13	7.350E+11	

3.2.3 Groundwater Yields

Relationship between groundwater drawdown and releasing water volume (yields) in the case of SSM are shown in Figure 3.3 As shown in the figure, there are two cases; for unconfined aquifer and for confined aquifer. In the case of unconfined aquifer, aquifer volume *v* is a function of the depth ($v = f(d)$), and the water volume *q* is calculated as $q = \lambda v$ (herein, $\lambda$is same to Storativity. In the case of confined aquifer, the situation is a little complicated because the aquifer has no groundwater table, having only a piezometric head. In this case, groundwater volume *(q)* when the head is *(h)* is calculated as $q = q_0 \{ 1 + S(h - z)\}$. Therefore, the groundwater volume $(q_2 - q_1)$ when the heads are changed from h_2 to h_1 is estimated as $(q_2 - q_1) = q_0 \{ 1 + S(h_2 - z)\} - q_0 \{ 1 + S(h_1 - z)\} = q_0 S(h_2 - h_1)$.

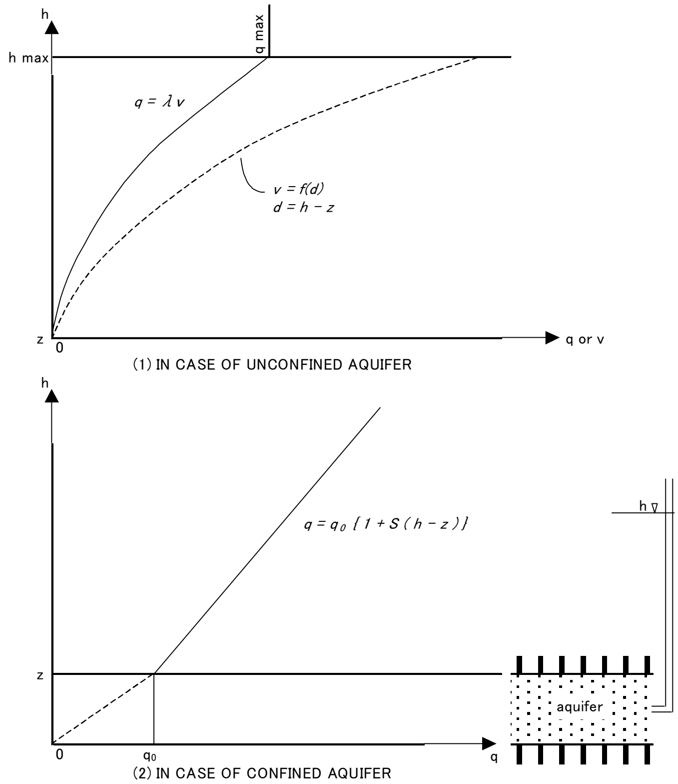


Figure 3.3 Groundwater Table/Head & Volumes

Groundwater yields in the case of unconfined aquifer is easy, it can be obtained through the calculation of ñthe Area x drawdown (equals volume) x Storativity (*S*) or Specific Yields (Sy)ò. As shown in the table, Sy was set as 0.15 as same as the Storativity for groundwater storage. Then, supposed drawdown on the aquifer was set as 10m from the SWL (5.0m below the ground surface). Because of the huge wideness of the basin, groundwater yield from Alluvial aquifer was estimated as 6.491 x 10^{11} m^3 (649.1 GCM).

In the case of confined aquifer, the original groundwater volumes contained in each aquifer is important. In the study, effective porosities of 0.12 and 0.10 were adopted because of the different compaction conditions through sediments depth. Suppositions of drawdown were 50m and 100m for the shallow and the deep aquifers, and Storativity of 0.0002 and 0.0001 was applied for each aquifer.

Under above mentioned conditions, groundwater yields were estimated as 6.49 x 10^{11}, 4.60 x 10^{10}, and 3.99 x 10^{10} m^3 for Alluvial, Umm Ruwaba shallow, and the deep aquifers, respectively. Total groundwater yield shall be 7.35 x 10^{11} m^3 (735.0 GCM), around 6.4 % of the groundwater storage. These figures are summarized in Table 3.1, together with the groundwater storage volumes.

3.3. Groundwater Development Potential

Groundwater storage and yields were, based on several assumptions though, estimated out as huge figures (refer to Table 3.1). Those are statistic storage and total yields under a certain groundwater drawdown. However, in the consideration on groundwater development potential, easiness of groundwater develop (well depth, condition, successful rate, etc.), actual yielding from a well, and water quality, and so on, must be evaluated.

Purpose of the groundwater development in this Study is for irrigation water, which needs rather large volume to discharge comparing to the other water usages such as domestic water supply or industrial usage. Therefore, groundwater storage volume must be the top one of priority item for development potential. Groundwater storage volume is directly related to the volume of aquifer, and it means, the deeper the aquifer deposits is the higher potential rank it has. Isobathic contour map on total sediments in the Sudd Basin, combined with the figures of ñLayer 1 Thickness Contoursò and ñLayer 2 (Aquifer) Thickness Contoursò displayed in the Report on 7 towns Water Resources Assessment[1] is shown as Figure 3.4 together with some other hydrogeological information such as the distributions of brackish groundwater and Nubian Sandstone, another excellent aquifer in RSS. Total thickness of the sediments in the Sudd Basin, the depth to the Basement Complex in other words, is estimated at around 350m. The total depth was divided into three zones; the zone with depth less than 150m, the zone with depth more than150m but less than 250m, and the zone having depth of more than 250m. Each depth zone has groundwater development potential ranking in accordance with the depth (from level II to level IV).

In the northwest corner of the Sudd Basin, rather small area but Nubian Sandstone is distributing, and the formation may have quite high groundwater development potential because the sandstone is showing huge yield and artesian condition in other countries including the north Sudan. Of course itôs depends on the depth of the formation but when a production well is constructed in this formation, at least more than 100m (more than 200m sometimes) of the Alluvial and the Umm Ruwaba Formations overlying must be drilled and these formations are also good aquifer. Thus, the zone where Nubian Sandstone is distributing shall be given the highest potential, as level V.

Basement Complex; surrounding the Sudd Basin and forming the bottom of Umm Ruwaba Formation, is basically an impervious basement for the Sudd Groundwater Basin. However, usually it forms small scale aquifers in its weathered zone or in the fissure zone. In the hilly zone, the basement used to be covered by Laterite, and Laterite formation contains groundwater forming small aquifers. Thus, the wide area where the Basement Complex exposes can yield groundwater enough for rural or small town water supply, excepting the mountain area, so that the formation can be given the lowest groundwater development potential, as level I. While, in the eastern end of the country, rather new volcanic intrusive rocks are exposing. These intrusive rocks are usually massive and though, do not form aquifers yielding significant volume of groundwater. The area is, thus, no groundwater development potential is given (level 0).

Based on the previous study reports including the said 7 town report, a brackish groundwater body distributes in the northern branch of the Sudd Basin. Salinity of such groundwater ranges from 1,500 to 5,000, sometimes beyond 5,000 ppm of TDS. By the classification chart of water for irrigation by SAR (After U.S. Department of Agriculture, Driscoll, 1989), salinity hazard becomes ñHighò by 750 and ñVery Highò by 2,250 εS/cm of EC values, which are converted to 375 and 1,125 ppm of TDS. The salinity level of the water body is more than 1,500 ppm. Thus, the salinity degree of this groundwater body is too high to use as irrigation water or more likely dangerous for irrigation. The brackish groundwater zone is, therefore, ranked less than 0, as minus 1 (-I).

As explained so far, groundwater development potential in RSS is ranked as 7 classes from -I to V, as summarized in Table 3.2. Depths shown in the table are required depth of production wells but depending upon the position. Yields in the table are quite rough estimations; supposing Transmissivity,

[1] Feasibility Studies, Detail Design and Technical Specifications for Urban Water and Sanitation Facilities in Aweil, Kuajok, Rumbek and Yambio: Draft Water Resources Assessment Study Report AWEIL

drawdown and radius of influence in each aquifer. And the yield of every production well is easily changeable in big range through the depth, diameter, type and quality of screen, filter gravel, and by the quantity and quality of well development on each production well.

Table 3.2 Summary on Groundwater Development Potentials in RSS

	Rank	Geology	Hydrogeology	Depth (m)	Yields (lit/sec)*	Note
1	V	Paleozoics	Nubian Sandstone	>200	50 – 100	depend on the depth
2	IV	Tertiary Sediments	Umm Ruwaba 3	250 – 350	20 – 80	
3	III	Tertiary Sediments	Umm Ruwaba 2	150 – 250	10 – 50	
4	II	Allluvial/Tertiary	Alluvial/Umm R.1	50 – 150	3.0 – 30	
5	I	PreCambrian Basement	Basement Complex	20 – 50	0.5 – 3.0	for Domestic
6	0	New Intrusives	Volcanic Rocks	–	–	No use
7	–I	Tertiary Sediments	Umm Ruwaba	–	–	D'nt Touch

*: quite roughestimation.

As shown in above table, supposed yields of Sudd Basin are rather high, especially, the yields of Nubian Sandstone and Umm Ruwaba deep Aquifer looks like very promising. However, groundwater development is, as a general, quite costly because it needs to drill production wells of required number, to construct delivery pipelines and farm ponds, and most importantly of all it needs operation cost whenever it works. In the country blessed by rainfall or surface water, like RSS, groundwater resources should be the second alternative water sources for irrigation use. Only where, or only when, the surface water is lacking or quite uncertain, groundwater development plan for irrigation use shall be project out at first.

3.4. Groundwater Quality

3.4.1 Groundwater Quality for Irrigation Use

Appropriateness of the water quality for irrigation use depends on the farm products. The water quality of groundwater in a monsoon area is appropriate for almost all of the farm products, but in arid or semi-arid areas, groundwater has high salt concentration sometimes, which makes difficult to use it for many farm products. Even though it is only a trace but containing of heavy-metal may affect to human health severely. Thus, to analyze the contamination of so-called a trace component should be required. To know the water quality of irrigation water exactly is one of the import things, but in addition, it shall be another important to know in detail the tolerance of farm products for certain water quality.

Items of water quality to be analyzed before irrigation use are listed in Table 3.3 (After Ayers and Wescot, 1976).

Table 3.3 Water Quality Analysis Items necessary for evaluation of Irrigation Water

(Ayers and Wescot, 1976)

Acidity-Alkalinity	Iron[2]
Adjusted Sodium Absorption Ratio	Lithium2
Ammonium-Nitrogen[1,2]	Magnesium
Bicarbonate	Nitrate-Nitrogen[1]
Boron	Phosphate Phospherous[2]
Calcium	Potassium[2]
Carbonate	Sodium
Chloride	Suphate
Electric Conductivity	

1:Nitrate-nitrogen (NO3-N) is nitrogen in the form of nitrate (NO3) and ammonium-nitrogen (NH4-N) is nitrogen in the form of ammonia (NH4), reported as nitrogen (N) in mg/t
2:Special situations only.

The most meaningful component on irrigation water is a ratio of calcium (Ca) and magnesium (Mg) to sodium (Na). Sodium-rich water can easily be adhered to clay, preventing the clay from taking in calcium and/or magnesium through substituting, which may make delay the growth of products. Clay after taken in sodium becomes sticky and slippery, reducing its permeability when it drenched, obstructing cultivation through shrinkage hardly when it dried, on the contrary. When the concentration of calcium and magnesium is higher than that of sodium, the clay can be cultivated easily, maintaining good permeability. In 1954, the United State Salinity Laboratory proposed the Sodium Adhesion Ratio (SAR method) to indicate the influence of sodium, as shown below:

$$\mathrm{SAR} = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$$

Na, Mg are converted to mili-equivalents per liter.

When the SAR is ten (10) or more, a sodium problem occurs. The following shows the evaluation of water for irrigation.

<Salinity Hazard >

C1: Low-salinity water — can be used for irrigation on most crops in most soils with little likelihood that soil salinity will develop.

C2: Medium-salinity water — can be used if a moderate amount of leaching occurs.

C3: High-salinity water — cannot be used on soils with restricted drainage.

C4: Very high-salinity water — is not suitable for irrigation under ordinary conditions, but it may be used occasionally under very special circumstances.

<Sodium Hazard>

S1: Low-sodium water — can be used for irrigation almost all soils with little danger of developing harmful levels of sodium.

S2: Medium-sodium water — may cause an alkalinity problem in fine-textured soils under

	low-leaching conditions. It can be used on coarse-textured soils with good permeability.
S3: High-sodium water	may produce an alkalinity problem. This water requires special soil management such as good drainage, heavy leaching, and possibly the use of chemical amendments such as gypsum.
S4: Very high-sodium water	is usually unsatisfactory for irrigation purposes.

Then, Table 3.4 shows water quality standards for paddy rice in Japan.

Table 3.4 Maximum Allowable Concentrations of Trace Components Contained in Irrigation Water

(National Academy of Sciences and National Academy o Engineering, 1972)

Elements (Symbol)	For Water Used Continuously on Soil (mg/lit)	For Use Up to 20 Years on Fine-Textured Soil of pH 6.0 to 8.5 (mg/lit)
Aluminum (AL)	5.0	20.0
Arsenic (As)	0.1	2.0
Beryllium (Be)	0.1	0.5
Boron (B)	[1]	2.0
Cadmium (Cd)	0.01	0.05
Chromium (Cr)	0.1	1.0
Cobalt (Co)	0.05	5.0
Copper (Cu)	0.2	5.0
Fluoride (F)	1.0	15.0
Iron (Fe)	5.0	20.0
Lead (Pb)	5.0	10.0
Lithium (Li)[2]	2.5	2.5
Manganese (Mn)	0.2	10.0
Molybdenum (Mo)	0.01	0.05[3]
Nickel (Ni)	0.2	2.0
Selenium (Se)	0.02	0.02
Vanadium (V)	0.1	1.0
Zinc (Zn)	2.00	10.0

1: These levels normally don't adversely affect plants and soil. No data are available for mercury (Hg), silver (Ag), tin (Sn), titanium (Ti), or tungsten (W).
2: No problem when less than 0.75 mg/l; increasing problem when between 0.75and 2.0mg/l; severe problem when greater than 2.0 mg/l.
3: For only acid fine-textured soils and acid soils when relatively high iron oxide contents..

3.4.2 Groundwater Quality for Drinking Water

Drinking water quality standards vary from nation to nation. Measuring items to be required also differ in each country. Many developing countries have adopted the WHO guidelines as their drinking water quality standards, however, RSS has own standards called SSDWG: South Sudan Drinking Water Guidelines. While, Japan is known as one of the countries having the most severe drinking water quality indexes. Table 3.5 shows drinking water quality standards comparing Japan, WHO, and SSDWG.

Table 3.5 Drinking Water Quality Standards (Comparison of Japanese, WHO, and SSDWG)

(1) Items related to health (29 items)

No.	Item	Japanese guidelines	WHO guidelines	SSDWG
1	Bacteria	Number of colonies, formed in 1 ml of test water, must be less than 100.	-	-
2	Coloform group	Must not be detected.	Not detected in 100 ml.	10 mpn/100ml
3	Cadmium	0.01 mg/l or less	0.003 mg/l	-
4	Mercury	0.0005 mg/l or less.	0.001 mg/l	0.006 mg/l
5	Selenium	0.01 mg/l or less	0.01 mg/l	0.01 mg/l
6	Lead	0.05 mg/l or less	0.01 mg/l	0.01 mg/l
7	Arsenic	0.01 mg/l or less	0.01 mg/l	less than 0.05 mg/l
8	Hexavalent chromium	0.05 mg/l or less	0.05 mg/l	0.05 mg/l
9	Cyanide	0.01 mg/l or less	0.07 mg/l	-
10	Nitrate-N and nitrite-N	10 mg/l or less.	NO_3: 50 mg/l NO_2: 3mg/l	NO_3: 30 mg/l NO_2: 0.5mg/l
11	Flourite	0.8 mg/l or less	1.5 mg/l	-
12	Carbon tetrachloride	0.002 mg/l or less.	0.002 mg/l	-
13	1,2-dichloroethane	0.004 mg/l or less.	0.03 mg/l	-
14	1,1-dichloroethylene	0.02 mg/l or less.	0.03 mg/l	-
15	Dichloromethane	0.02 mg/l or less.	0.02 mg/l	-
16	Cis-1,2-dichloroethylene	0.04 mg/l or less.	0.05 mg/l	-
17	Tetrachloroethylene	0.01 mg/l or less	0.04 mg/l	-
18	1,1,2-trichloroethylene	0.006 mg/l or less.	-	-
19	Trichloroethylene	0.003 mg/l or less.	0.07 mg/l	-
20	Benzene	0.01 mg/l or less	0.01 mg/l	-
21	Chloroform	0.06 mg/l or less.	0.2 mg/l	-
22	Dibromochlromethane	0.1 mg/l or less.	0.1 mg/l	-
23	Bromodichloromethane	0.03 mg/l or less.	0.06 mg/l	-
24	Bromoform	0.09 mg/l or less.	0.1 mg/l	-
25	Total trihalomethane	0.1 mg/l or less.	Total value of each component compared to its guideline must be less than 1.0	-
26	1,3-dichloropropene	0.002 mg/l or less.	0.02 mg/l or less	-
27	Simazine	0.003 mg/l or less.	-	-
28	Thioram	0.006 mg/l or less.	-	-
29	Thiobencarb	0.02 mg/l or less.	-	-

(2) Items related to properties of tap water (17tems)

No.	Item	Japanese guidelines	WHO guidelines	SSDWG
1	Zinc	1.0 mg/l or less	3.0 mg/l	-
2	Iron	0.3 mg/l or less	0.3 mg/l	0.5 mg/l
3	Copper	1.0 mg/l or less	1.0 mg/l	1.5 mg/l
4	Sodium	200 mg/l or less	200 mg/l	100 mg/l
5	Manganese	0.05 mg/l or less	0.1 mg/l	0.4 mg/l
6	Chlorine ion	200 mg/l or less	250 mg/l	200 mg/l
7	Calcium and magnesium	300 mg/l or less	-	30 - 70 mg/l
8	Residue of evaporation	500 mg/l or less	1000 mg/l	< 1000 mg/l
9	Salfactant ion	0.2 mg/l or less	-	-
	(Salphate)	-	500 mg/l	200 mg/l
10	1,1,1-trichloroethane	0.3 mg/l or less	2.0 mg/l	-
11	Phenols	0.005 mg/l or less	0.001 - 0.3 mg/l	-
12	Organic compounds, etc.	10 mg/l or less	-	-
13	pH value	5.8 - 8.6	-	6.5 - 8.5
14	Taste	Not abnormal	-	-
15	Odor	Not abnormal	-	-
16	Chromaticity	5° or less	15 TCU	-
17	Turbidity	2° or less	5 NTU	5 NTU

(3) Other items defined in SSDWG

No.	Item	Japanese guidelines	WHO guidelines	SSDWG
1	Conductivity			1500 μS/cm
2	Magnesium			30 - 70 mg/l
3	Potasium			25 - 50 mg/l
4	Nitrite			0.5 mg/l
5	Nitrate			30 mg/l
6	Hardness			(as $CaCO_3$) 200 mg/l
7	Alminium		0.2 mg/l	0.2 mg/l
8	Barium		0.3 mg/l	0.7 mg/l
9	Nickel		0.02 mg/l	0.07 mg/l
10	Chromium		0.05 mg/l	0.05 mg/l

3.5. Groundwater Potential Map

Based on the potential ranking and zooning depending upon the hydrogeology and depth of sediments, ñGroundwater Development Potential Mapò was drawn up as shown in Figure 3.4. The map shall be one of the water resources potential maps, and later, it shall be combined with surface water resources potential map, and finally ñIrrigation Development Potential Mapò shall be provided.

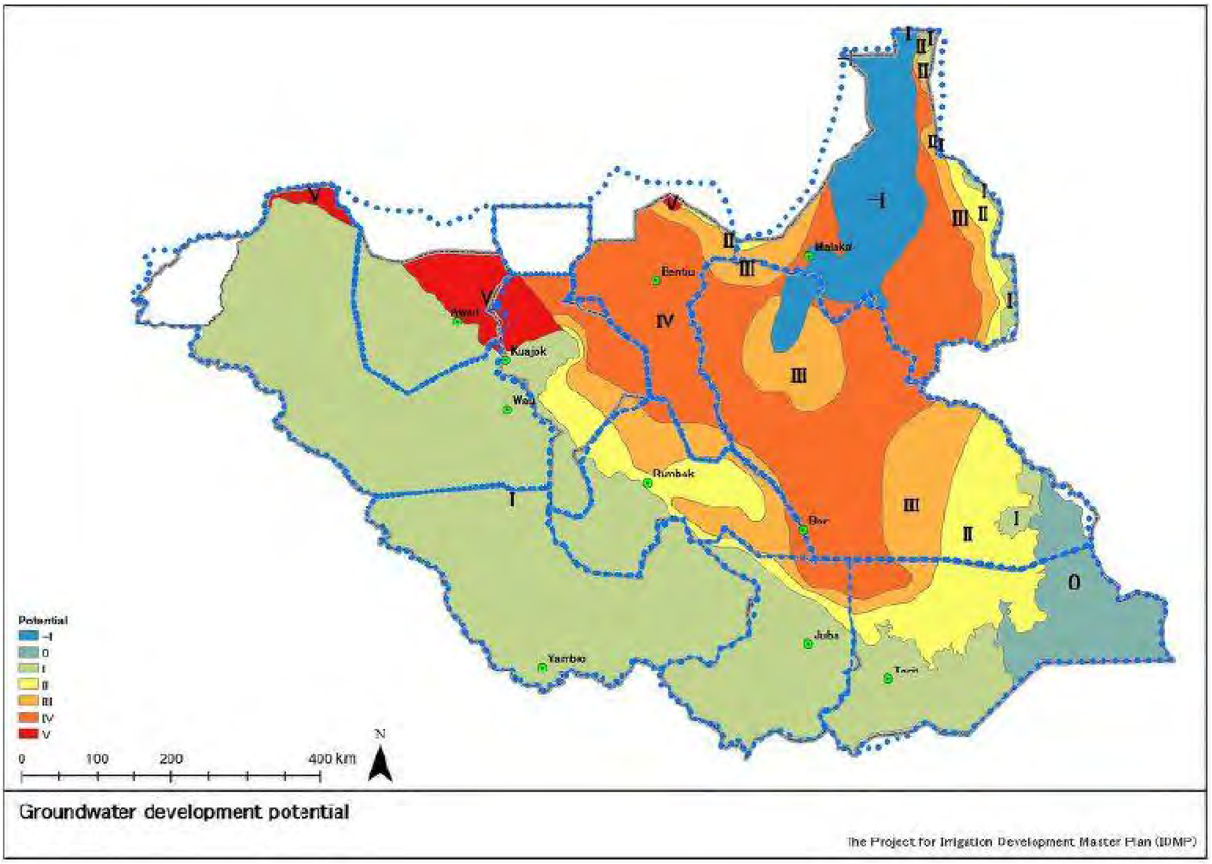


Figure 3.4 Groundwater Development Potential Map

4. REVIEWS ON WELL DATABASE/INFORMATION

Some kinds of well databases (or borehole inventories) such as ñWater Points Inventoryò by WIMS: Water Information Management System, ñBorehole Informationò by Pact: Program Agency Collaborate Together, Inventory of Water Sources in Warrap State supported by UNICEF, and UN GIS Database on Water Points (OCHA), were reviewed. The last one, GIS database has only position of water points, around 2,200 points, but no other information. On the contrary, the other database have so many items to be filled up, 27 items in Pact data, 34 items in WIMS, and 37 items in Warrap data, most were not filled though. As one of the sample, items to be filled in the case of WIMS are shown below. If all items were fulfilled it shall be one of available database:

> 1.ID, 2.Unique code, 3.Facility Type, 4.State, 5.Country, 6.Payam, 7.Boma, 8.Village, 9.Site, 10.Location Name, 11.Latitude, 12.Longitude, 13.Altitude, 14.Current Status, 15Project Name, 16.Population serving, 17.Funding Agency, 18.Contractor, 19.Drilling start date, 20.Drilling end date, 21.Completion date, 22.Status after completion, 23.Handed over to, 24.Total depth, 25.Static water level, 26.Water strike, 27.Bedrock hit at, 28.Dynamic water level, 29.Casing level, 30.Yield, 31.Pump type, 32.Date record entered, 33.Date last modified, and 34.Entered by.

Numbers of data (wells) were 4,256 in WIMS, 1166 in Pact, and 1,543 in Warrap data, however there are many duplicated data in them. WIMS database has the largest number of well points but around a half of them have no location data, and including so many same data and it became only 1,780 wells after omitted the duplicated data. As the results obtained through the reviews, primitive knowledge and/or techniques on database and well are lacking. For example, the location (Latitude and Longitude) must be a number but most of them were wrote by ASCII cord (to express °), not a number (figure) so that it cannot make mathematical operation in Excel Sheet, then, well yields and dynamic water level were lacking mostly and if it had, the unit on yield were not uniform and no information on it usually.

ñBorehole Completion Reportò, another kind of well information systems are operated by Ministry of Cooperative and Rural Development (Directorate of Rural Water), and by MWRI (Directorate of Rural Water Supply and Sanitation). These reports have more wide and detail information on newly drilled well including pump test and water quality tests. However, the reporter, who drilled the well or is field engineer, has not enough knowledge on the aquifer and well structure, so that the description of the lithological condition which is the most important matter in the report was usually quite poor, and mostly no information on SWL and DWL, casing type and structure. There were some pumping test data but the time continuing pumping is too short and no step drawdown test. It means basic knowledge and techniques of the field engineers and/or drillers on well construction and hydrogeologic condition are still low.

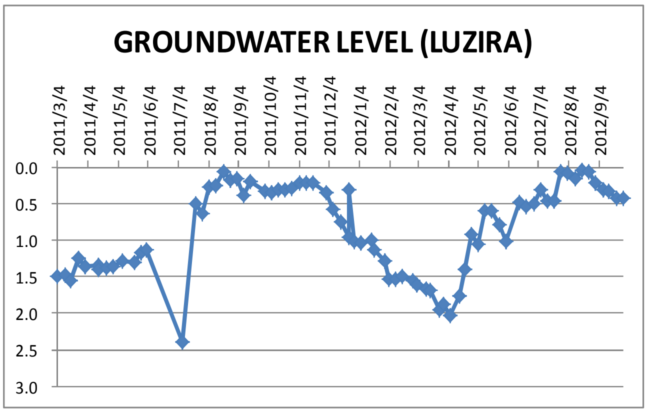


Figure 4.1 Groundwater Hydrograph (Luzira)

Groundwater hydrograph; time series groundwater level observation records, is one of the most fundamental hydrogeological information to study hydrogeologic condition in any area. Only one such kind observation data, Groundwater Monitoring Data on Luzira Well was obtained as shown as Figure 4.1.

The data were groundwater monitoring data since 4th March, 2011 to 28th September, 2012, measured not daily but in 5,6 days interval. In accordance with the data, groundwater level in Luzira Well was going down to 1.5 to 2.0m depth from the ground surface in the end of dry season, and recovering to near around the ground surface in the end of rainy season. From 1.5 to nearly 2.0m of groundwater fluctuation (nearly 2.4m in July, 2011 shall be mistake) means quite large volume of groundwater recharge can be expect in near around Luzira Well. Unfortunately, the Study could not find out the other groundwater hydrograph in RSS.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Review on existing reports

Several water resources assessment reports, several kinds of Geological and Hydrogeological Maps, satellite images and other information on the hydrogeology of RSS were collected and reviewed carefully and significantly. Through these studies, quite unique hydrogeological setting of RSS was defined that only one huge but closed groundwater basin called as ñSudd Basinò and only four major aquifers consist all groundwater resources in this country: they are ñAlluvial Aquiferò, ñUmm Ruwaba Formationò, ñNubian Sandstone Formationò, and ñBasement Complex Aquiferò.

Geological setting

Geological setting of RSS is simple, Pre-Cambrian Basement Complex mainly consisted of Granites and Gneiss occupies throughout the country, overlying by Nubian Sandstone partially, and by Umm Ruwaba Formation for all Sudd Basin, and covered by Alluvial deposits along with major river routes.

Hydrogeological setting

Hydrogeologically, Basement Complex forms a small aquifer system but basically it is an impervious base (bottom) of all other aquifers, and Sudd Basin is an enormous depression of the basement filled back by unconsolidated sediments through Tertiary and Quaternary. Thus, Sudd Basin is huge but closed individual groundwater basin, only one in RSS.

Groundwater storage

Sudd Basin was conceptually modeled by SSM. Total area of Sudd Basin was as large as nearly 433,000 km^2. Because of the hugeness of the Basin, groundwater storage in the Sudd Groundwater Basin is also huge volume. When, the depth of Alluvial deposits is estimated as 50m, and the depth of Umm Ruwaba formation around 350m, total volume of the aquifer shall be around $9.77x10^{13}$ m^3, and groundwater storage in this aquifer shall be $1.151x10^{13}$ m^3. Groundwater yields are estimated as total $7.35x10^{11}$ m^3, under some assumptions on Transmissivity, Storativity and radius of influence.

Groundwater development potential

Groundwater development potential is basically depending on the groundwater storage, and the storage depends on the depth of aquifer. Isobathic contour map on Sudd Basin was classified into three zones (at 150m and 250m) and each zone was given potential ranking depending on its depth class (II to IV). Nubian Sandstone was given highest rank because of its excellent aquifer property and consequently accompanied Umm Ruwaba formation (V). Remaining wide area of the country underlain by Basement Complex was given the lowest potential as ñIò because it yield some groundwater enough for rural or urban water supply. However, new volcanic intrusive rocks distributing eastern hedge of the basin was estimated as no development potential (0). Then, brackish water body existing in the northern branch of the basin was given minus potential because of its dangerous salinity level (-I).

Groundwater development for irrigation use

Groundwater development potential in Sudd Basin, especially on Nubian Sandstone and Umm Ruwaba deep aquifer, are rather promising. However, groundwater development for irrigation use is, usually, costly because of its rather high construction costs and operation cost which needs for ever. For irrigation use, groundwater resources shall be the second alternative water resources.

Database and Inventory

Databases on wells or well inventories also collected and reviewed. However, most of these have so many items to be filled, someone has 27 items and the other has 37 items, but mostly not fulfilled actually. On the other hand, important information for hydrogeological study such as lithological log, depth and type of aquifer, SWL and DWL, well yields, and Aquifer Constants, are not to be described. Items to be checked regularly must be slim and contents of the items shall severely be reconsidered. For hydrogeological information, fatal shortage is lacking of groundwater hydrograph; groundwater level observation records. Only one hydrograph was obtained though.

5.2. Recommendations

Sudd Basin is only one and number one groundwater basin in this country. All of the groundwater development potential is just depending on the basin. Nevertheless, the physical and hydrogeological properties, such as the depth, groundwater hydrograph, water quality change, lithological formations, and Aquifer Constants, etc. are not yet known exactly. To know the exact depth of the bottom, lithological situation and aquifer properties zone by zone, and behavior of groundwater in the Sudd Basin is quite essential for evaluating the groundwater development potential in this country. These important properties and information can be obtained through Test Well drilling accompanied with an observation well, well logging, a series of pumping test, and water quality analysis as well, to the bottom of the basin. Depth of the basin bottom was estimated at around 350m in this study but some report said it should be 500m or more. So, it is recommended to conduct large scale geophysical sounding for the points where Test Well drilling is planned out. Total around 10 test wells shall be drilled in any cities or towns inside the Basin, in proper spacing. Geophysical sounding shall be ñTDEM; Time Domain Electro-Magnetic prospectingò with analysis depth of around 600m. After completion of tests and analysis in the test well, the well shall be diverted to ñMonitoring Wellò installed by an AWLR: Automatic Water Level Recorder, for continuous water level observation[2]. In the monitoring well, water quality shall be analyzed periodically. The ten candidate towns where test well shall be drilled are shown in Figure 5.1, as a reference.

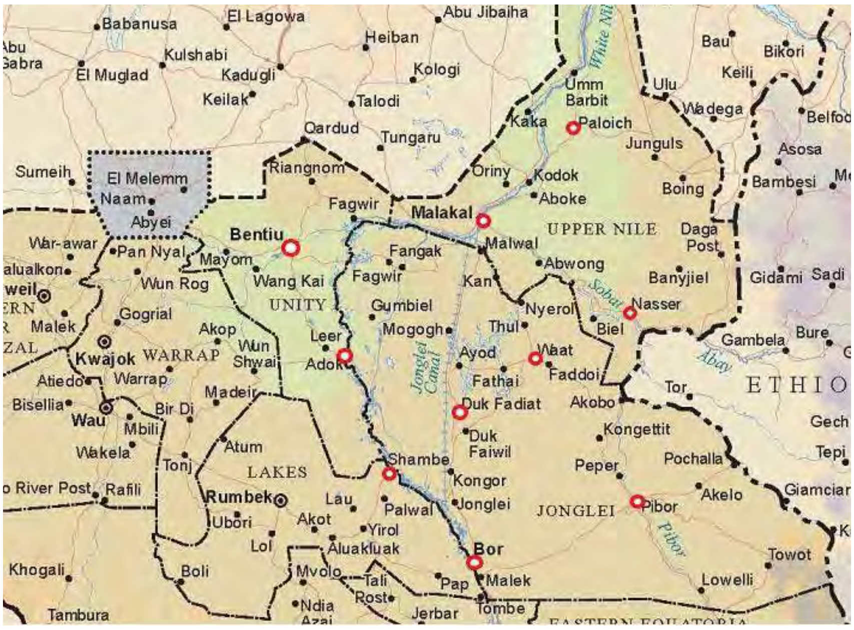


Figure 5.1 Candidate Towns for Test Well Drilling

As referred in the chapter 4.1. Conclusion, existing well (or borehole) databases had unnecessarily many items to be filled up but mostly kept unfilled actually, and information required for hydrogeological study and analysis, such as type and depth of aquifer, casing structure, SWL, well yield and DWL, Aquifer Constants, are not included properly. It is recommended to reconsider the form, structure, and items to be fulfilled, basically. However, through reviewing and analyzing these database and ñBorehole Completion Reportò, which is another reporting system on borehole drilling, on enhancement under MWRI and MCRD, the most fundamental issues come out. Data and

2 In Kabul Basin, Afghanistan, Sanyu Consultants Inc. conducted a series of hydrogeological investigation, including TDEM prospecting and 600m class test well drilling.

information on the well are generated in the drilling field and transmitted to the managing side, which are drilling company, public office, international agencies, and/or NGO. The troubles are; one is low drilling and well construction technique, and another is shortage of basic knowledge on well and groundwater. The former issue is mainly for the field side, and the latter is for both sides. In the drilling field, most of the drillers do not have the most primitive drilling techniques such as arrangement of drilling fluid, well logging, proper casing program, well development, proper screen and filter gravel, pumping test, and so on. Farther, the both sides do not know what is the data required or important and what data are negligible for hydrogeological analysis/study. All of these issues suggest strongly the necessity of capacity building on drillers and assistant drillers in the field. In the same time, to bring up proper numbers of Hydrogeologist, Geophysicist, and Water Quality Analyzer, is urgently required.

References

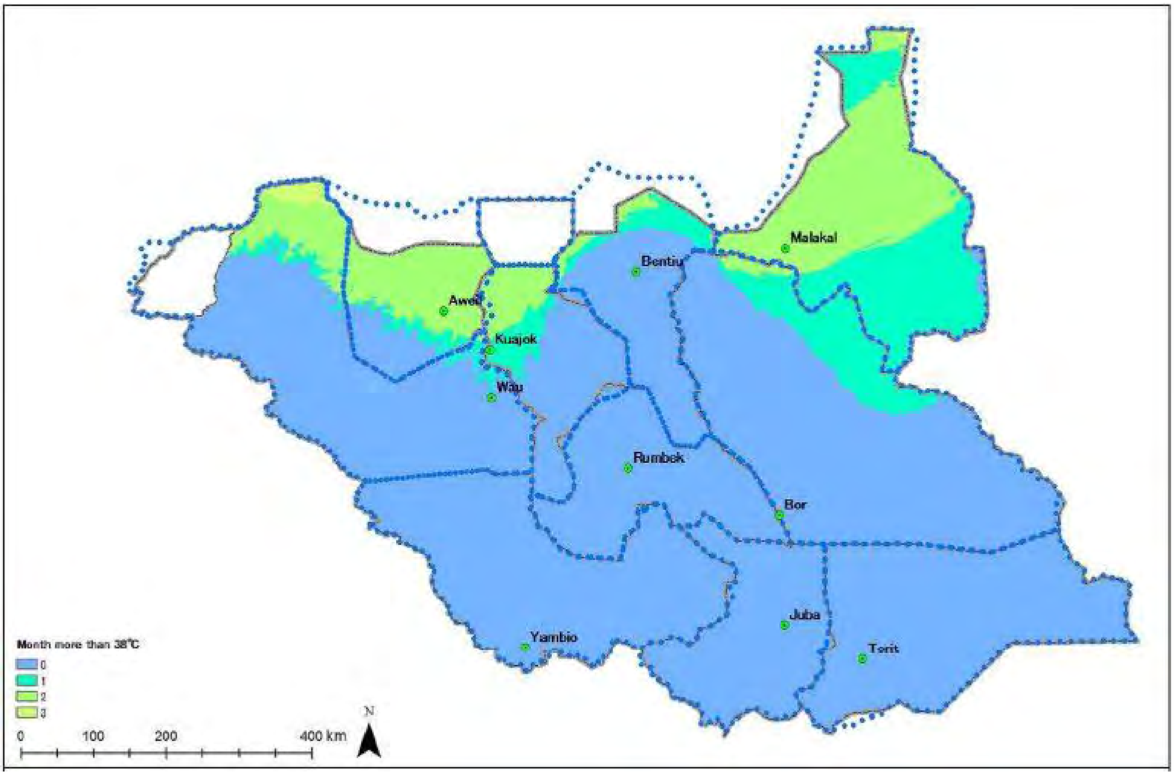
1. Nail Basin Initiative. 2012. *Final Report, Assessment of the Irrigation Potential in Burundi, Eastern,DRC, Kenya, Rwanda, South Sudan, Tanzania and Uganda*. July 2012.

2. The Ministry of Electricity, Dams, Irrigation and Water Resources. 2012. *DRAFT Water Resources Assessment Study Report for 7 Towns of Bentiu, Bor, Torit, Yambio, Aweil, Kuajok, and Rumbek*.

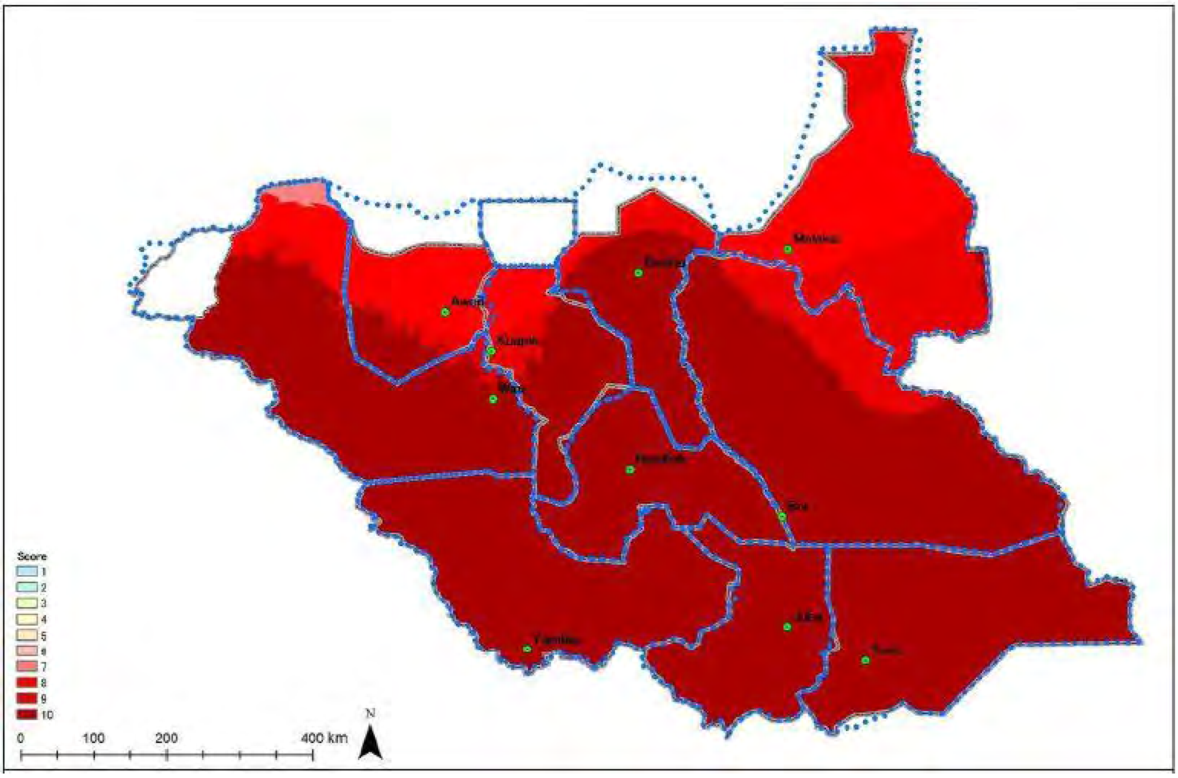
APPENDIX - 1

LAND PRODUCTIVITY/SOCIO-ECONOMIC POTENTIAL ASSESSMENTS

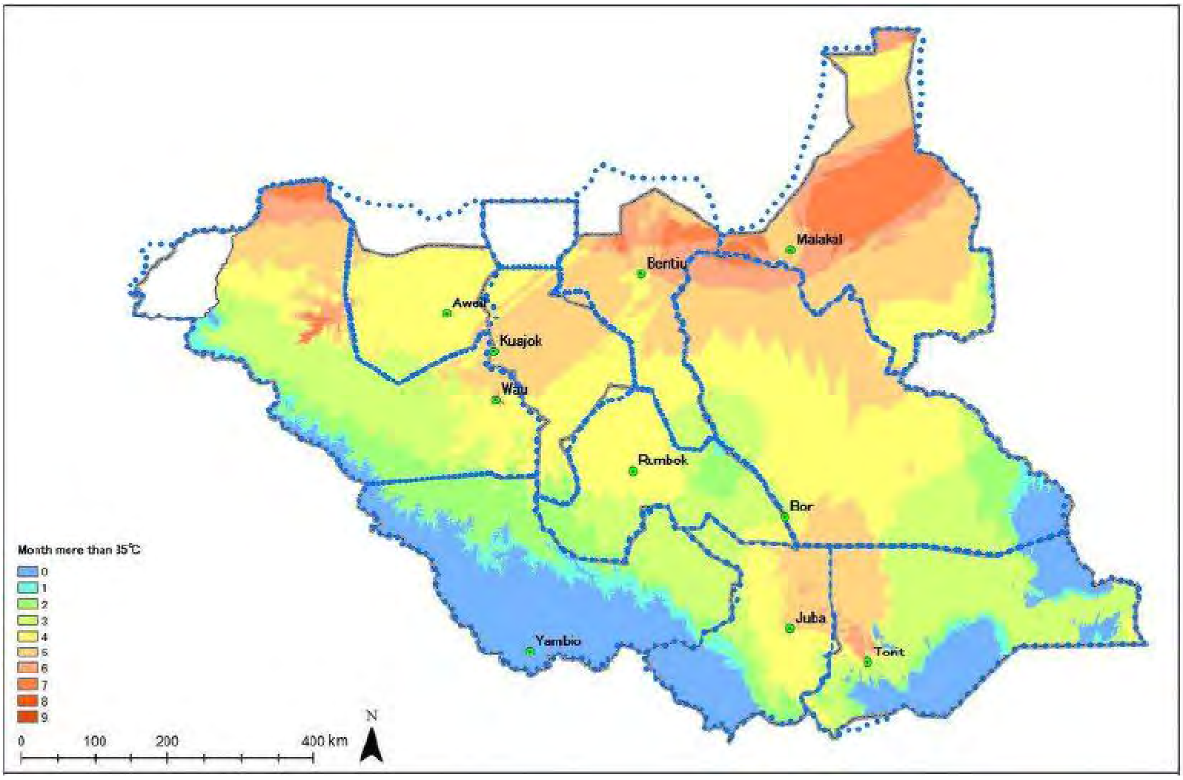
1. Temperature for Non-rice (Layer) for Step-1 Group



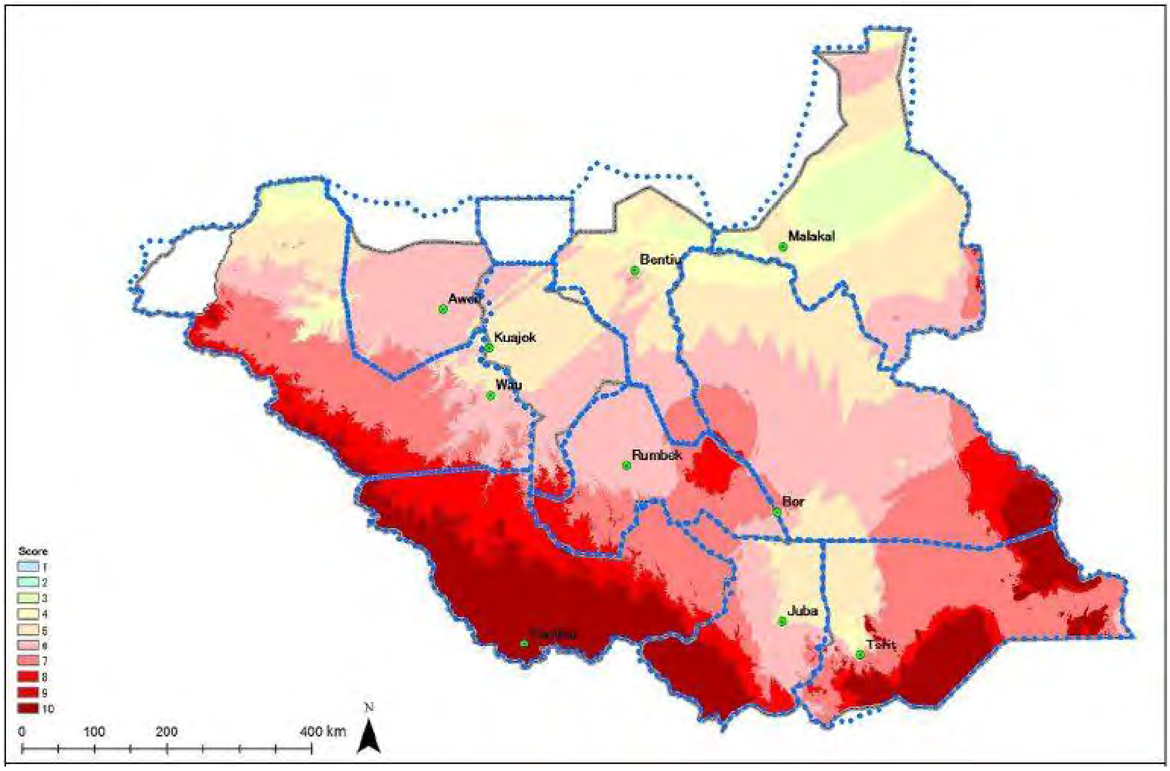
2. Temperature for Non-rice (Score) for Step-1 Group



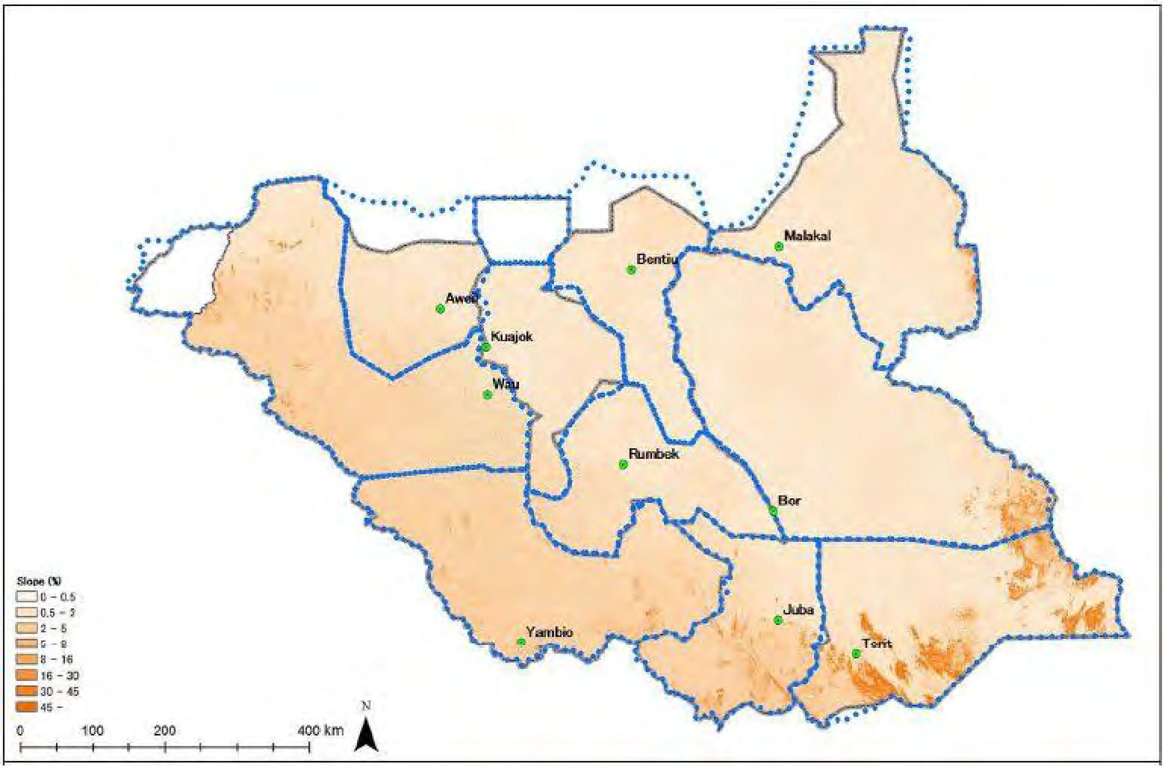
3. Temperature for Rice (Score) for Step-1 Group



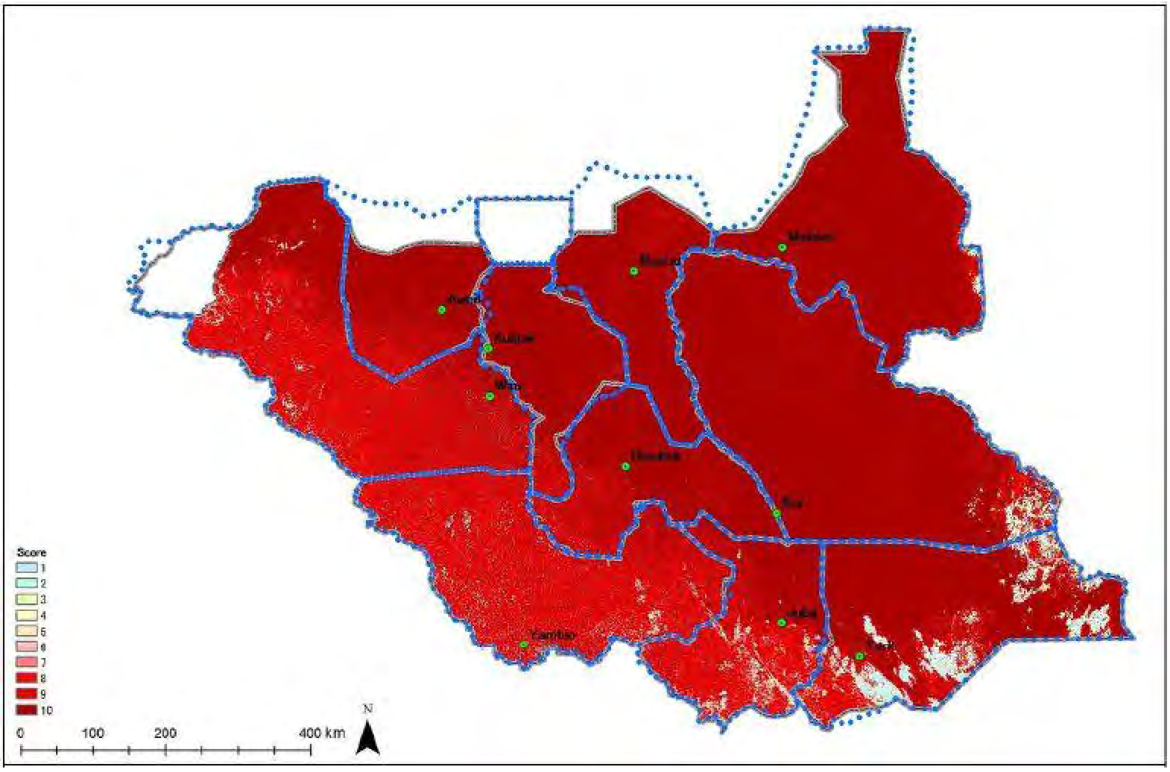
4. Temperature for Rice (Score) for Step-1 Group



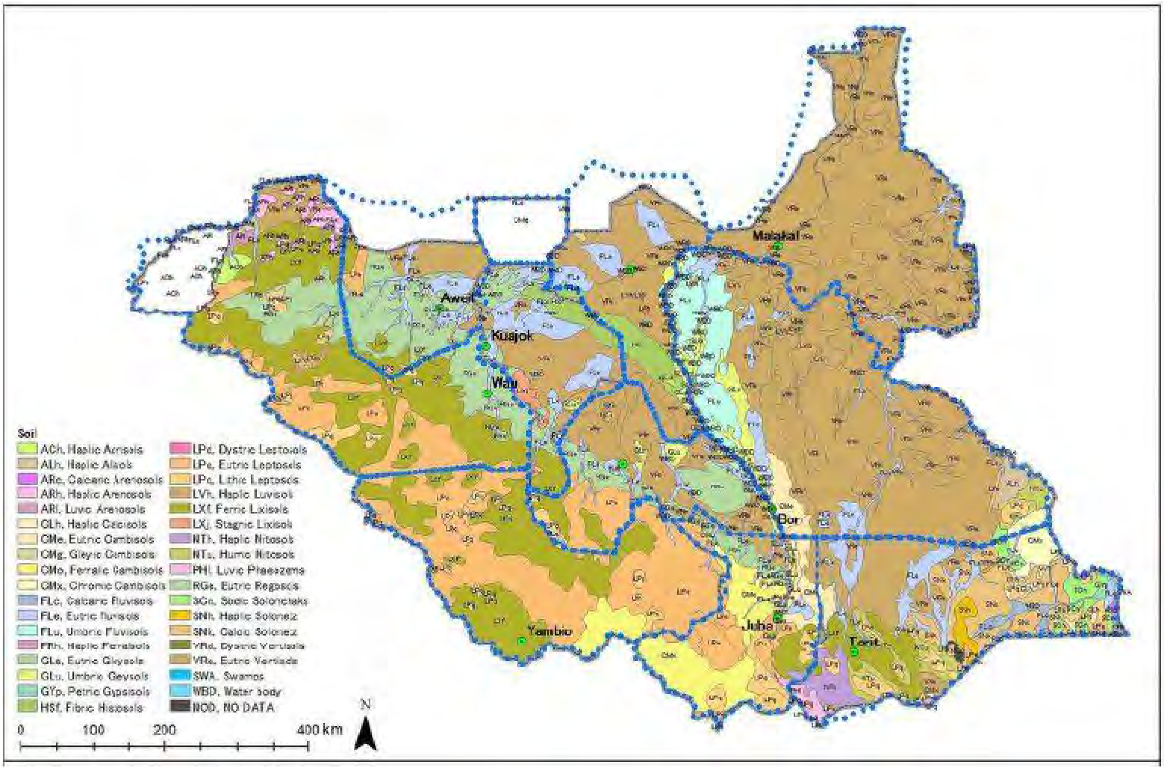
5. Slope (Layer) for Step-1 Group



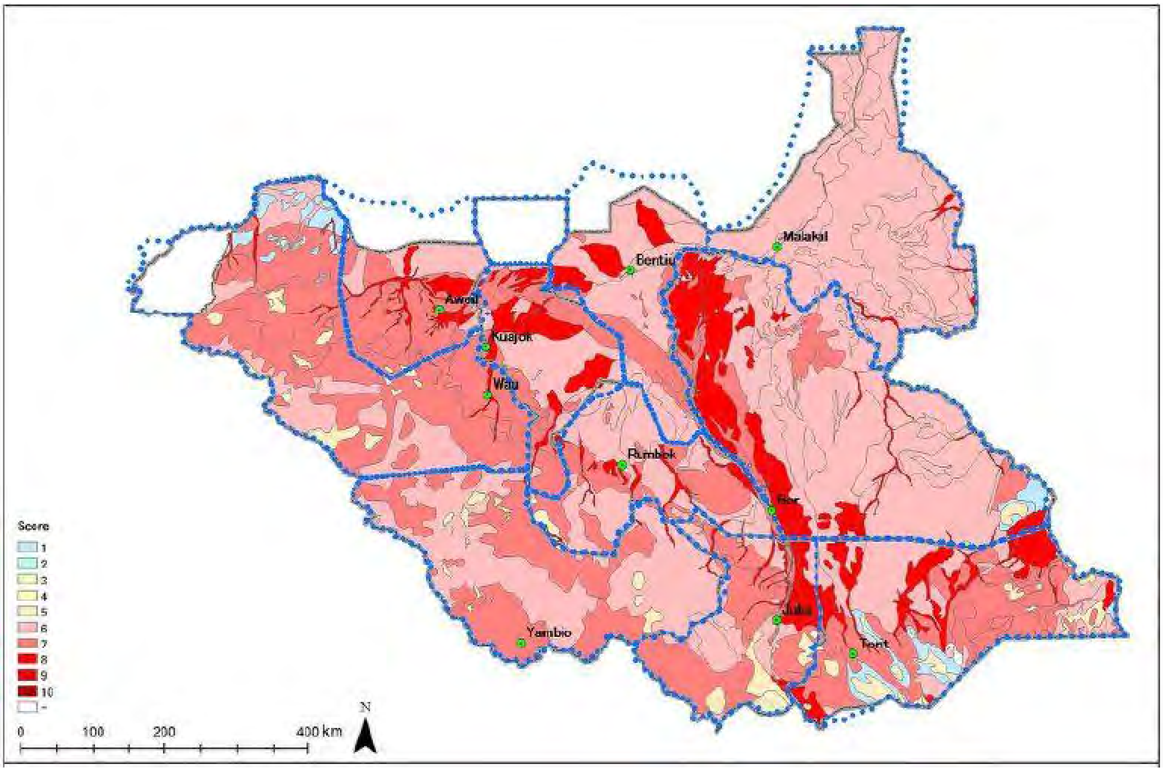
6. Slope (Score) for Step-1 Group



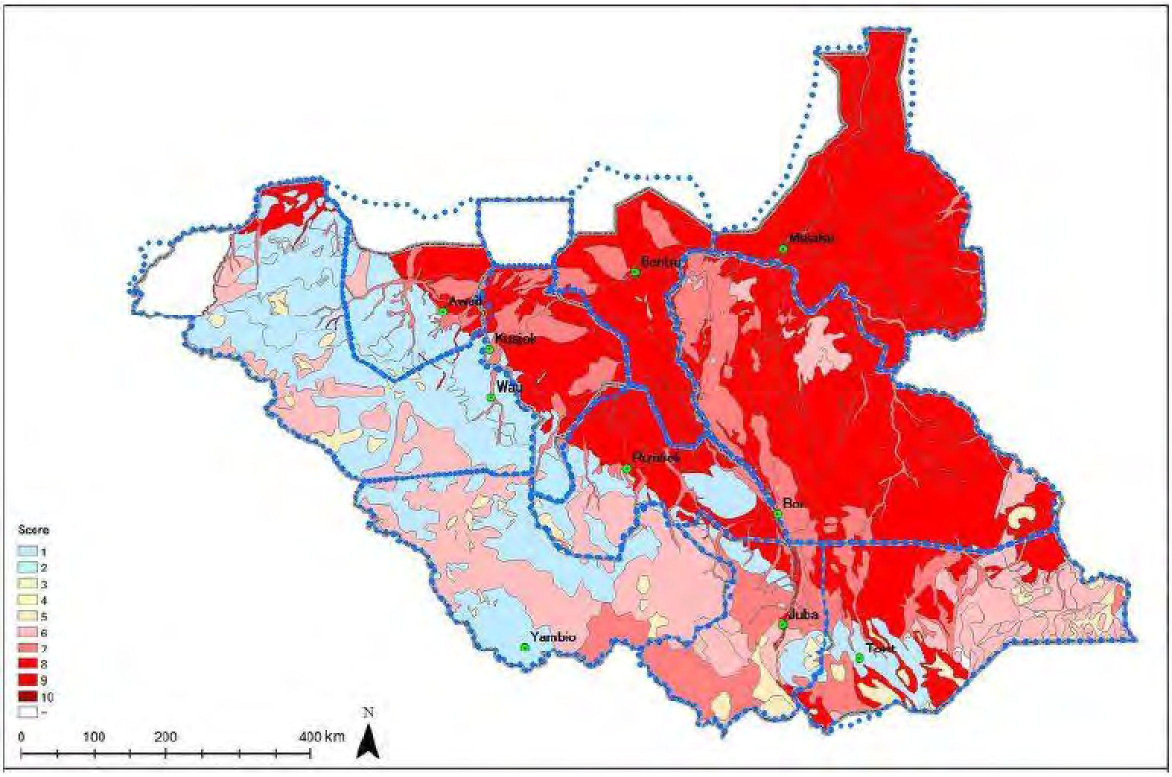
7. Soil (Layer) for Step-1 Group



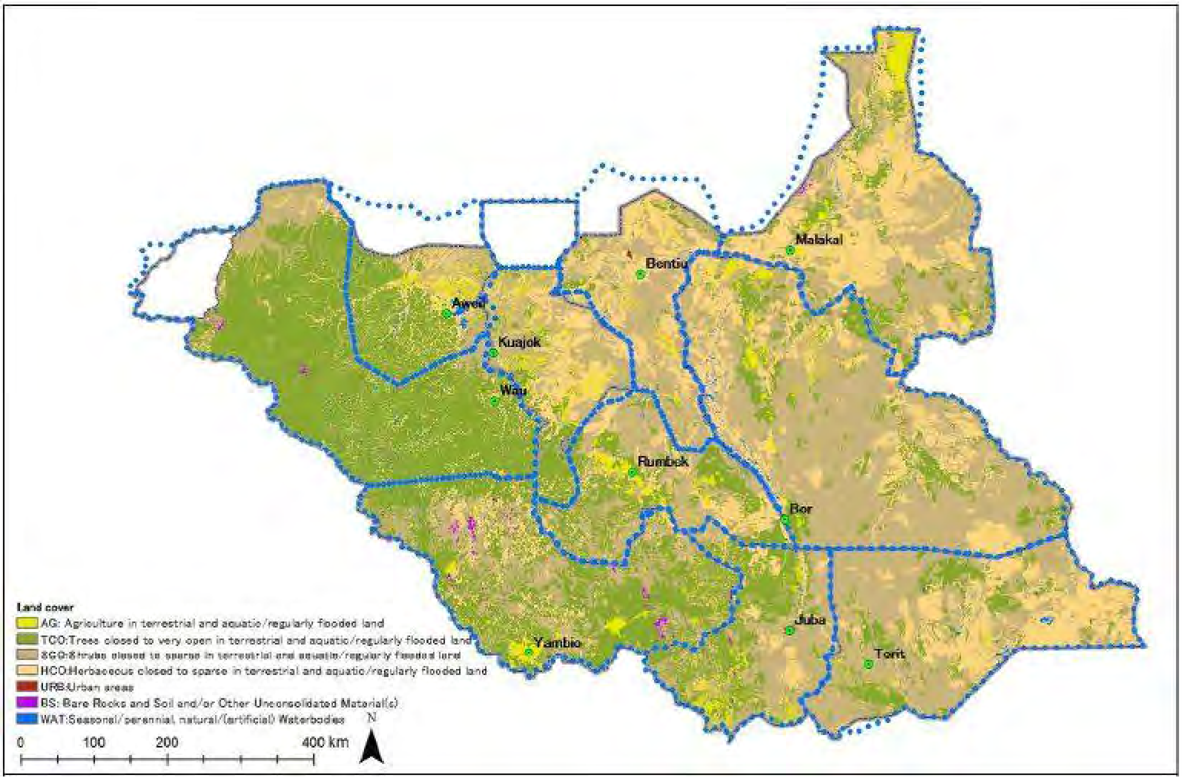
8. Soil for Non-rice (Score) for Step-1 Group



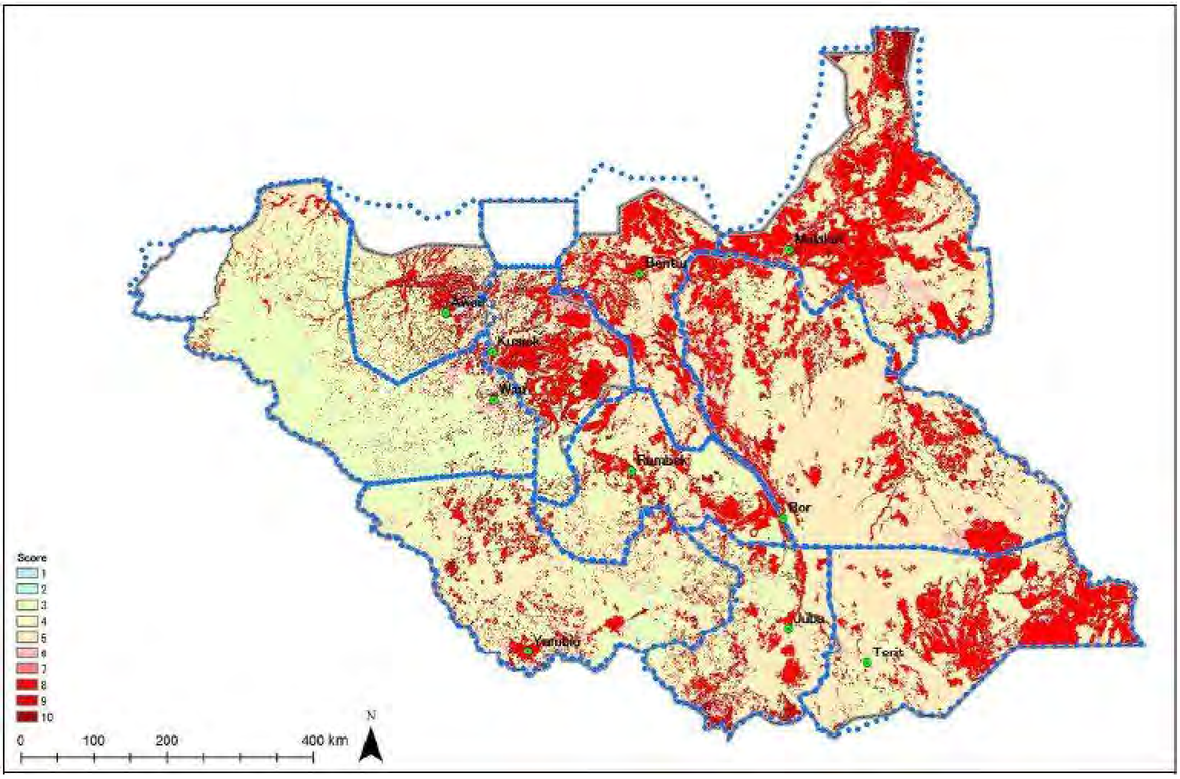
9. Soil for Rice (Score) for Step-1 Group



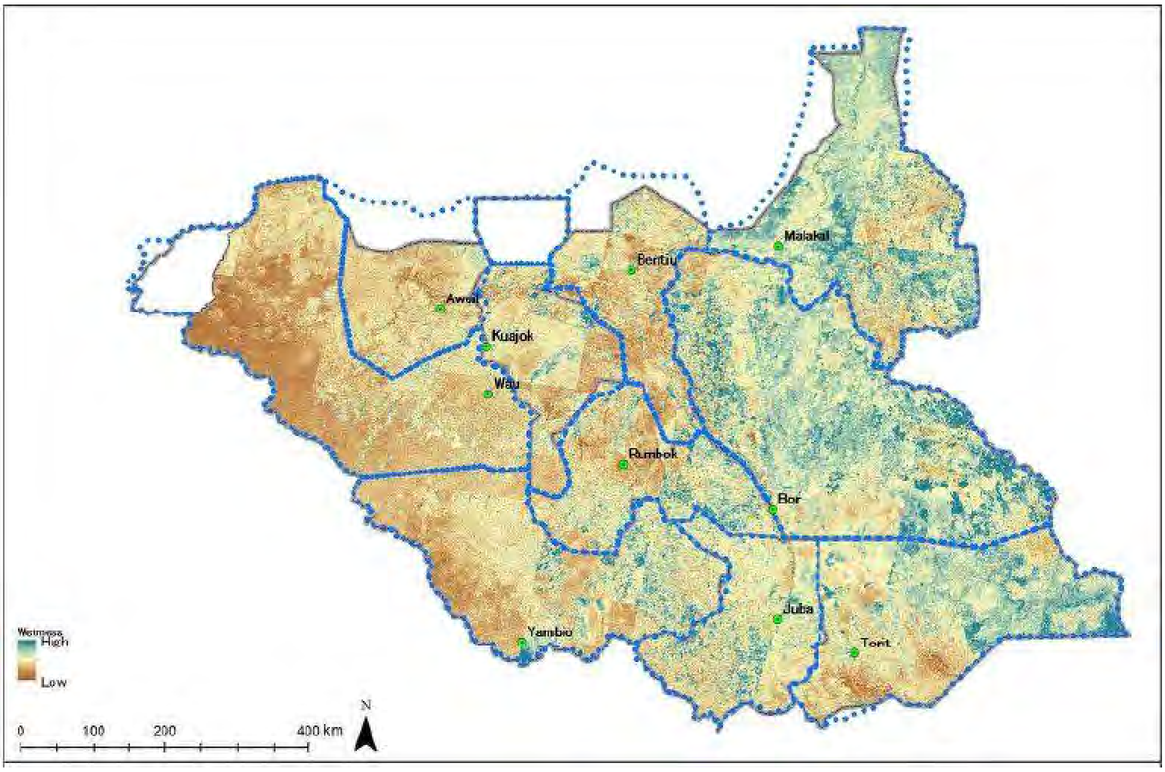
10. Land Cover (Layer) for Step-2 Group



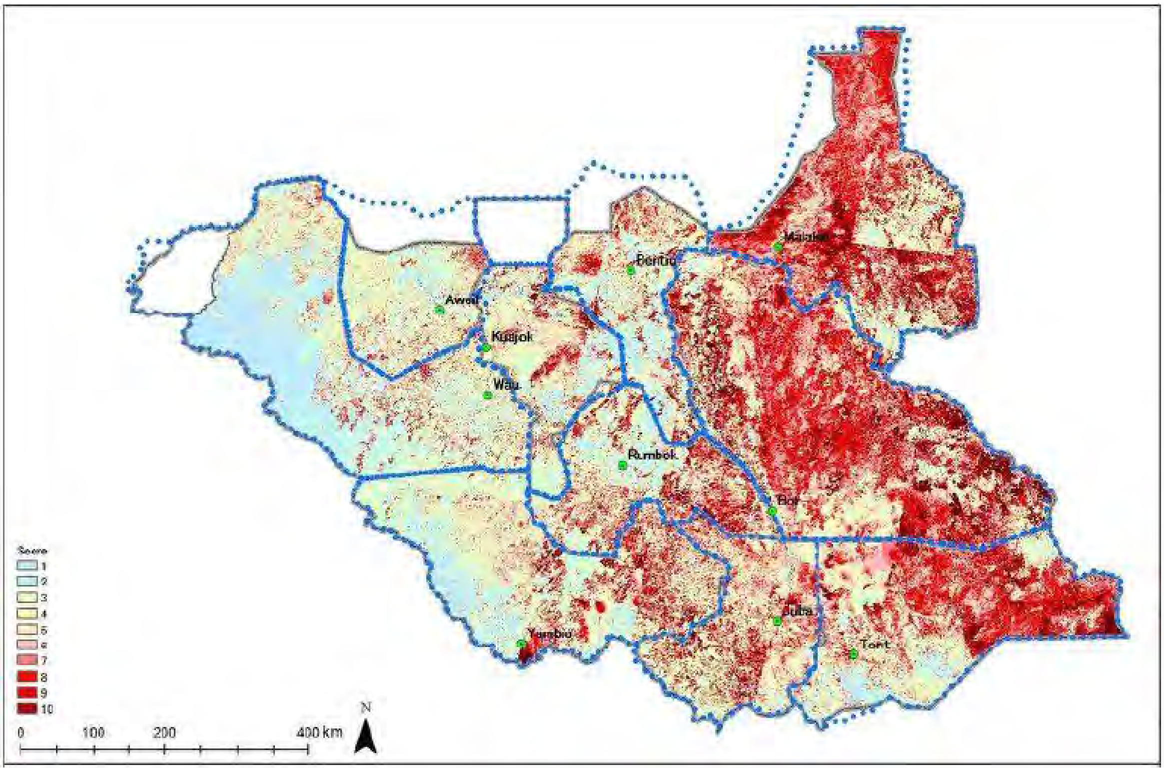
11. Land Cover (Score) for Step-2 Group



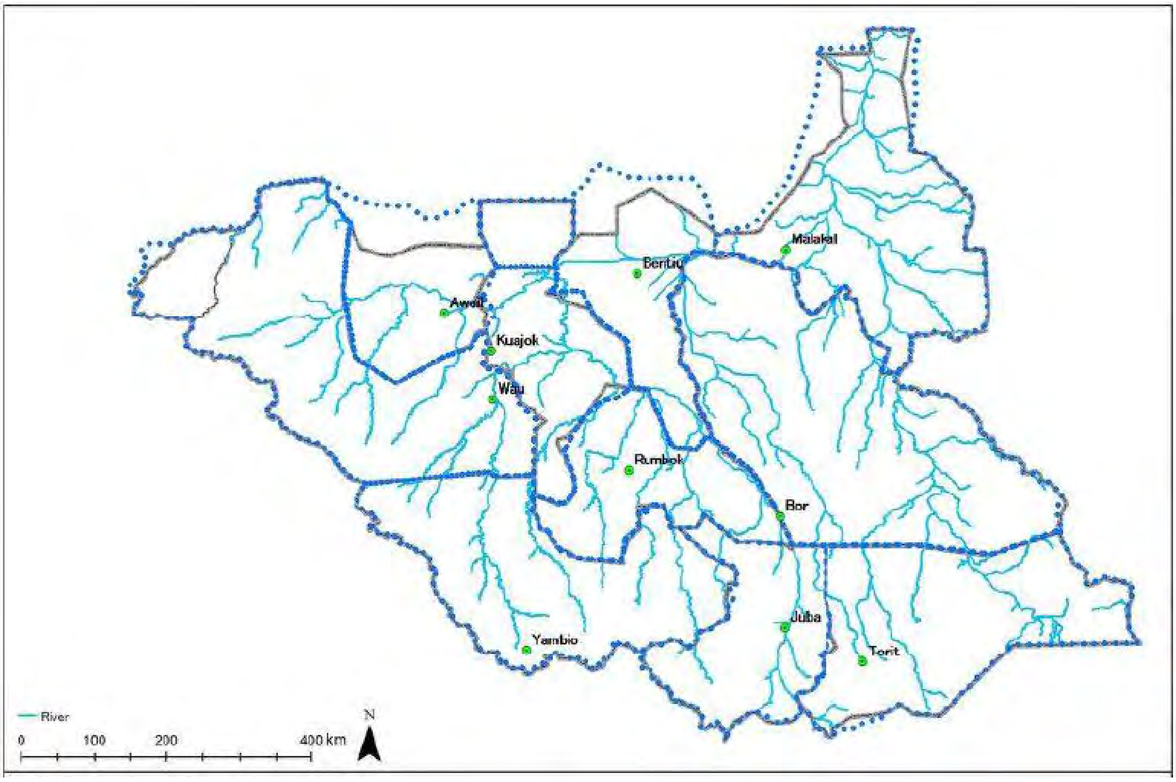
12. Step-2: Wetness (Layer) for Step-2 Group



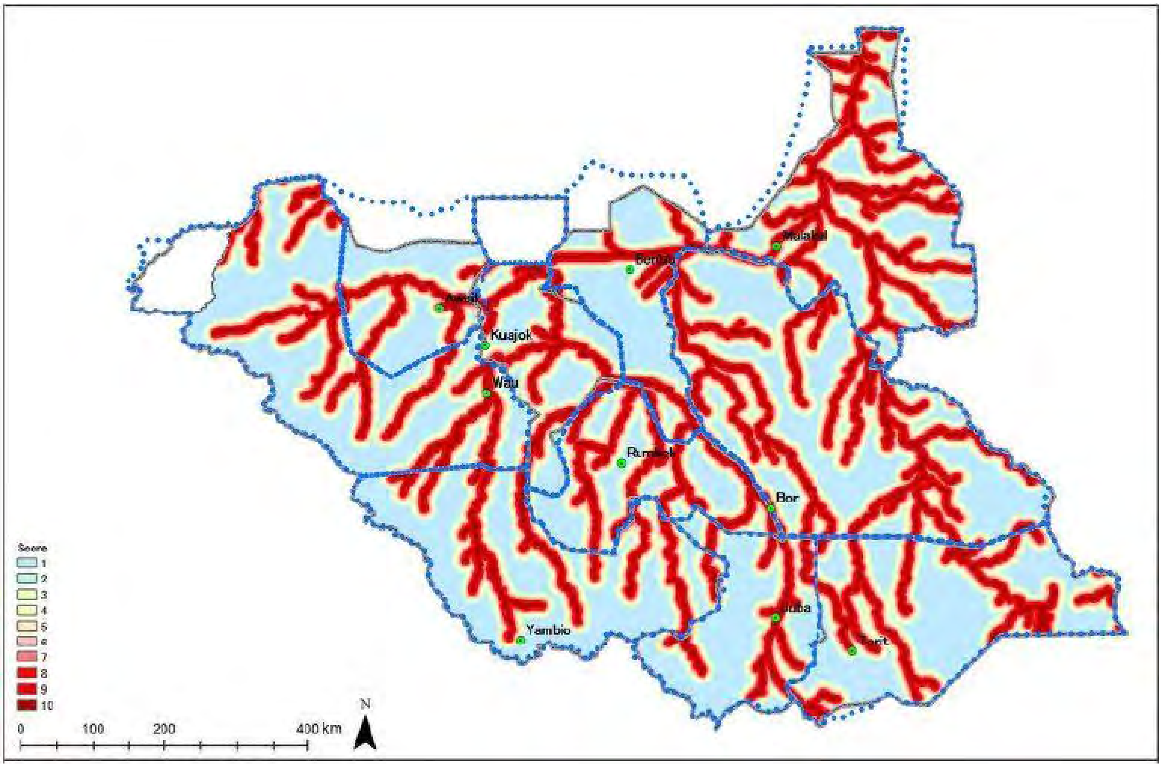
13. Wetness (Score) for Step-2 Group



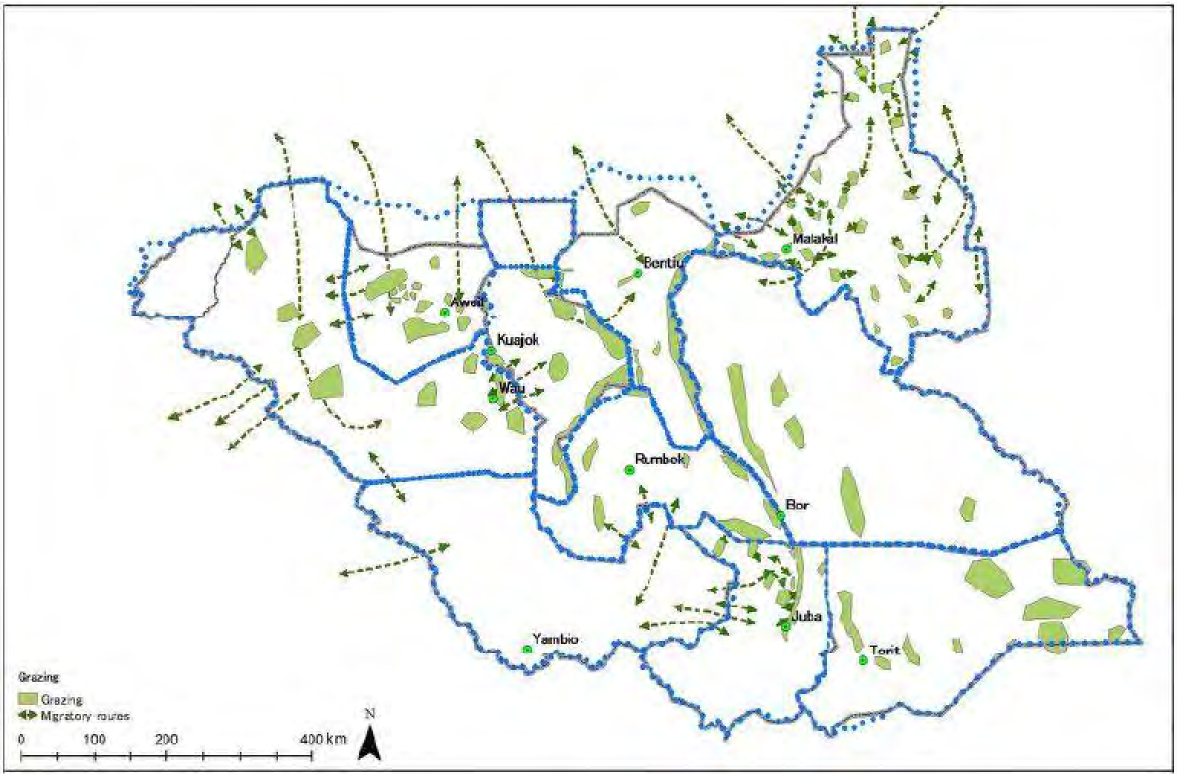
14. River Accessibility (Layer) for Step-2 Group



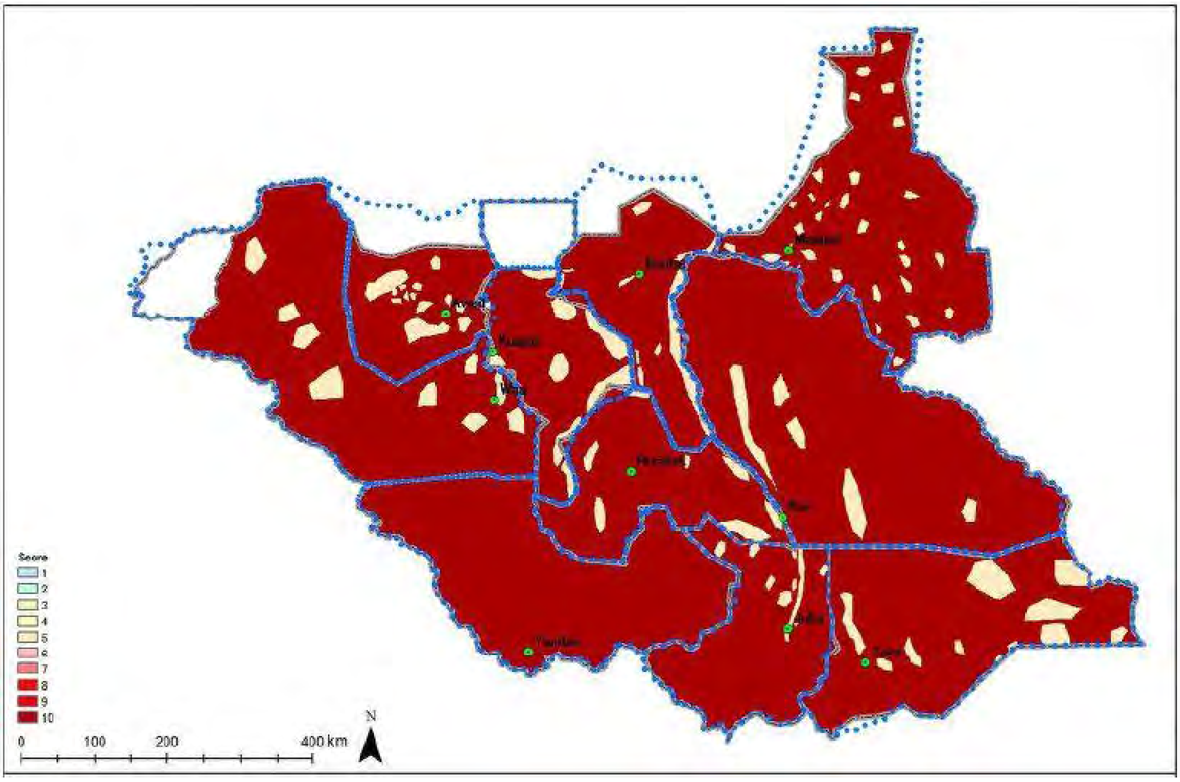
15. River Accessibility (Score) for Step-2 Group



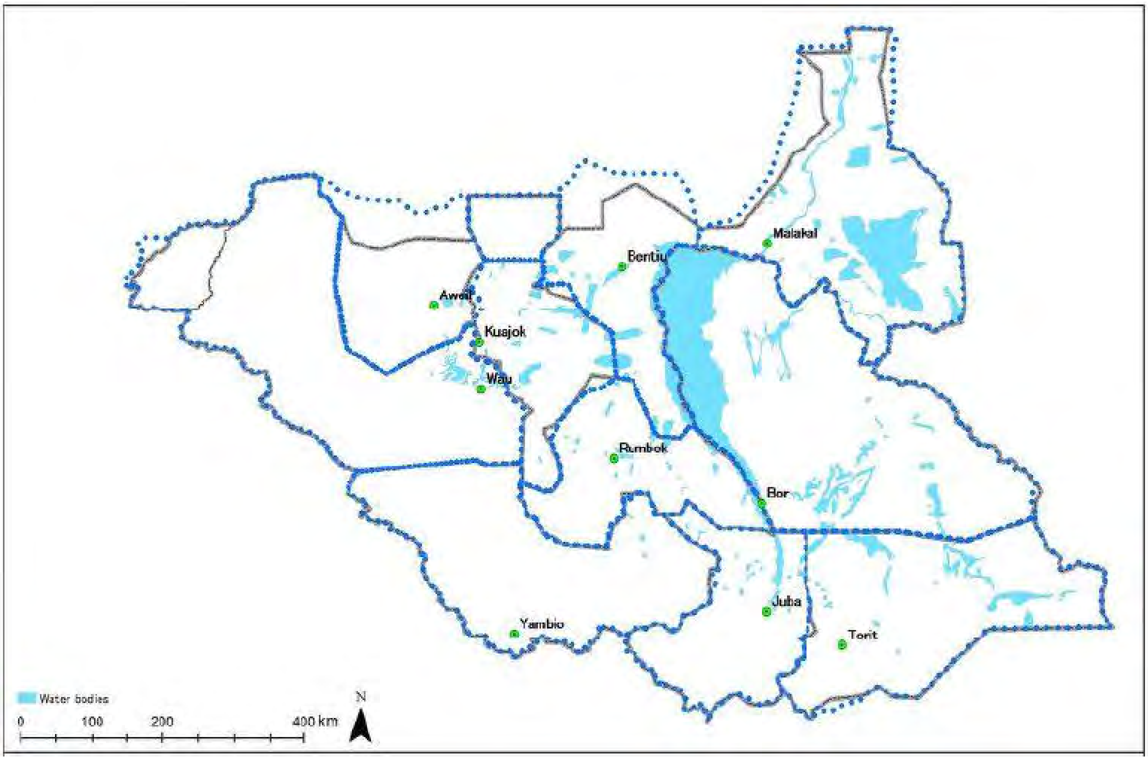
16. Grazing Area (Layer) for Step-2 Group



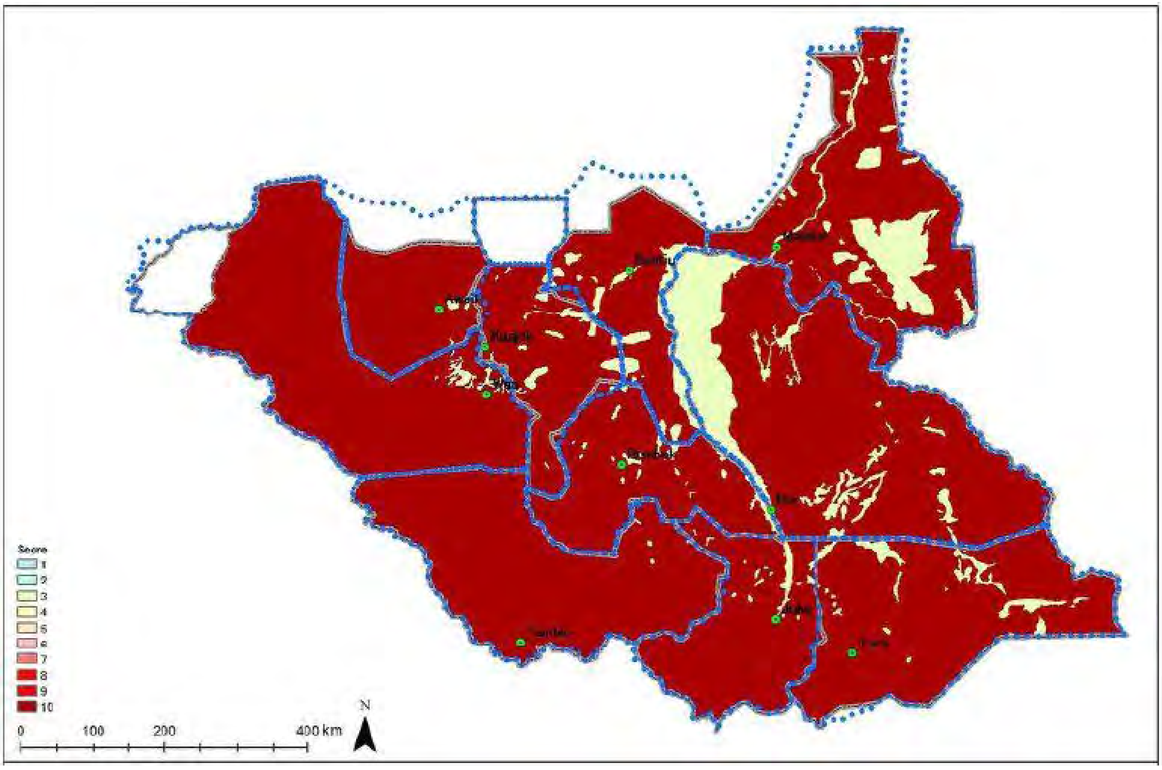
17. Grazing Area (Score) for Step-2 Group



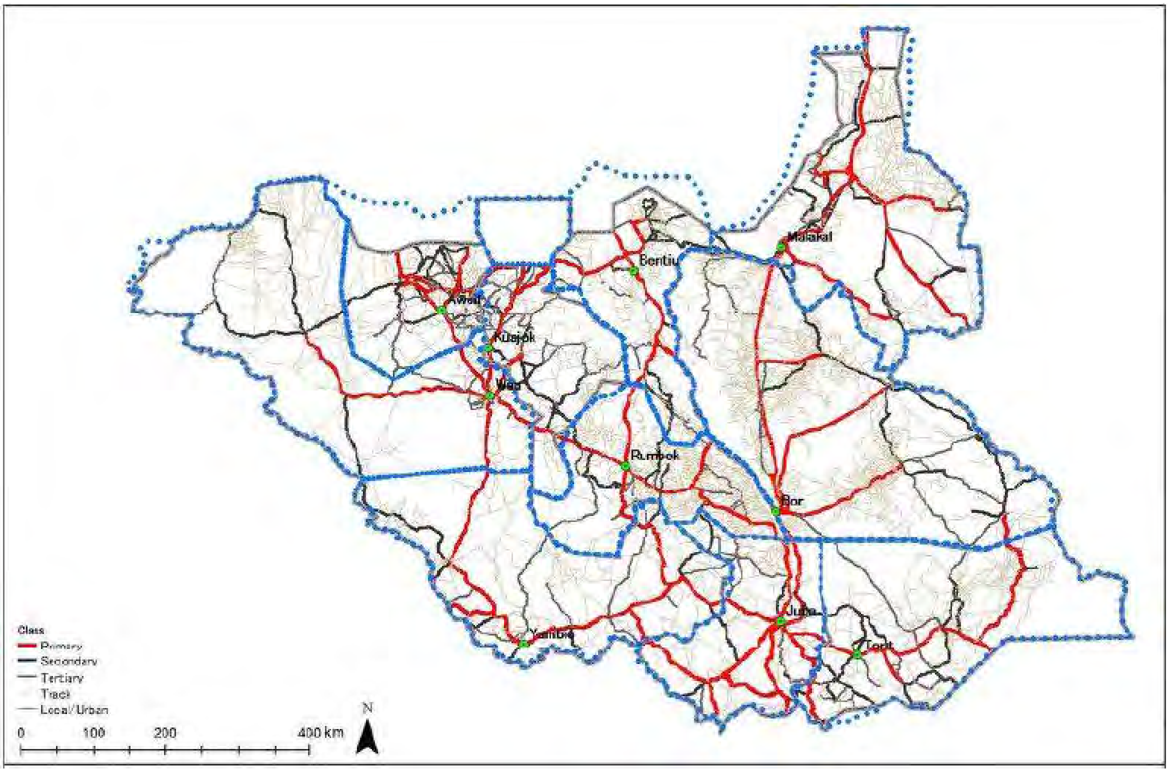
18. Water Bodies (Layer) for Step-2 Group



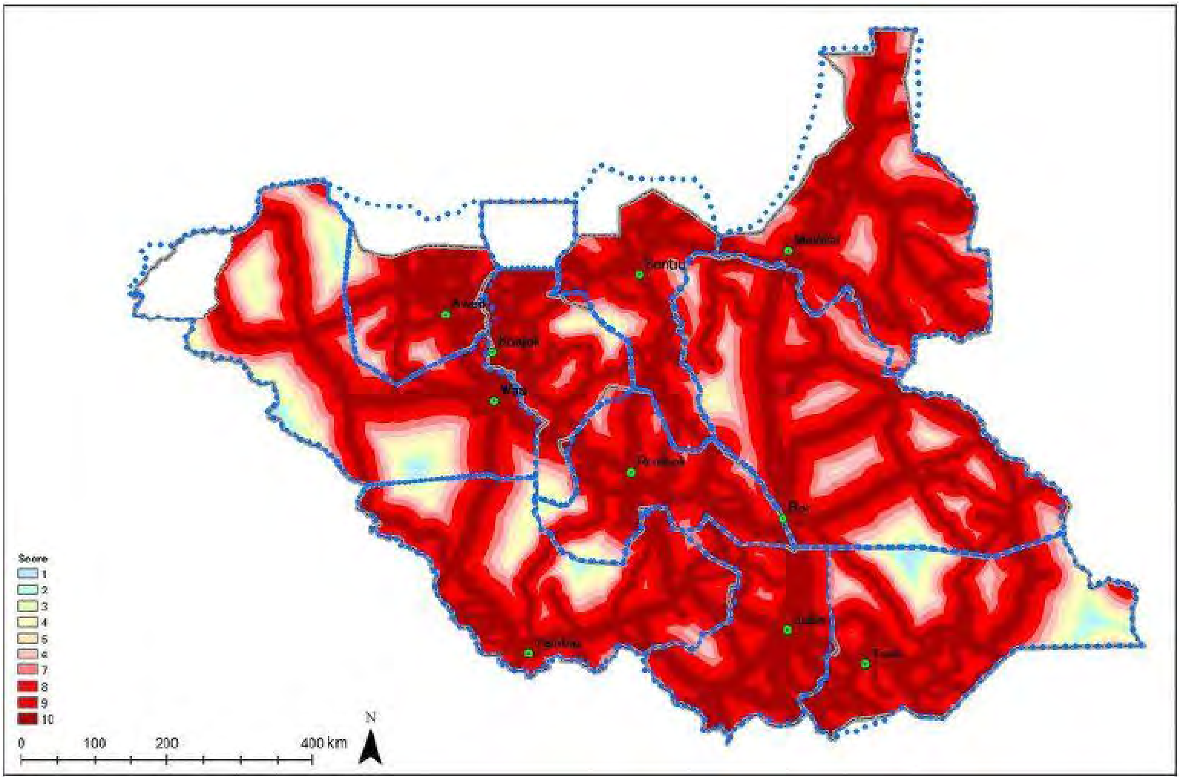
19. Water Bodies (Score) for Step-2 Group



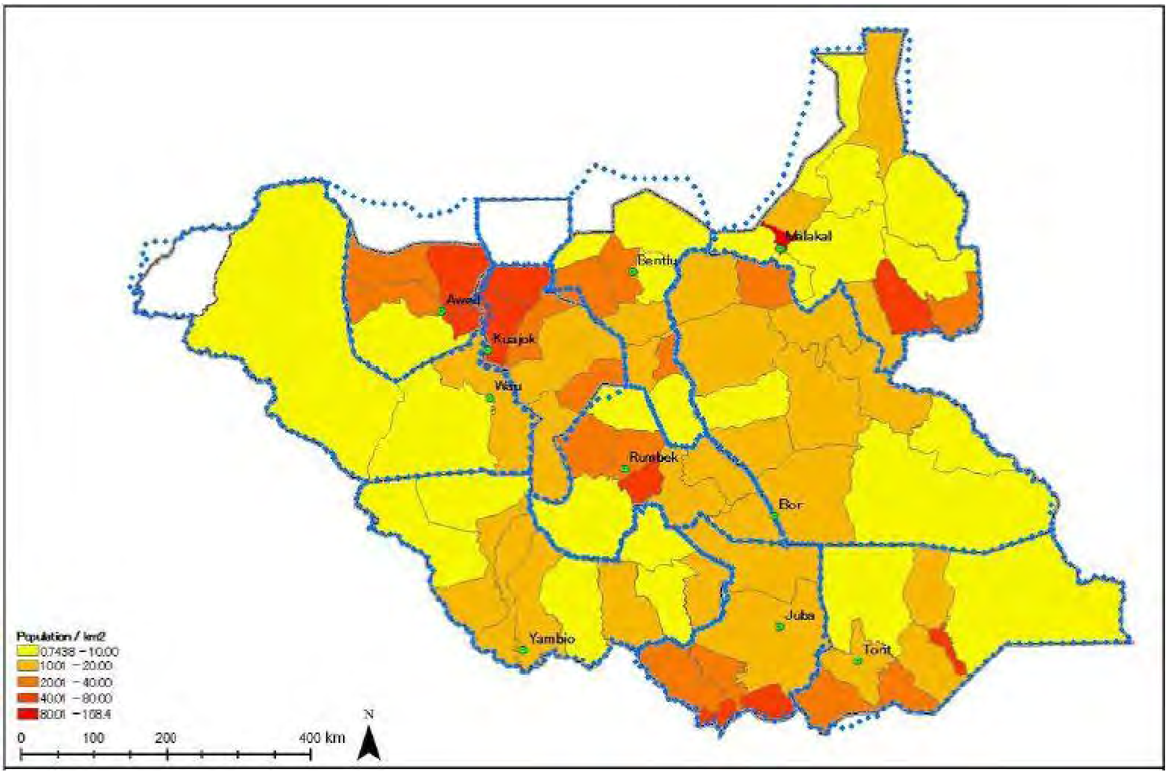
20. Road Accessibility (Layer) for Step-3 Group



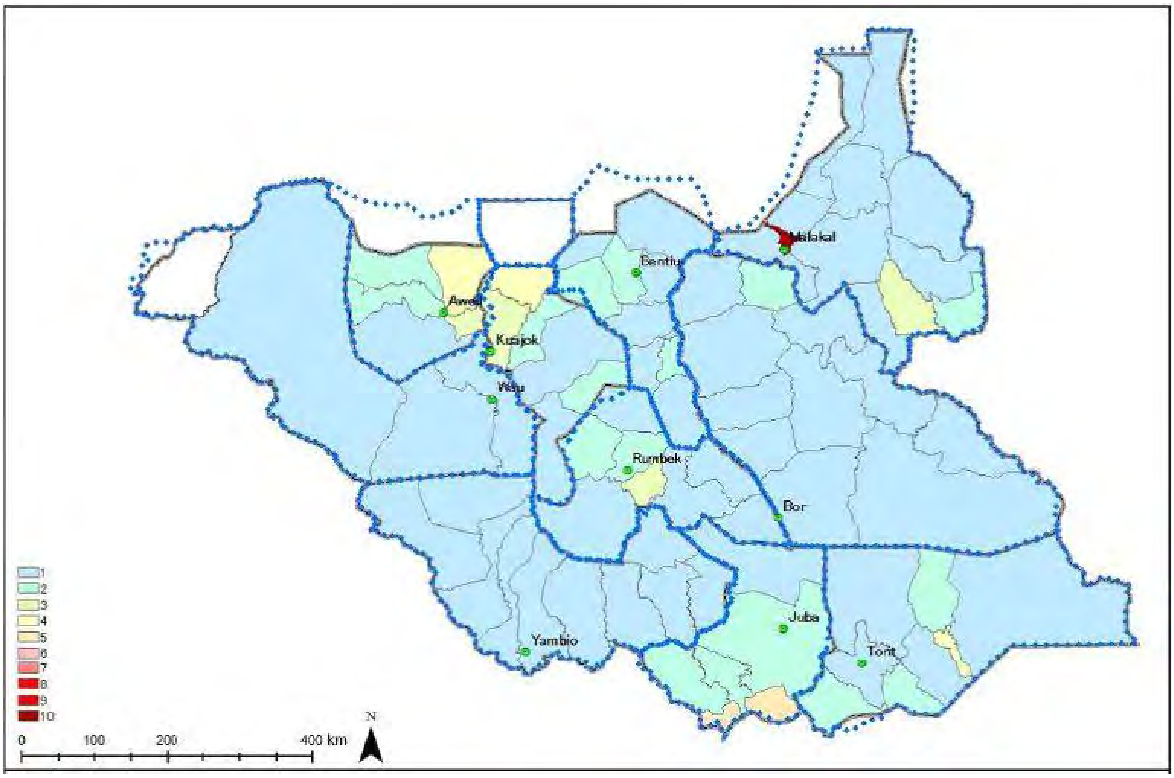
21. Road Accessibility (Score) for Step-3 Group



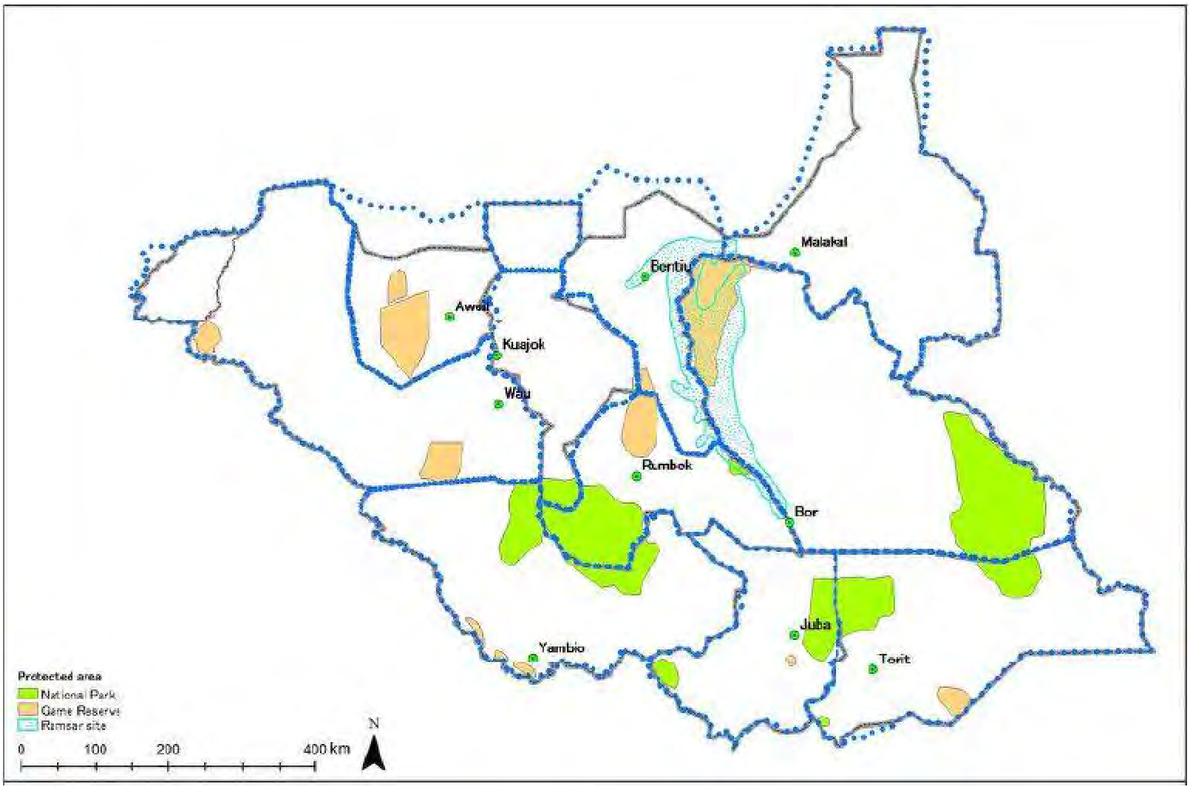
22. Population Density (Layer) for Step-3 Group



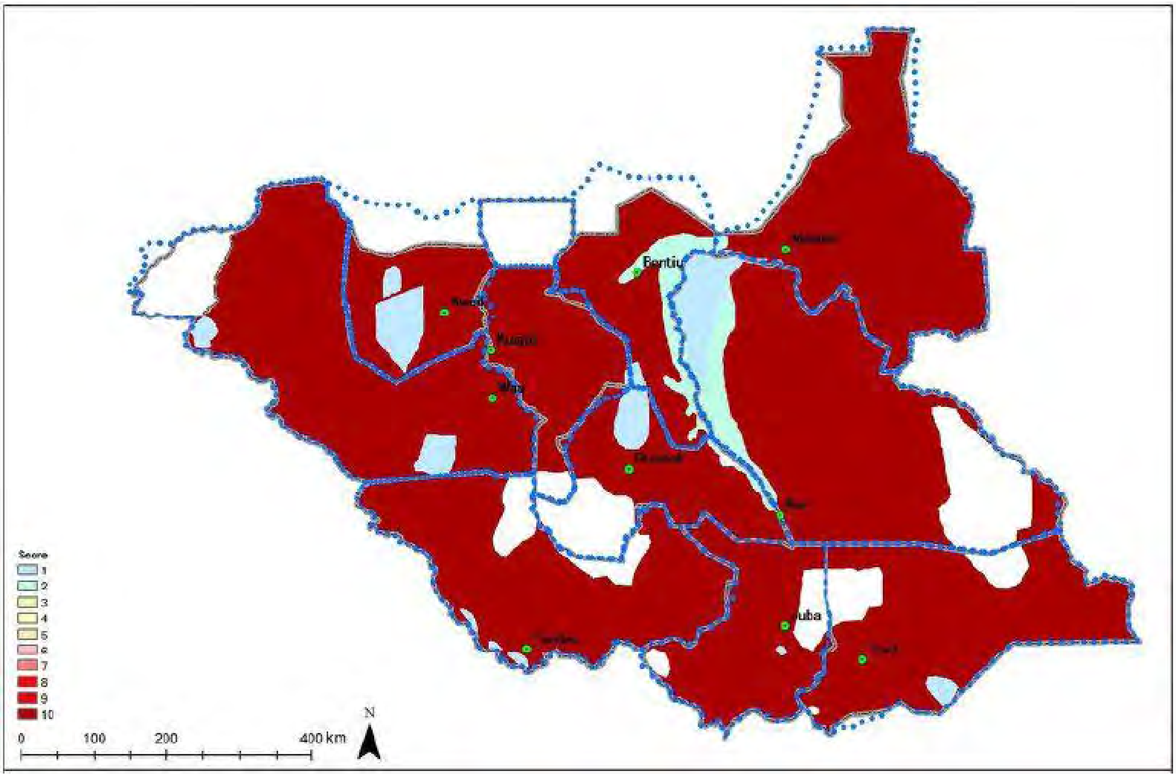
23. Population Density (Score) for Step-3 Group



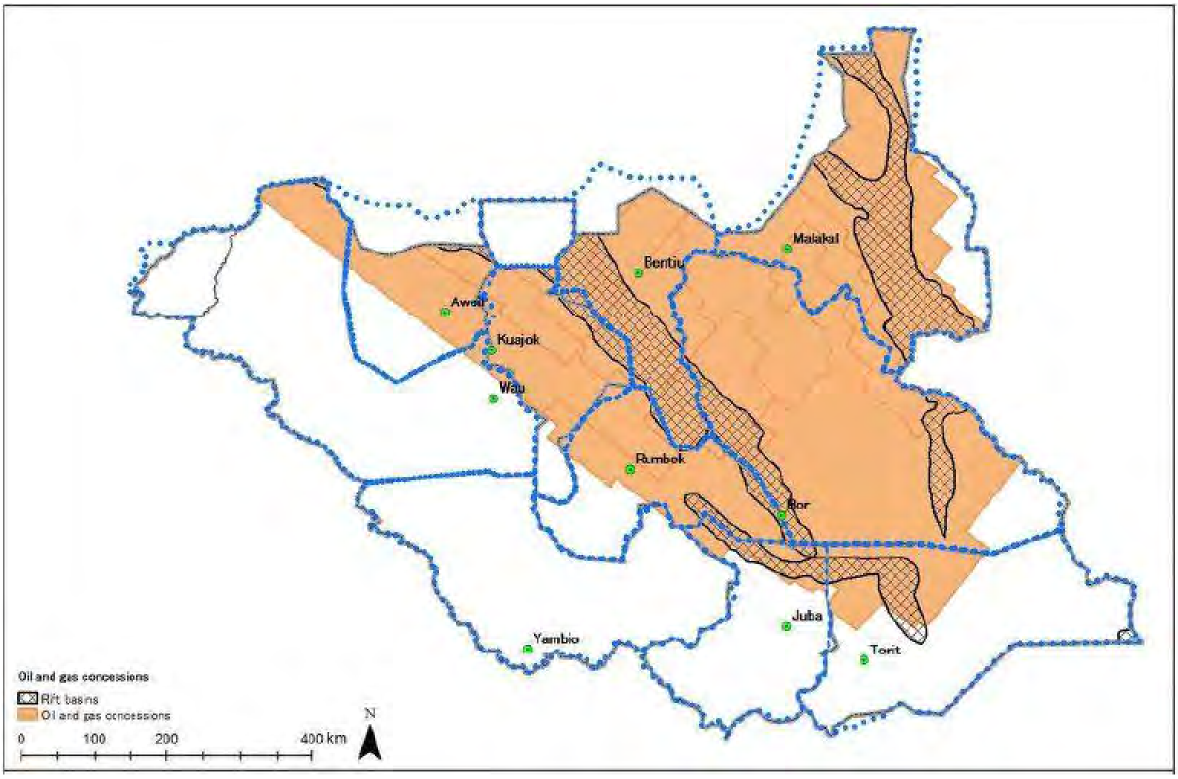
24. Protected Area (Layer) for Step-3 Group



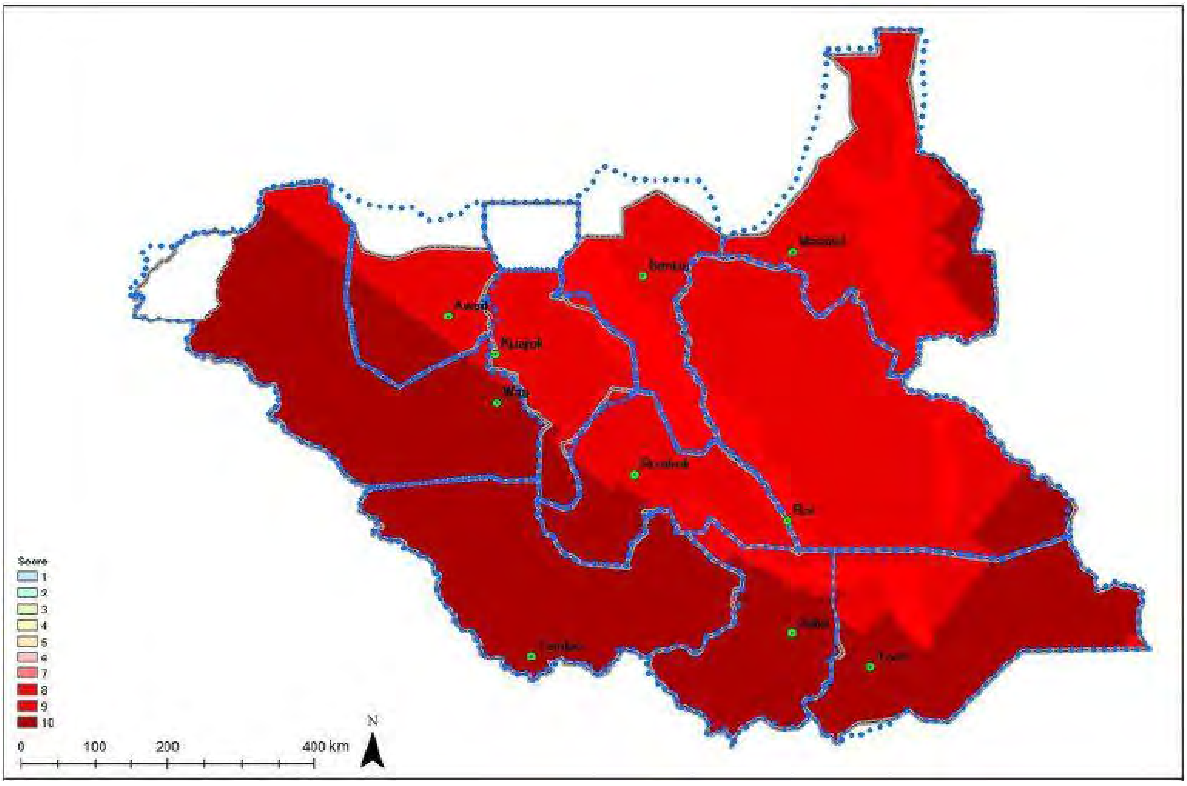
25. Protected Area (Score) for Step-3 Group



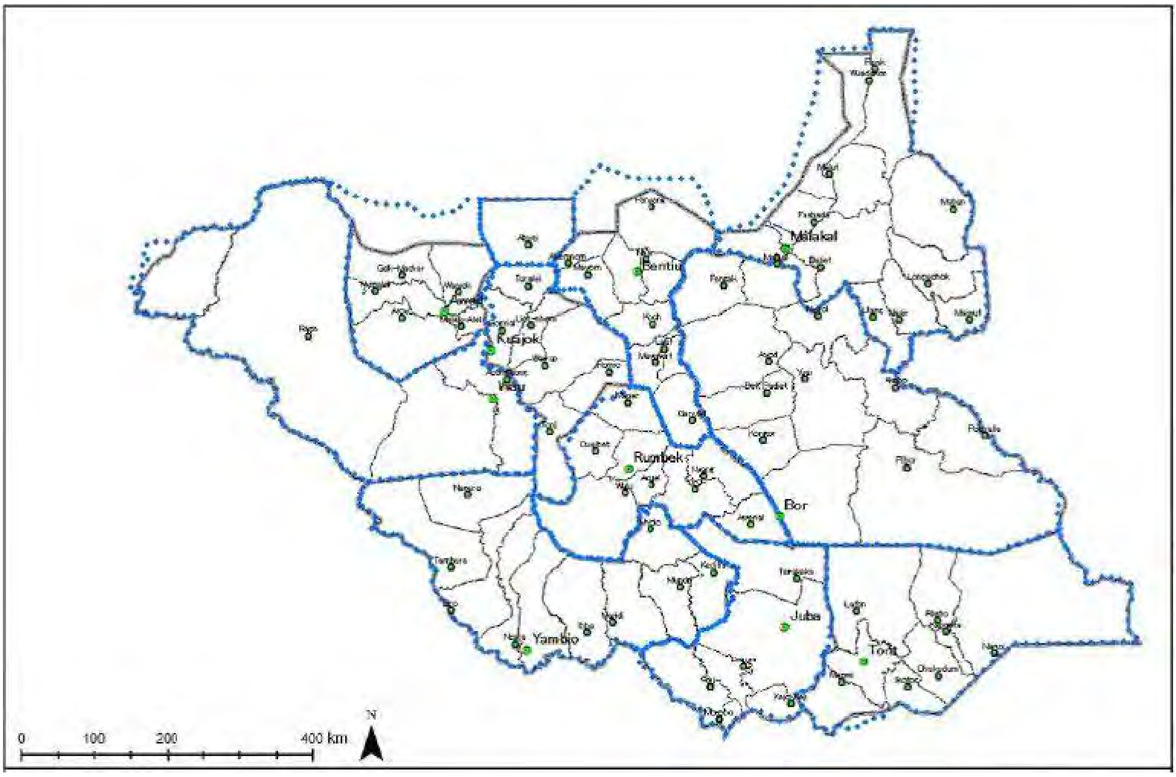
26. Oil and Gas Concessions (Layer) for Step-3 Group



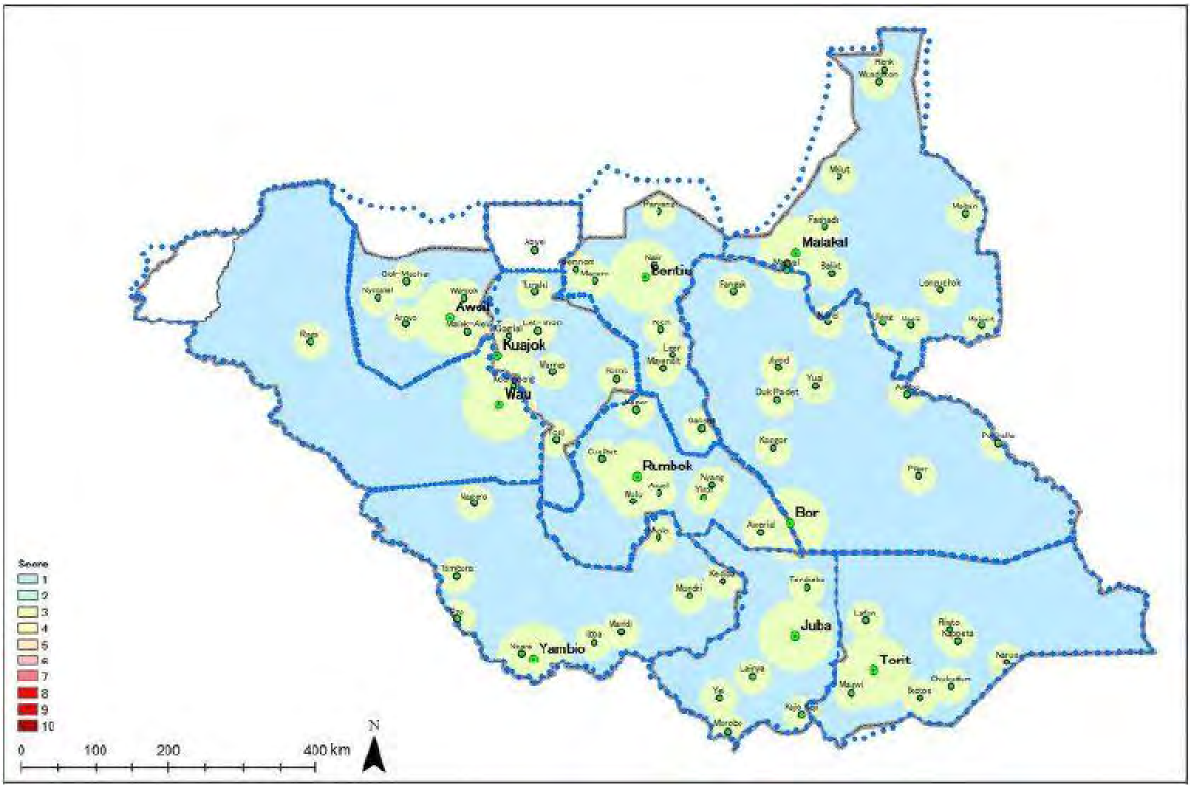
27. Oil and Gas Concessions (Score) for Step-3 Group



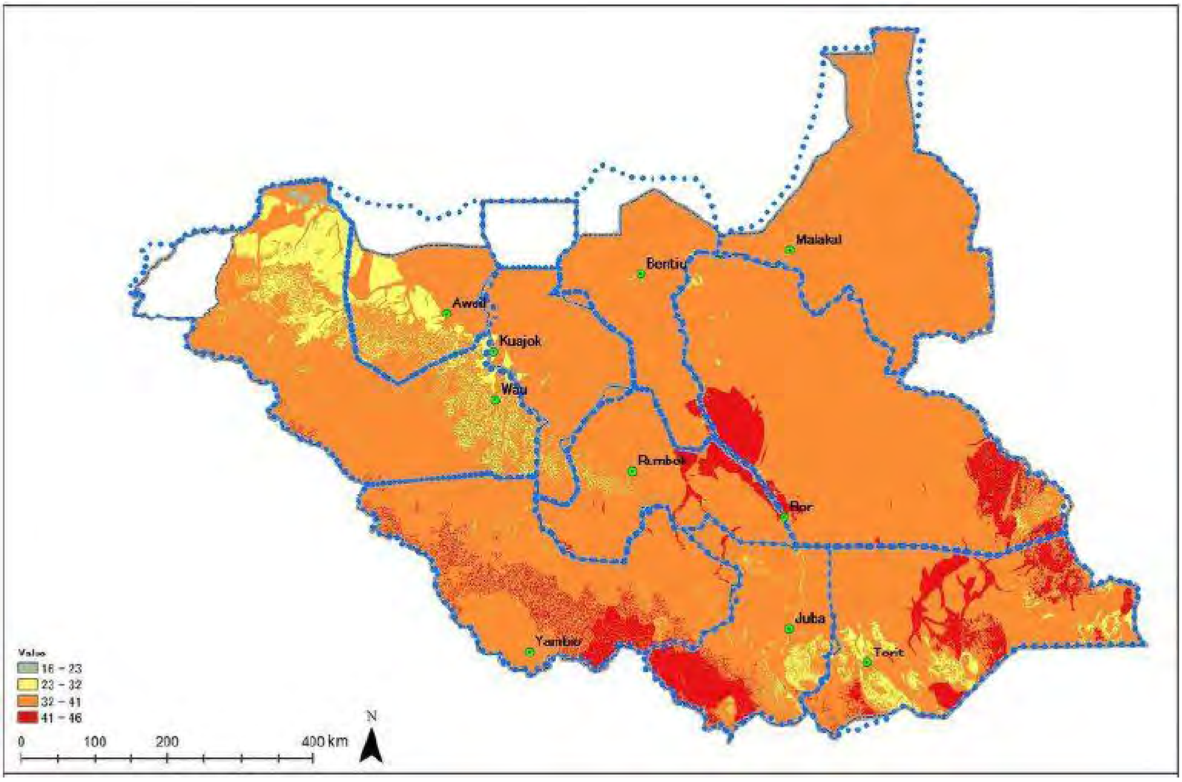
28. County Capital Advantage: CCA (Layer) for Step-3 Group



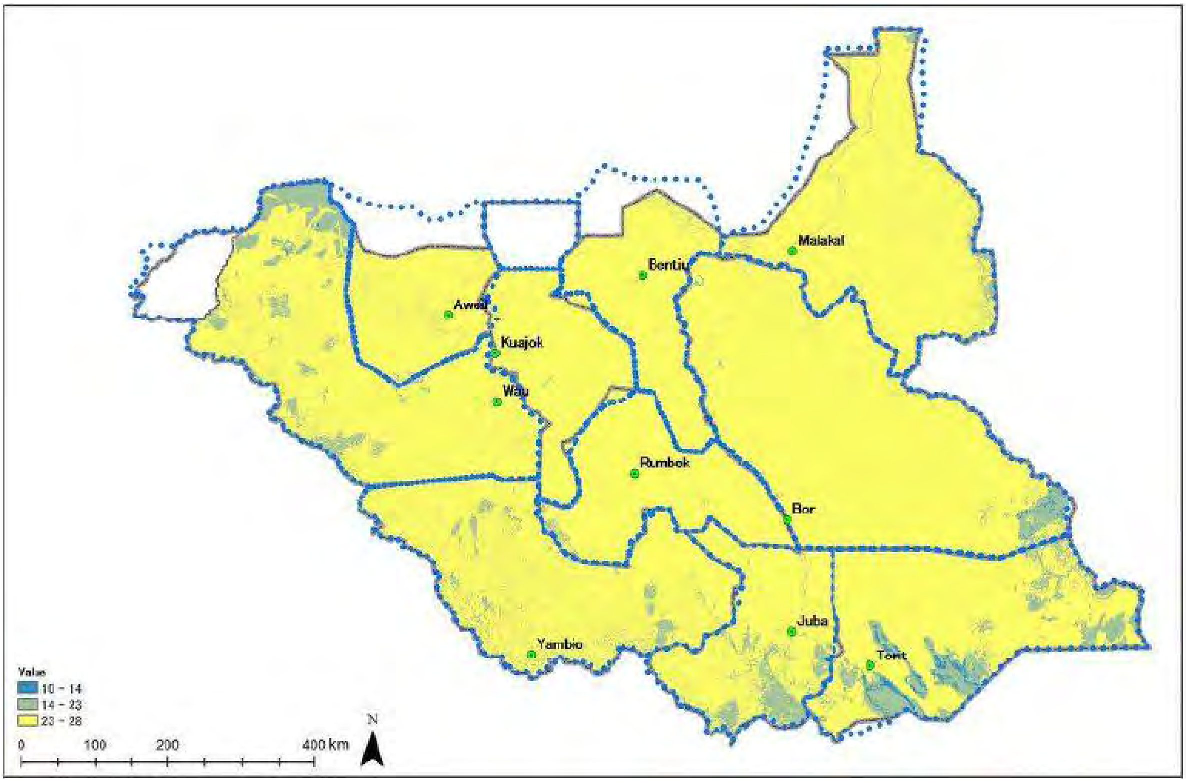
29. County Capital Advantage: CCA (Score) for Step-3 Group



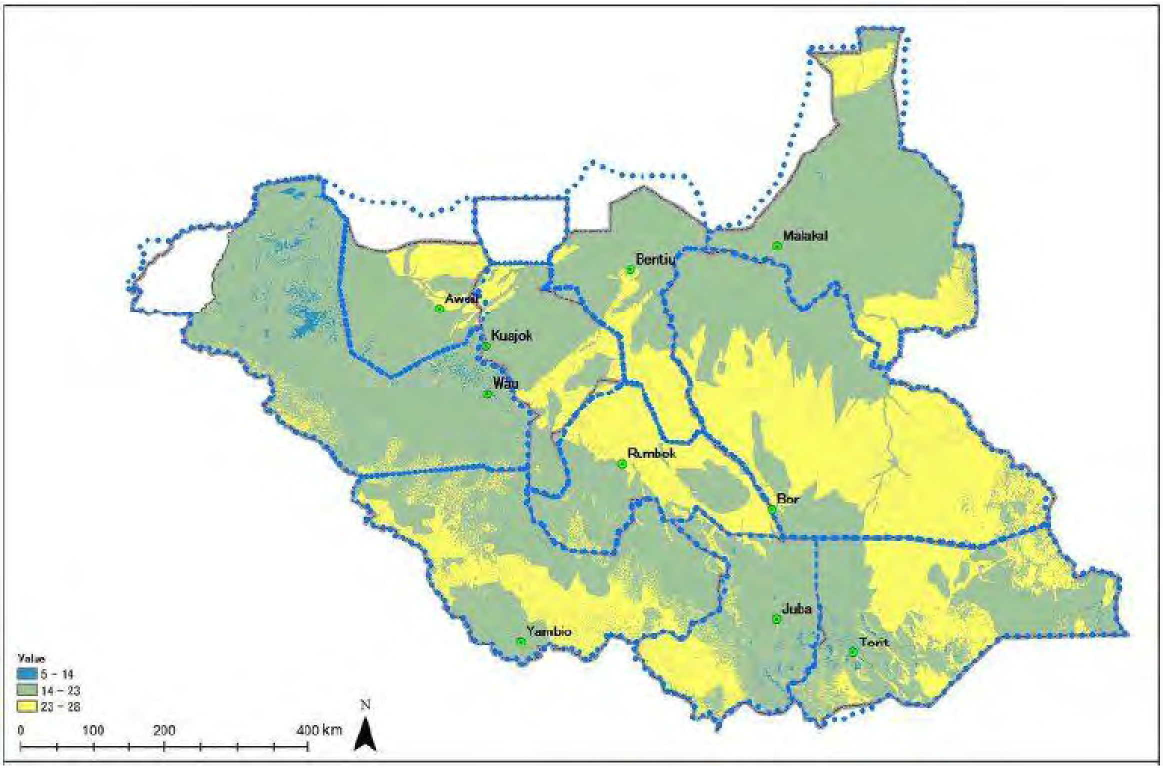
30. Step-1: Land Productivity Map (Non-rice & Rice)



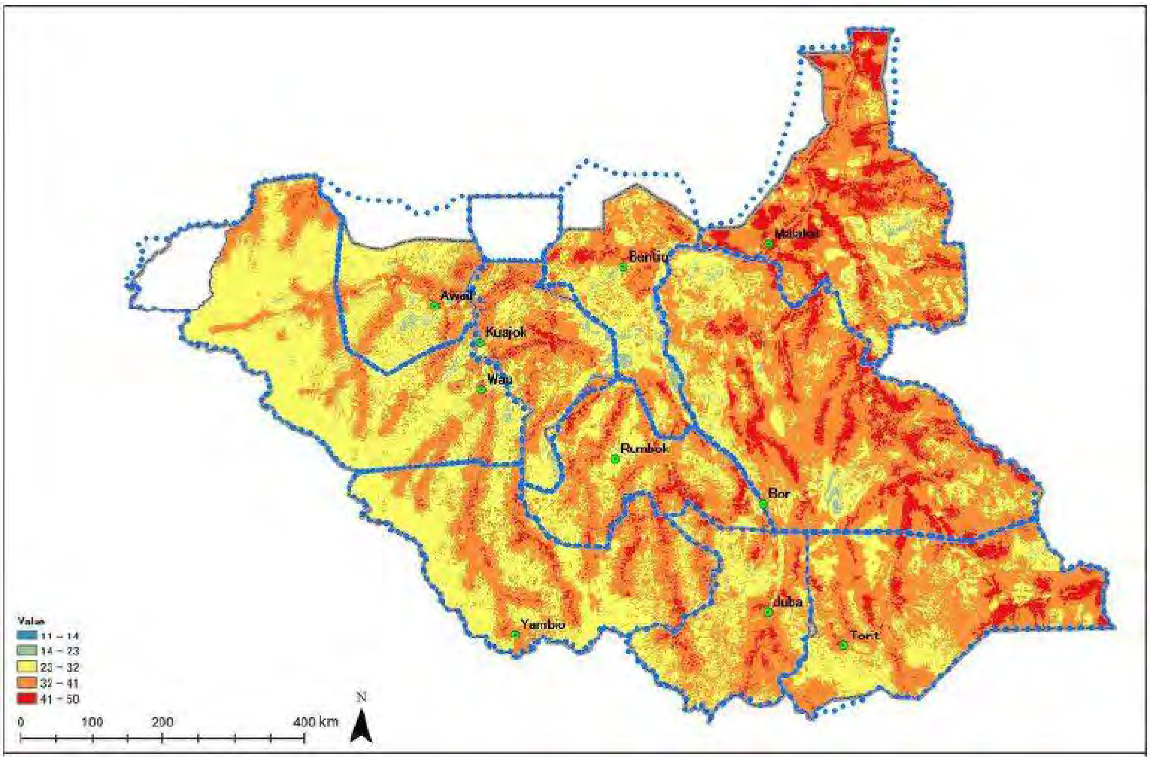
31. Step-1: Land Productivity Map for Non-rice



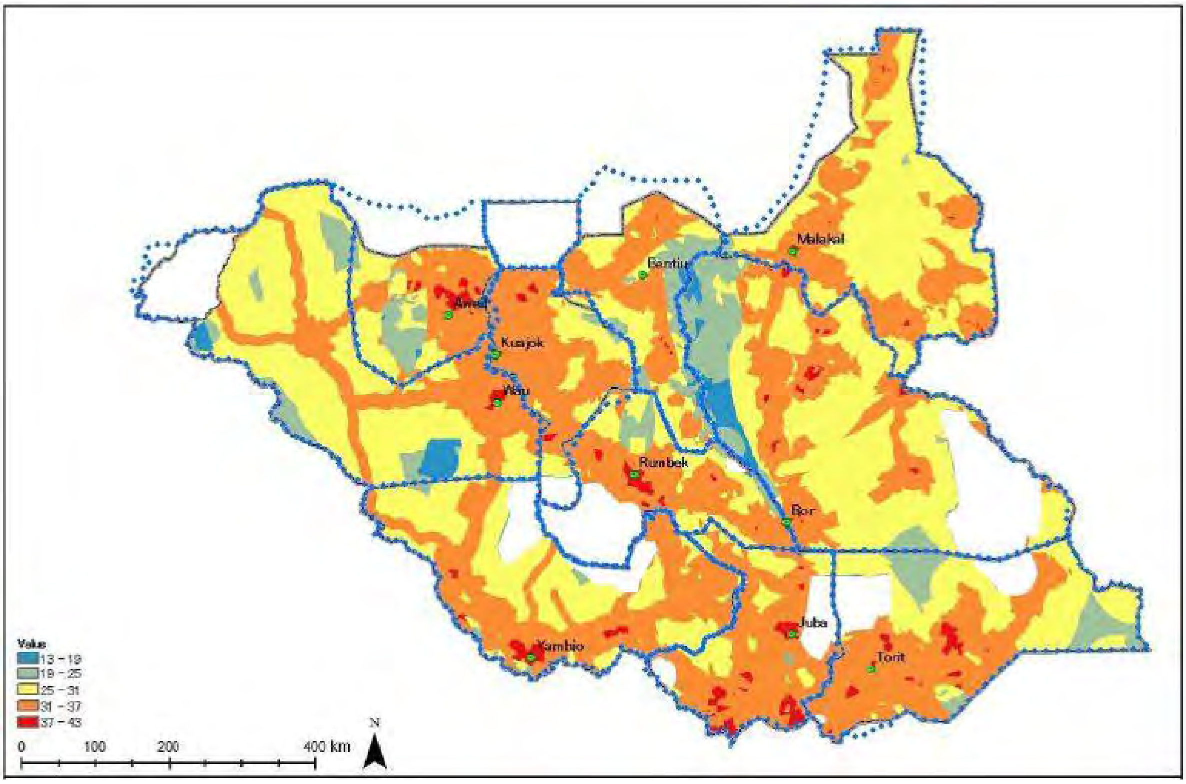
32. Step-1: Land Productivity Map for Rice



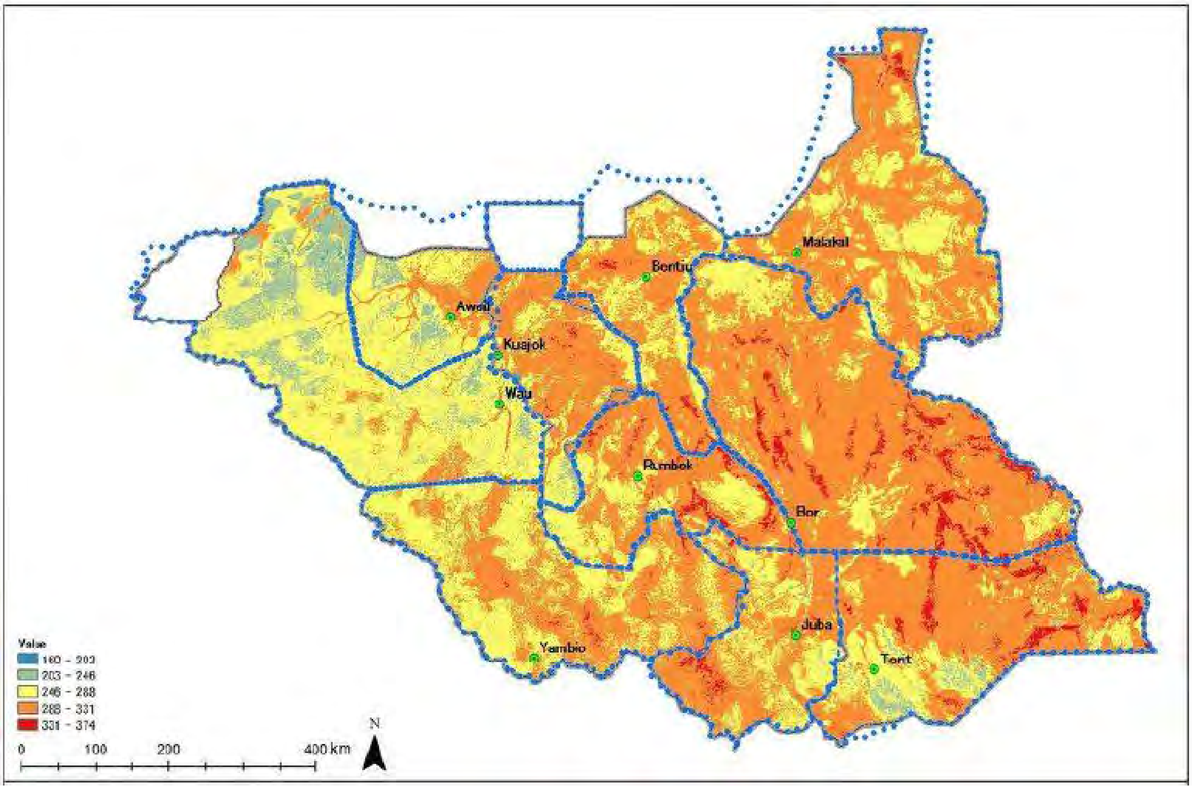
33. Step-2: Land Productivity Map



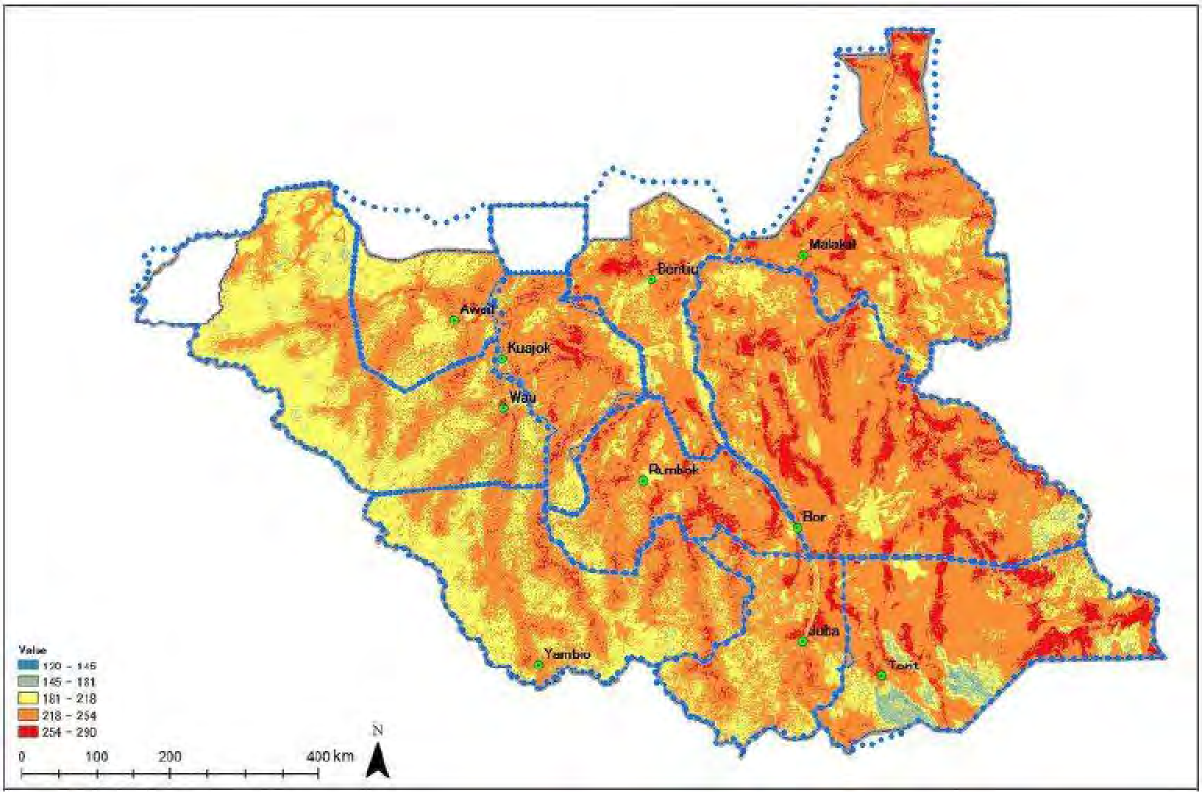
34. Step-3: Socio-economic Potential Map



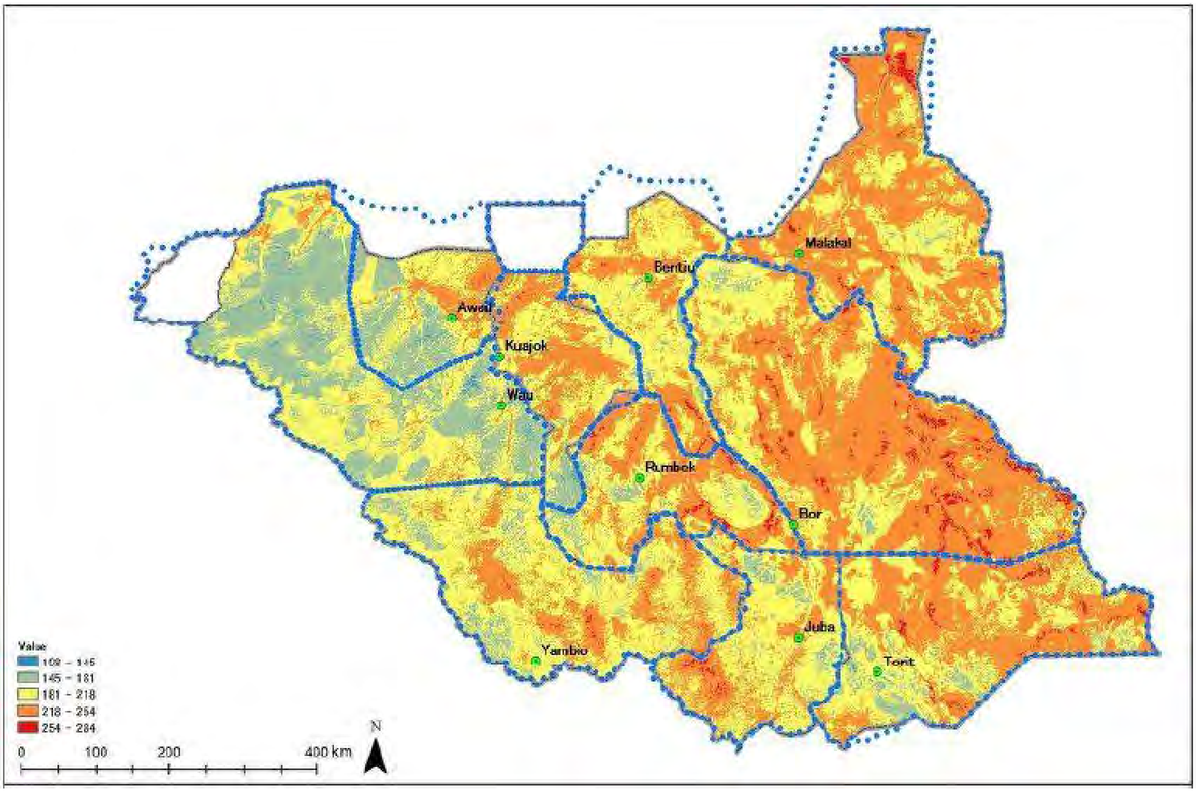
35. Step-4: Land Productivity Map (Non-rice & Rice)



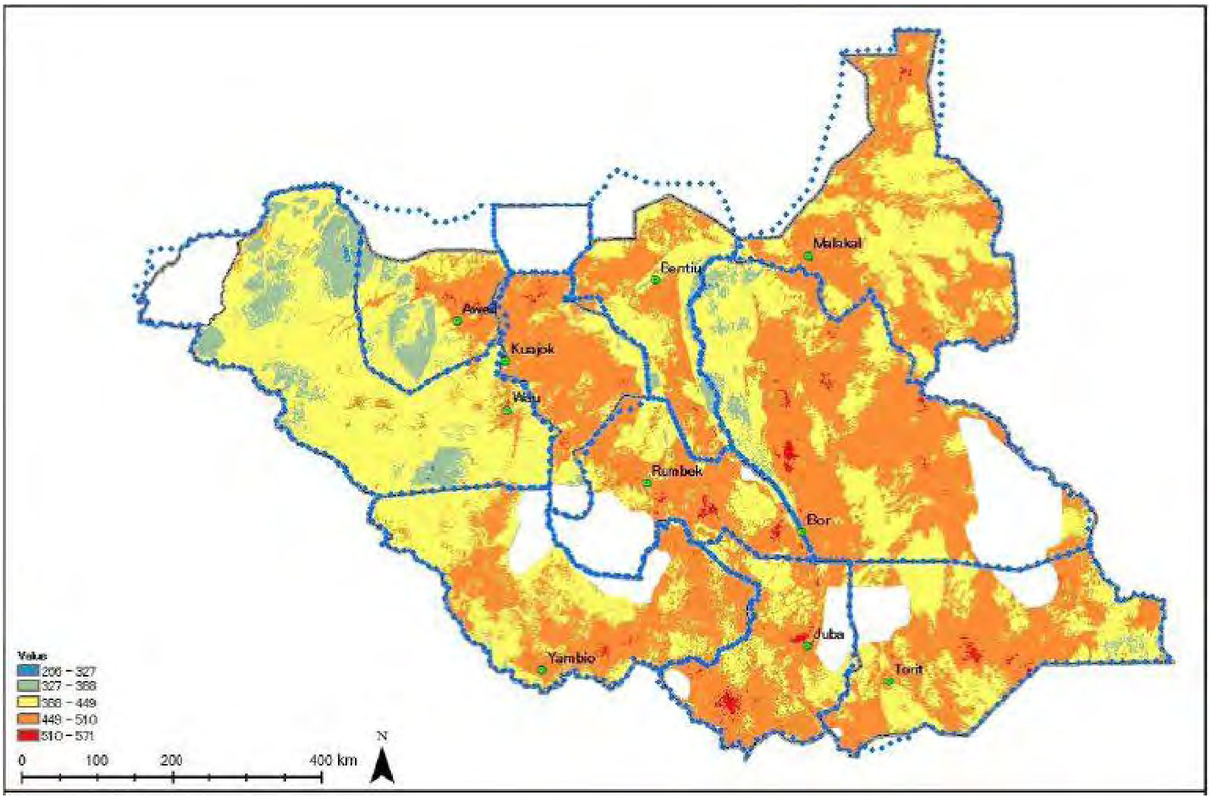
36. Step-4: Land Productivity Potential Map for Non-rice



37. Step-4: Land Productivity Potential Map for Rice



38. Step-5: Land Productivity / Socio-Economic Potential Map (Non-rice & Rice)

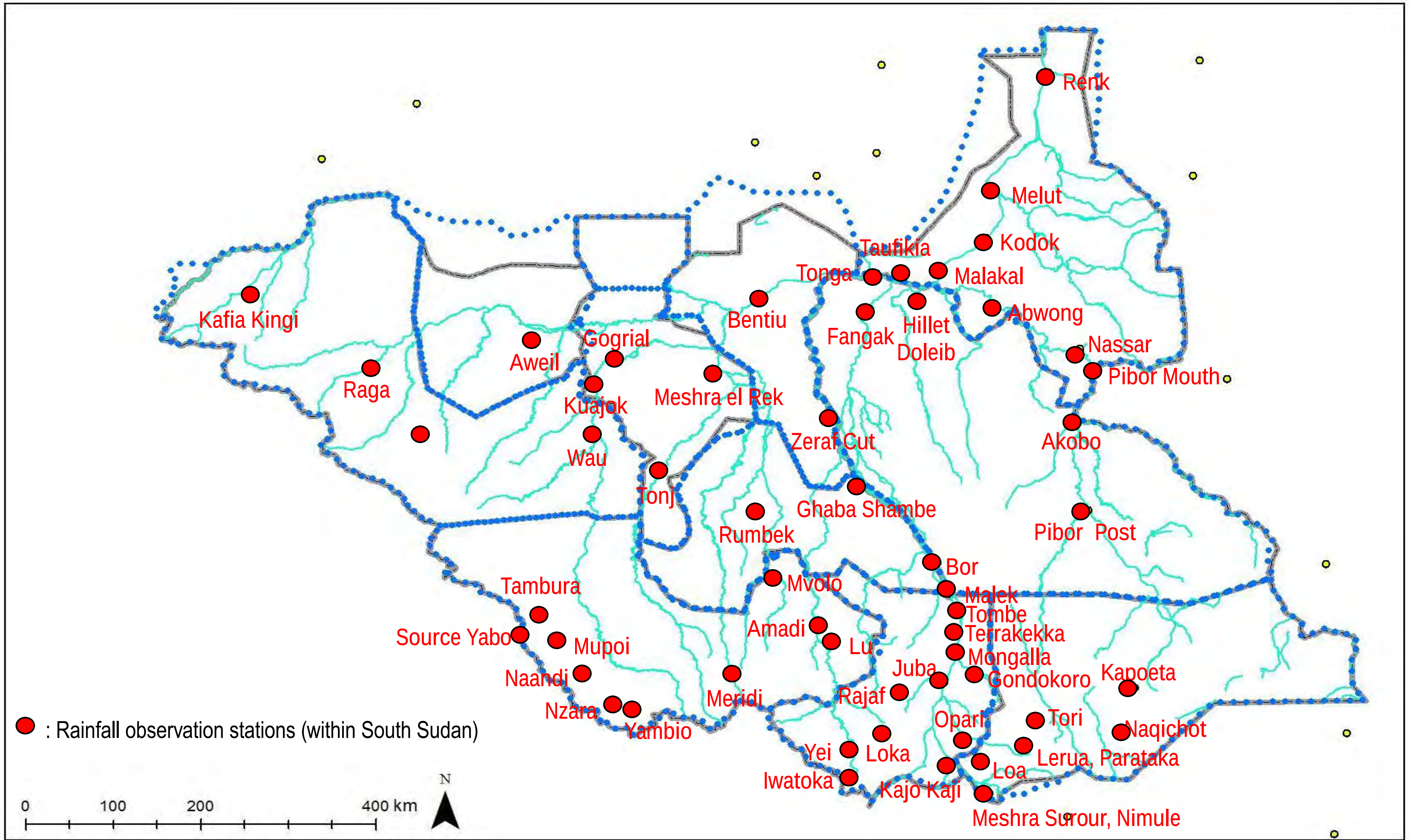


APPENDIX - 2

WATER RESOURCES POTENTIAL ASSESSMENT

APPENDIX - 2-1

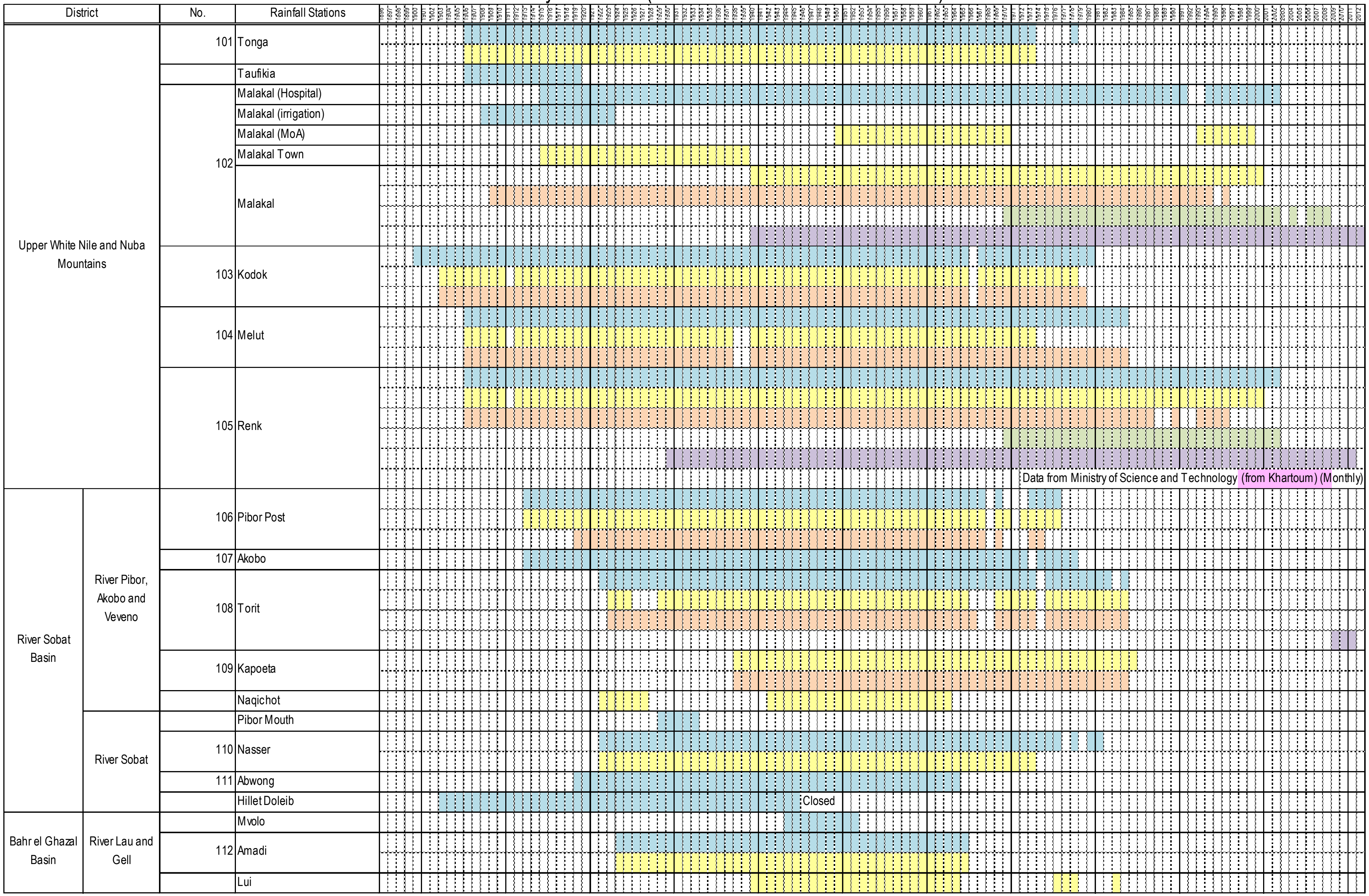
Rainfall Analysis



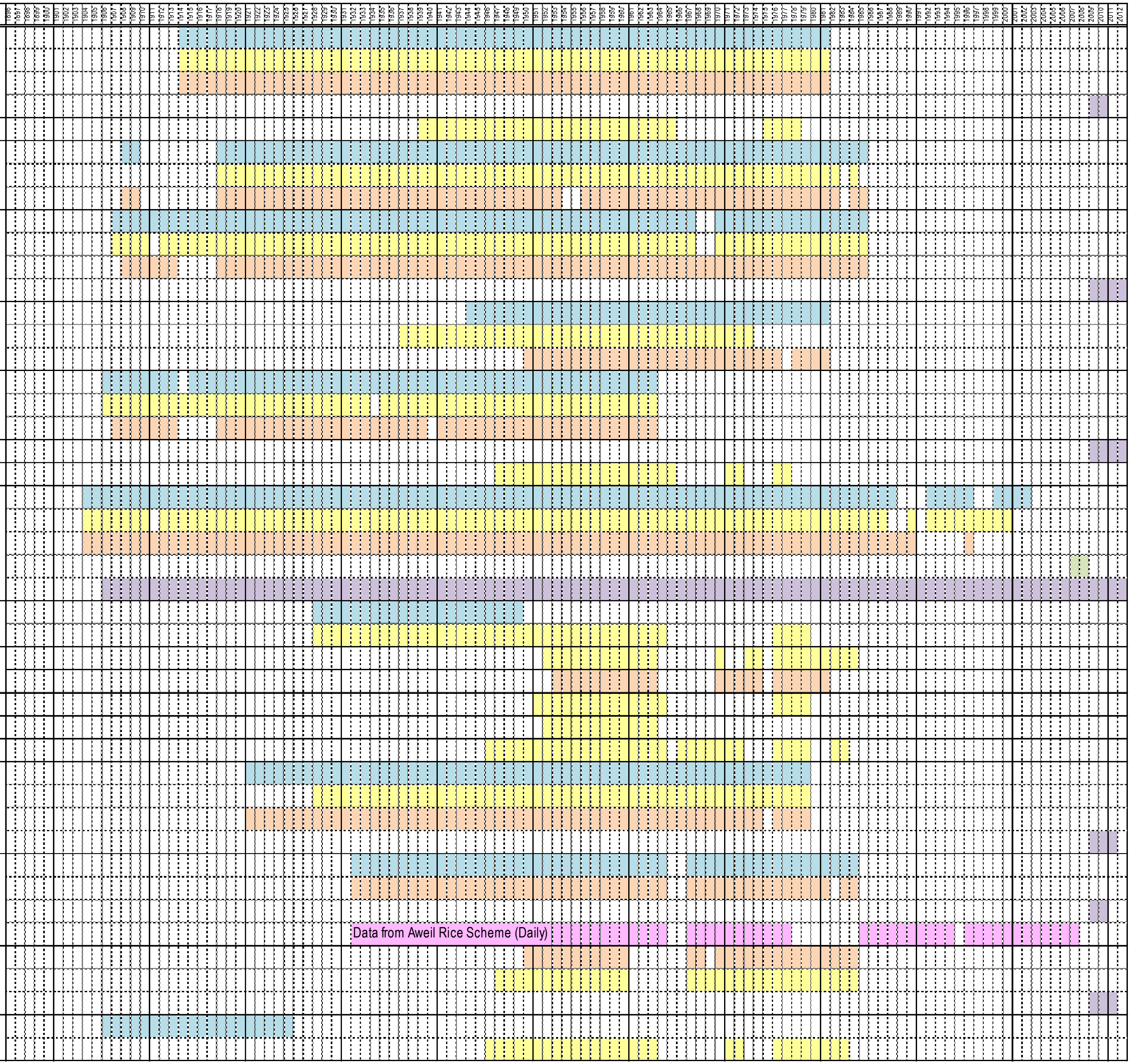
Location map of all the stations within South Sudan

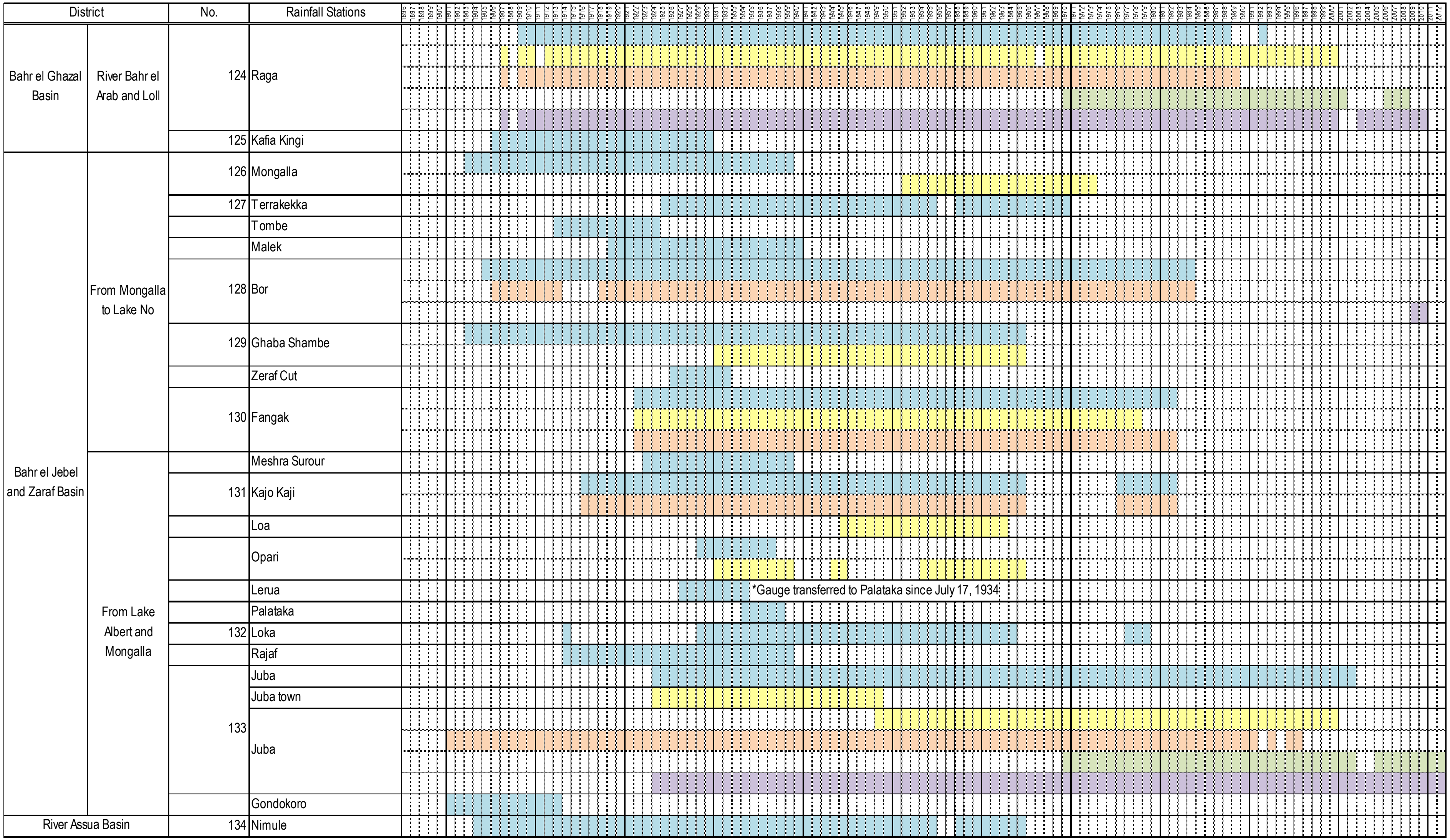
The Project for Irrigation Development Master Plan (IDMP)

Data availability of Rainfall (All the Stations within South Sudan)

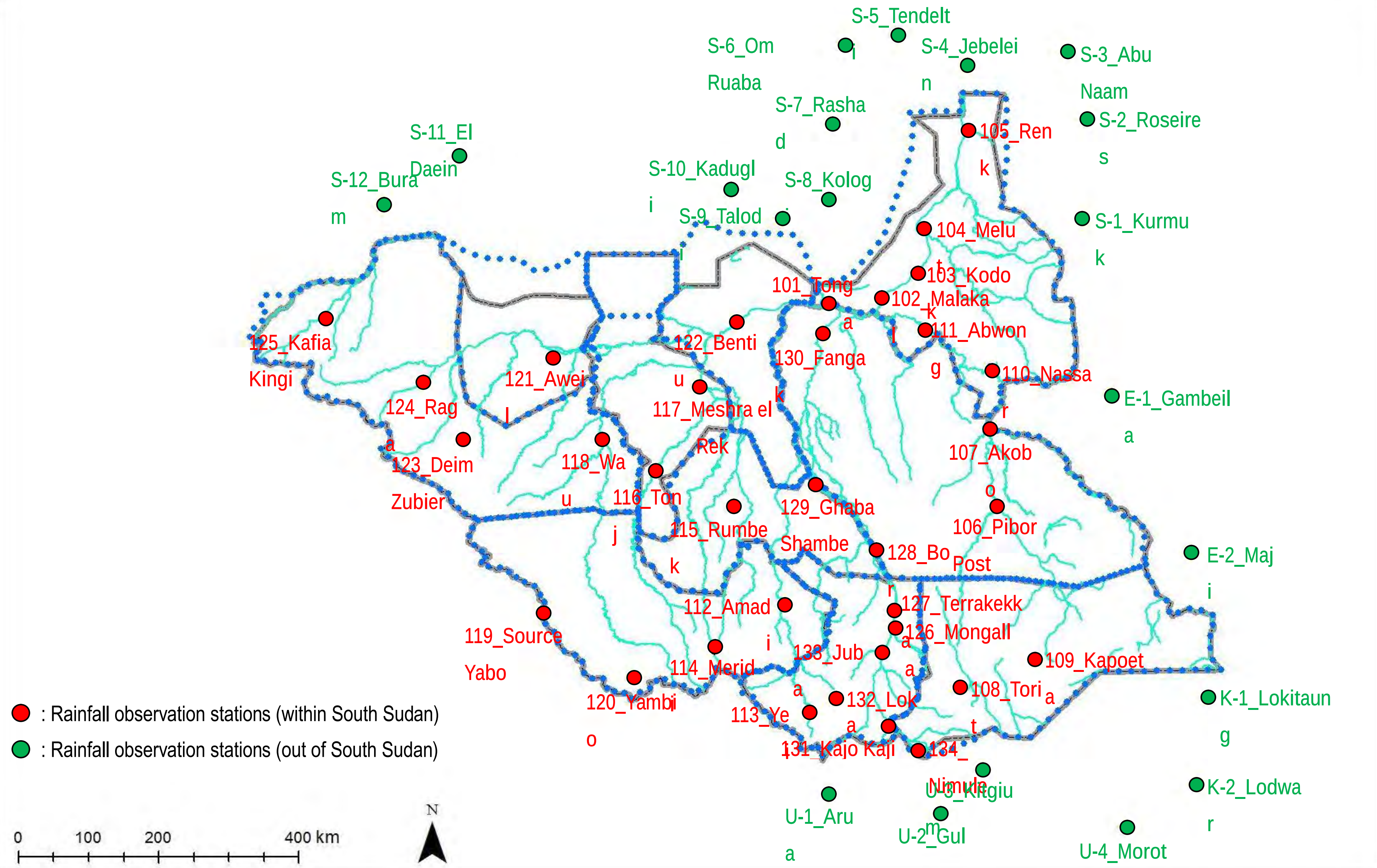


District		No.	Rainfall Stations
Bahr el Ghazal Basin	River Lau and Gell	113	Yei
			Iwatoka
		114	Meridi
		115	Rumbek
	River Jur and Tonj	116	Tonj
		117	Meshra el Rek
			Kuajok
			Gogrial
		118	Wau
		119	Source Yabo
			Tambura
			Mupoi
			Naandi
			Nzara
		120	Yambio
		121	Aweil
	River Bahr el Arab and Loll	122	Bentiu
		123	Deim Zubier





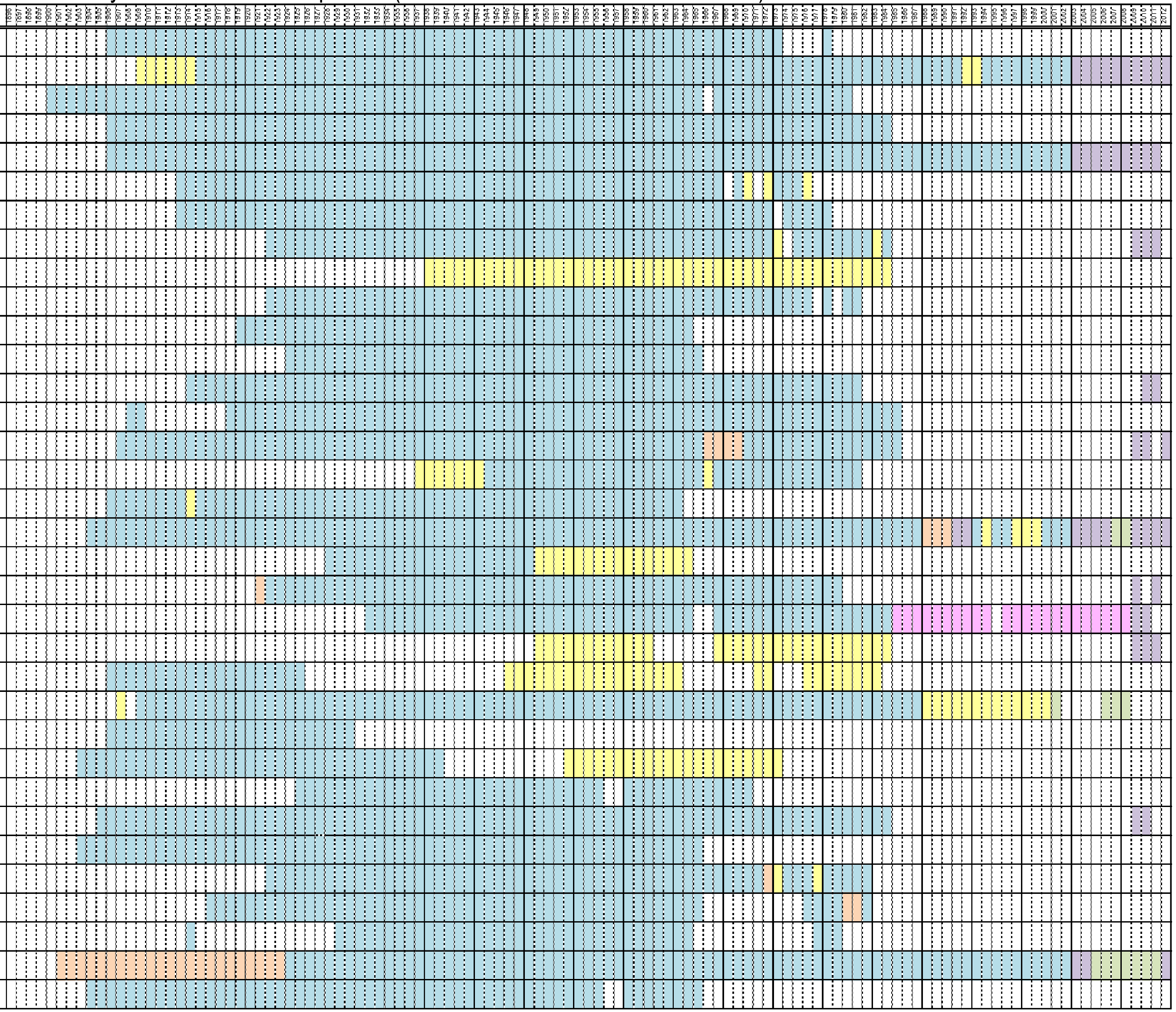
:Record on "The Nile Basin by H. E. .Hurst and P. Phillips" (Monthly)
:Nile DST (Daily)
: FAO-CLIM (Monthly)
:Data from FAO office (Daily)
:Data from Ministry of Transportation (Daily, Monthly)
: Others



Location map of selected

Data availability of Rainfall after compilation (Selected stations within South Sudan)

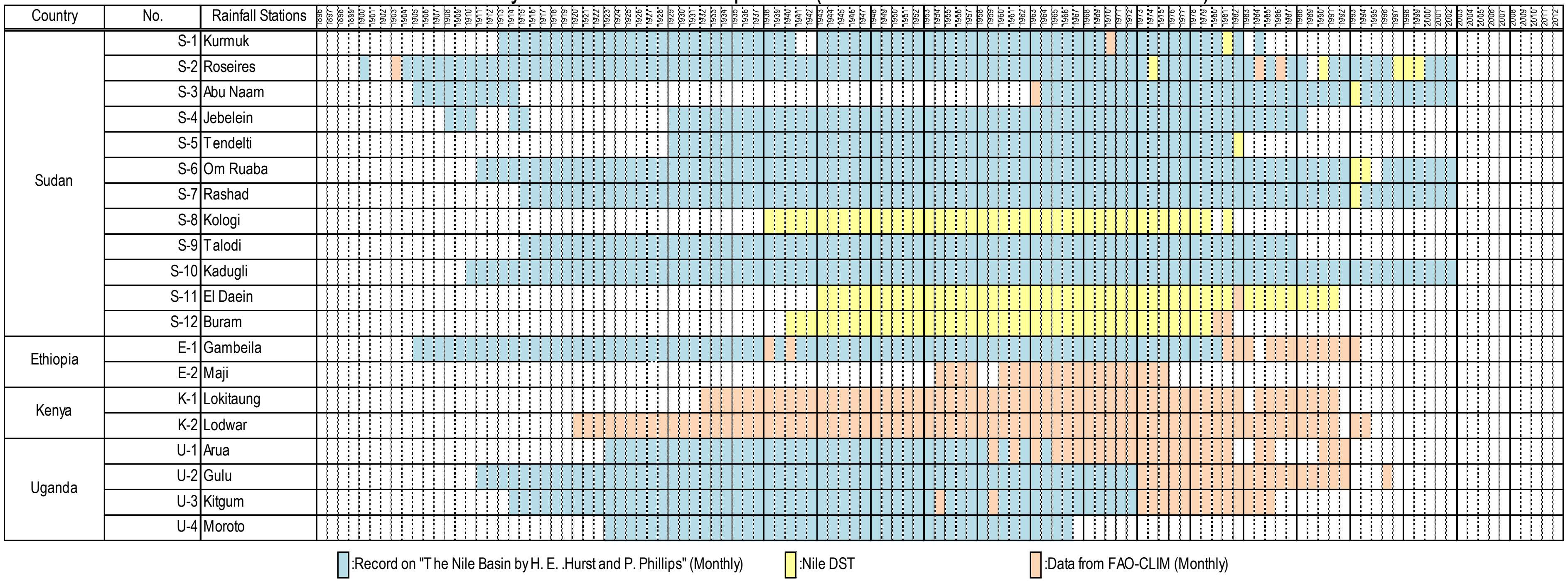
District		No.	Rainfall Stations
Upper White Nile and Nuba Mountains		101	Tonga
		102	Malakal
		103	Kodok
		104	Melut
		105	Renk
River Sobat Basin	River Pibor, Akobo and Veveno	106	Pibor Post
		107	Akobo
		108	Torit
		109	Kapoeta
	River Sobat	110	Nasser
		111	Abwong
Bahr el Ghazal Basin	River Lau and Gell	112	Amadi
		113	Yei
		114	Meridi
		115	Rumbek
	River Jur and Tonj	116	Tonj
		117	Meshra el Rek
		118	Wau
		119	Source Yabo
		120	Yambio
		121	Aweil
	River Bahr el Arab and Loll	122	Bentiu
		123	Deim Zubier
		124	Raga
		125	Kafia Kingi
Bahr el Jebel and Zaraf Basin	From Mongalla to Lake No	126	Mongalla
		127	Terrakekka
		128	Bor
		129	Ghaba Shambe
		130	Fangak
	From Lake Albert and Mongalla	131	Kajo Kaji
		132	Loka
		133	Juba
River Assua Basin		134	Nimule

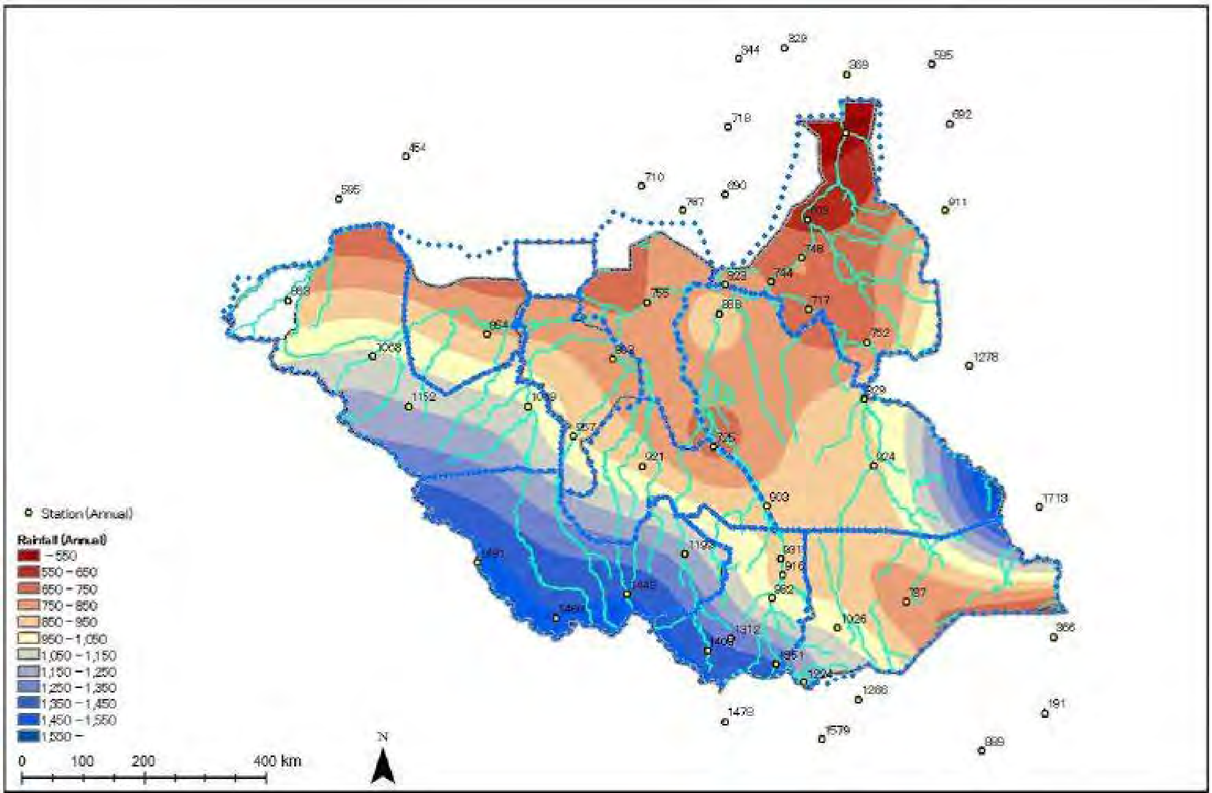


:Record on "The Nile Basin by H. E. .Hurst and P. Phillips" (Monthly) :Nile DST (Daily) : FAO-CLIM (Monthly) :Data from FAO office (Daily)

:Data from Ministry of Transportation (Daily, Monthly) : Others: Data from Ministry of Science and Technology (from Khartoum) (Monthly)

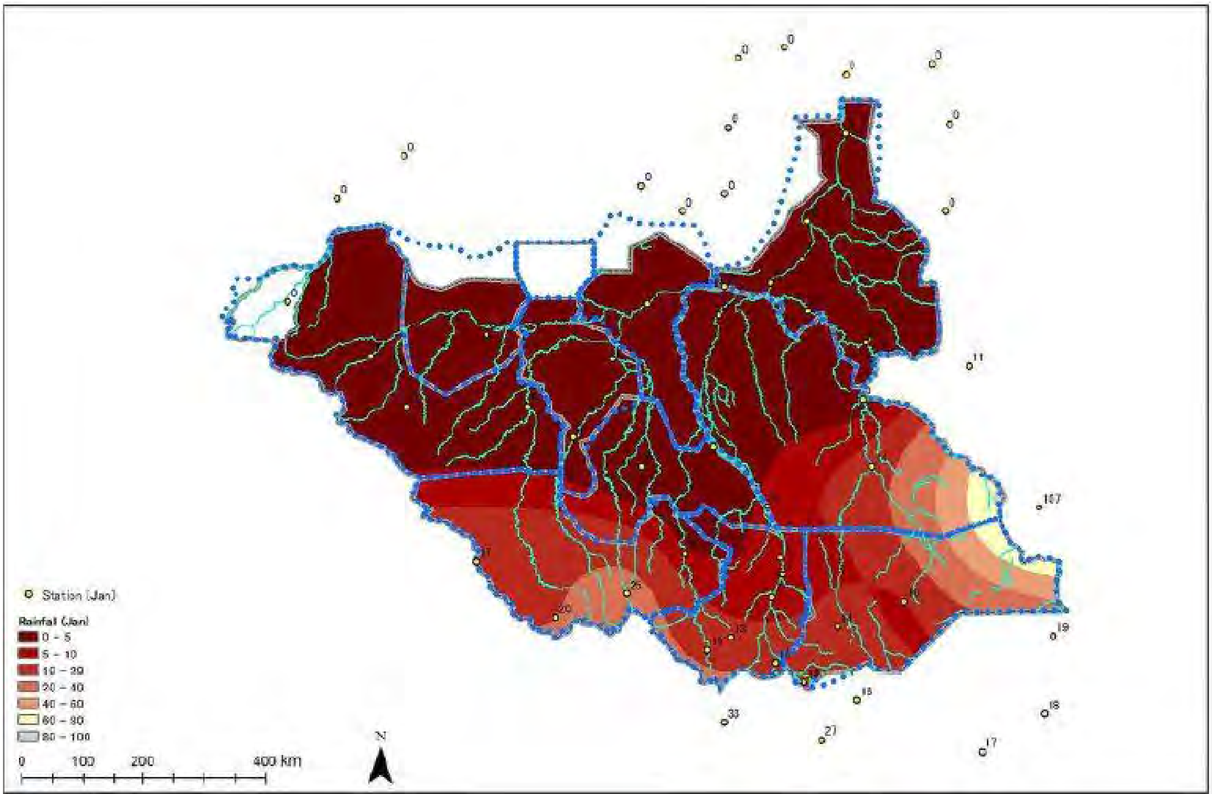
Data availability of Rainfall after compilation (Selected stations out of South Sudan)





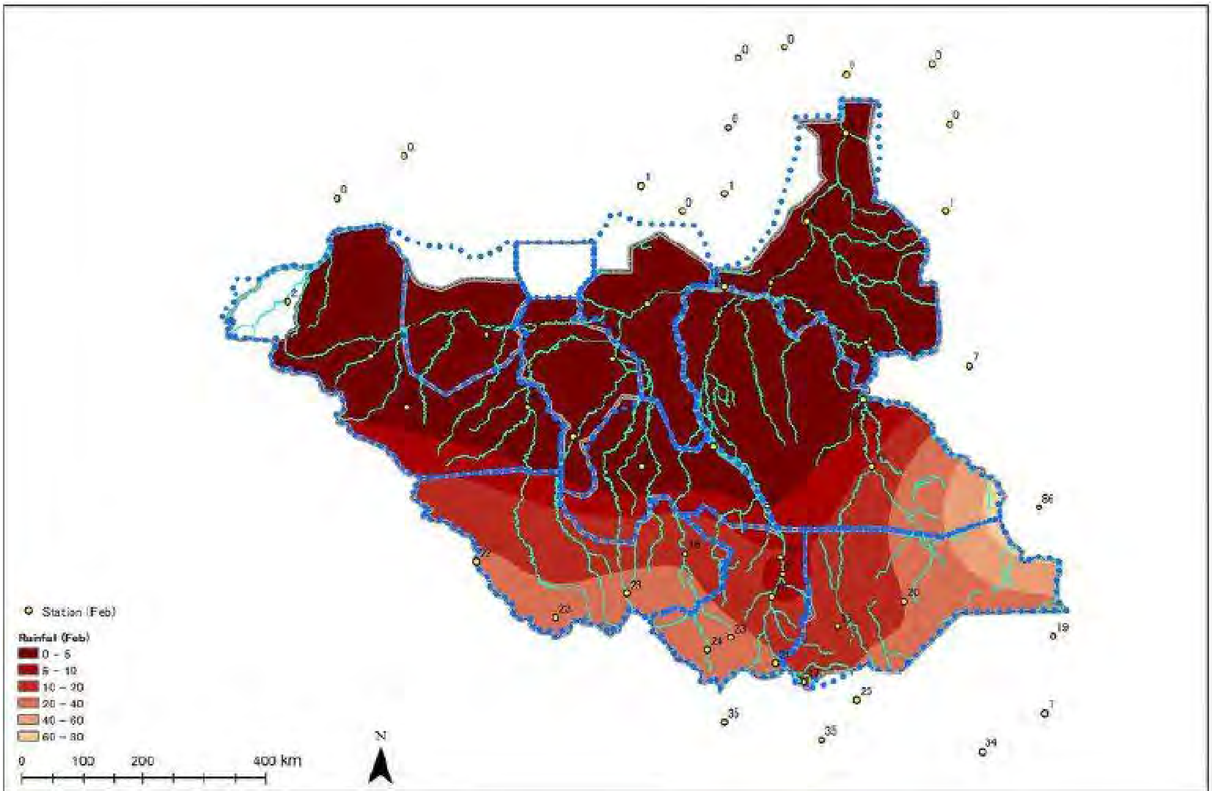
Rainfall (Annual)

The Project for Irrigation Development Master Plan (IDMP)



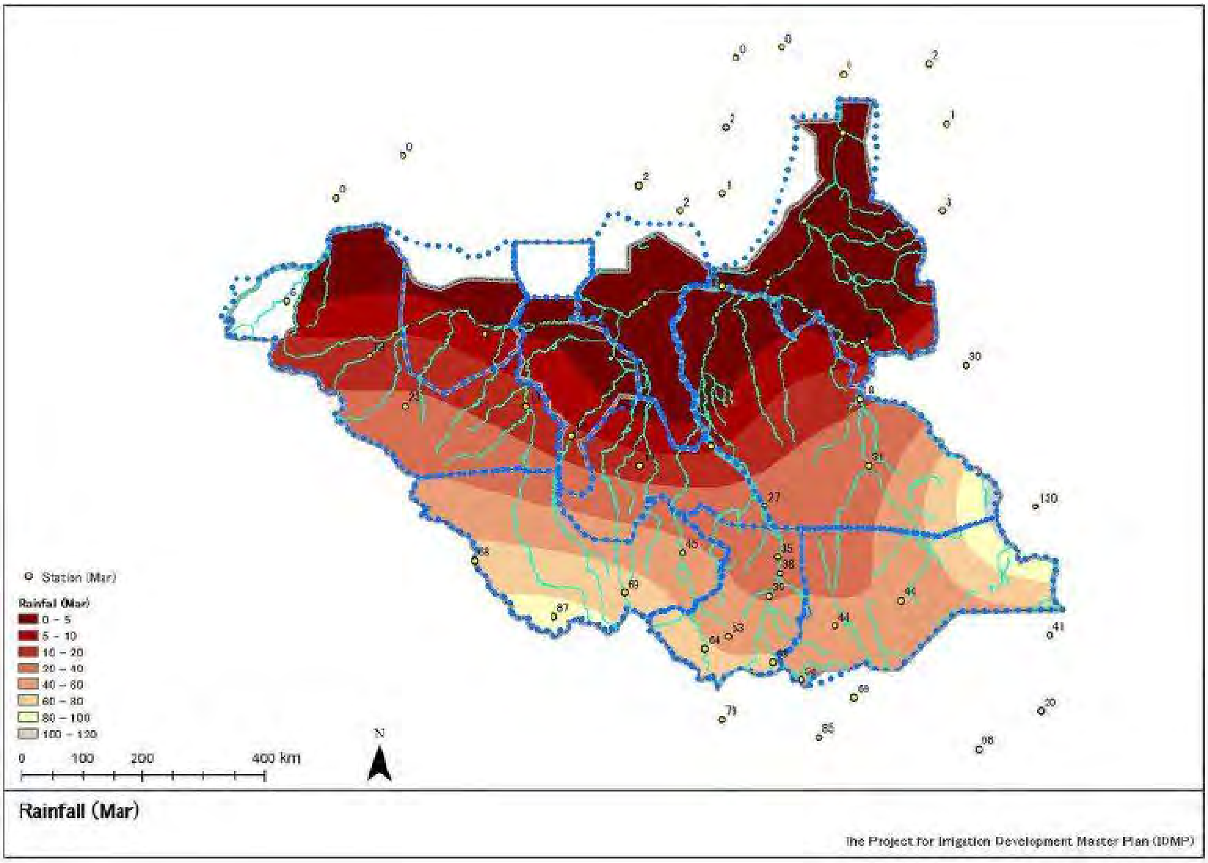
Rainfall (Jan)

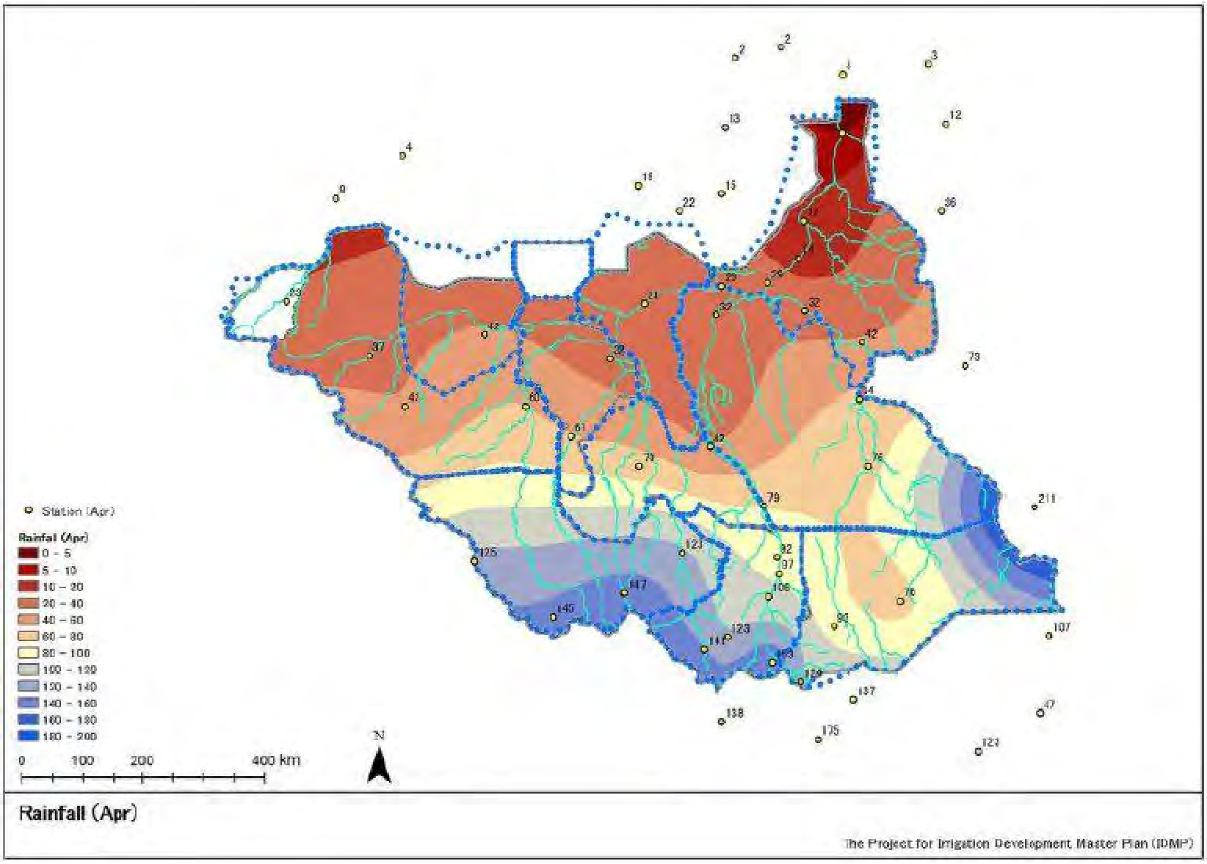
The Project for Irrigation Development Master Plan (IDMP)

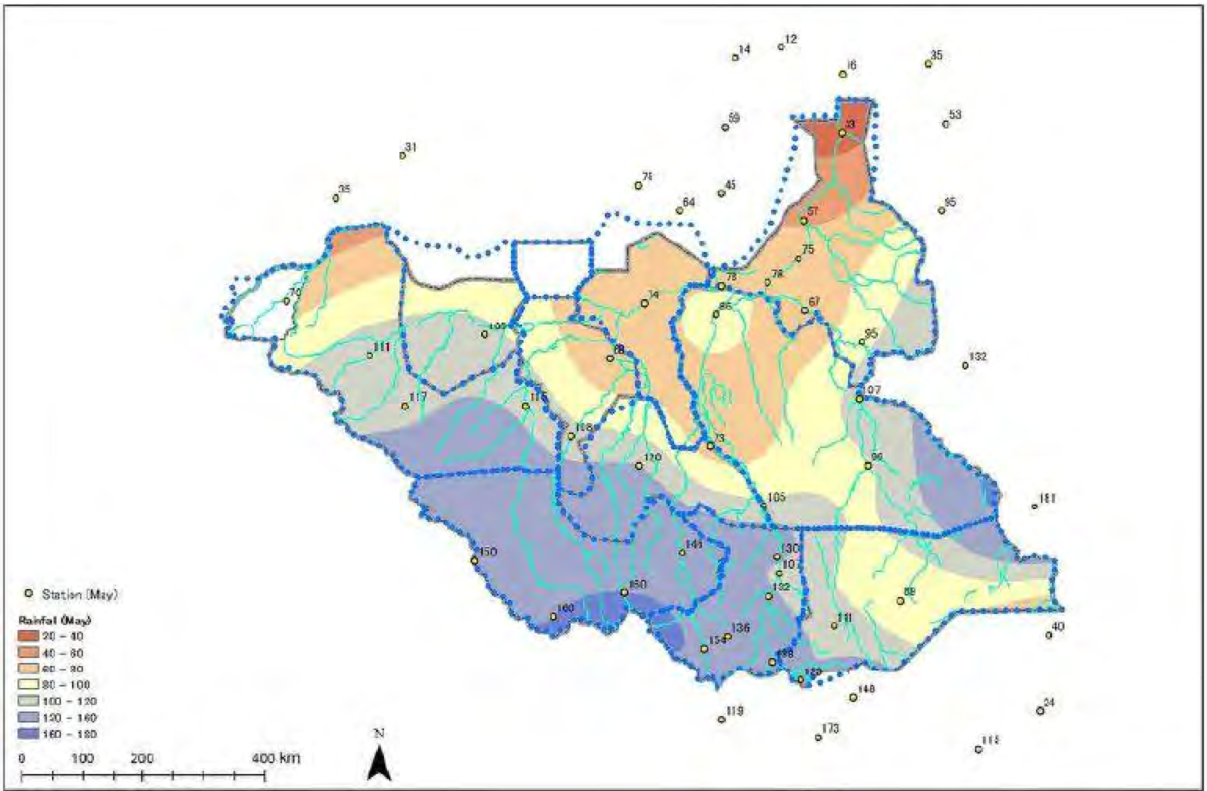


Rainfall (Feb)

The Project for Irrigation Development Master Plan (IDMP)

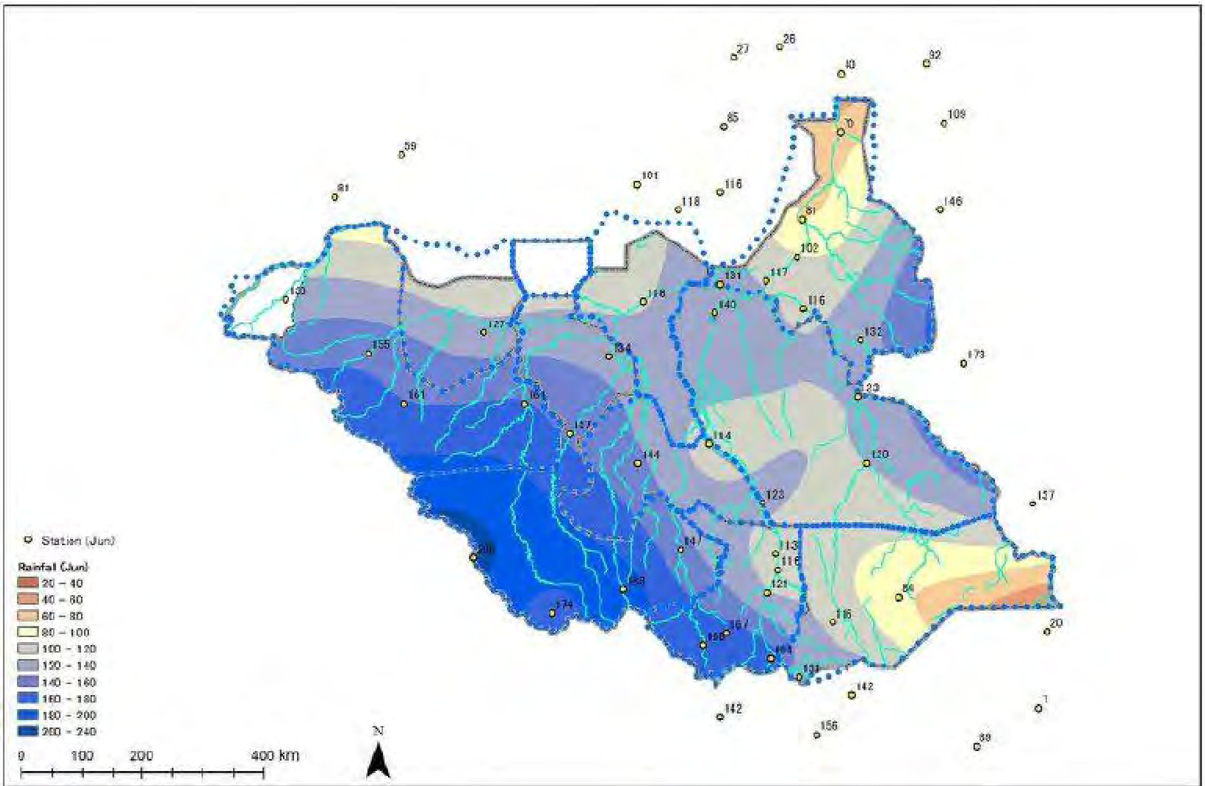

Station (Mar)
Rainfall (Mar)
0 - 5
5 - 10
10 - 20
20 - 40
40 - 60
60 - 80
80 - 100
100 - 120
0 100 200 400 km
N
Rainfall (Mar)
The Project for Irrigation Development Master Plan (IDMP)


Station (Apr)
Rainfall (Apr)
0 - 5
5 - 10
10 - 20
20 - 40
40 - 60
60 - 80
80 - 100
100 - 120
120 - 140
140 - 160
160 - 180
180 - 200
0 100 200 400 km
N
Rainfall (Apr)
The Project for Irrigation Development Master Plan (IDMP)



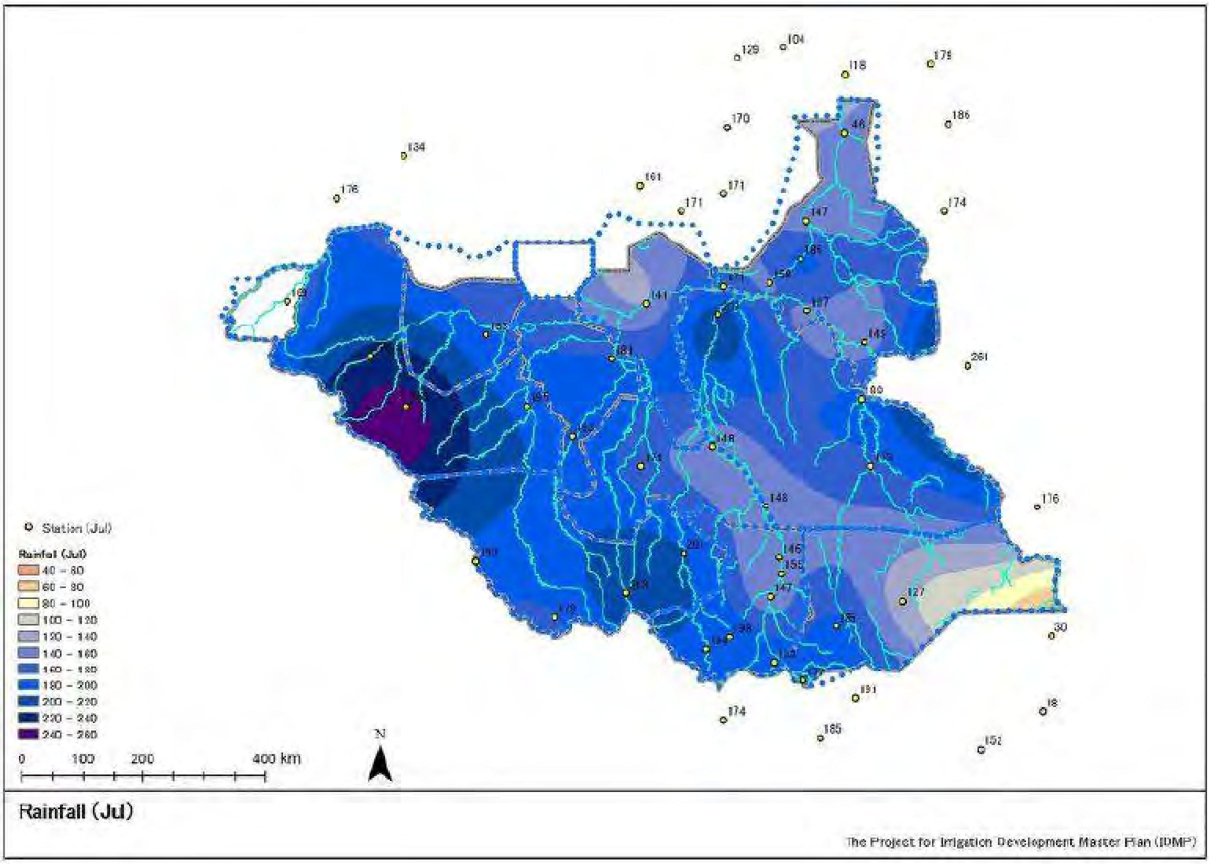
Rainfall (May)

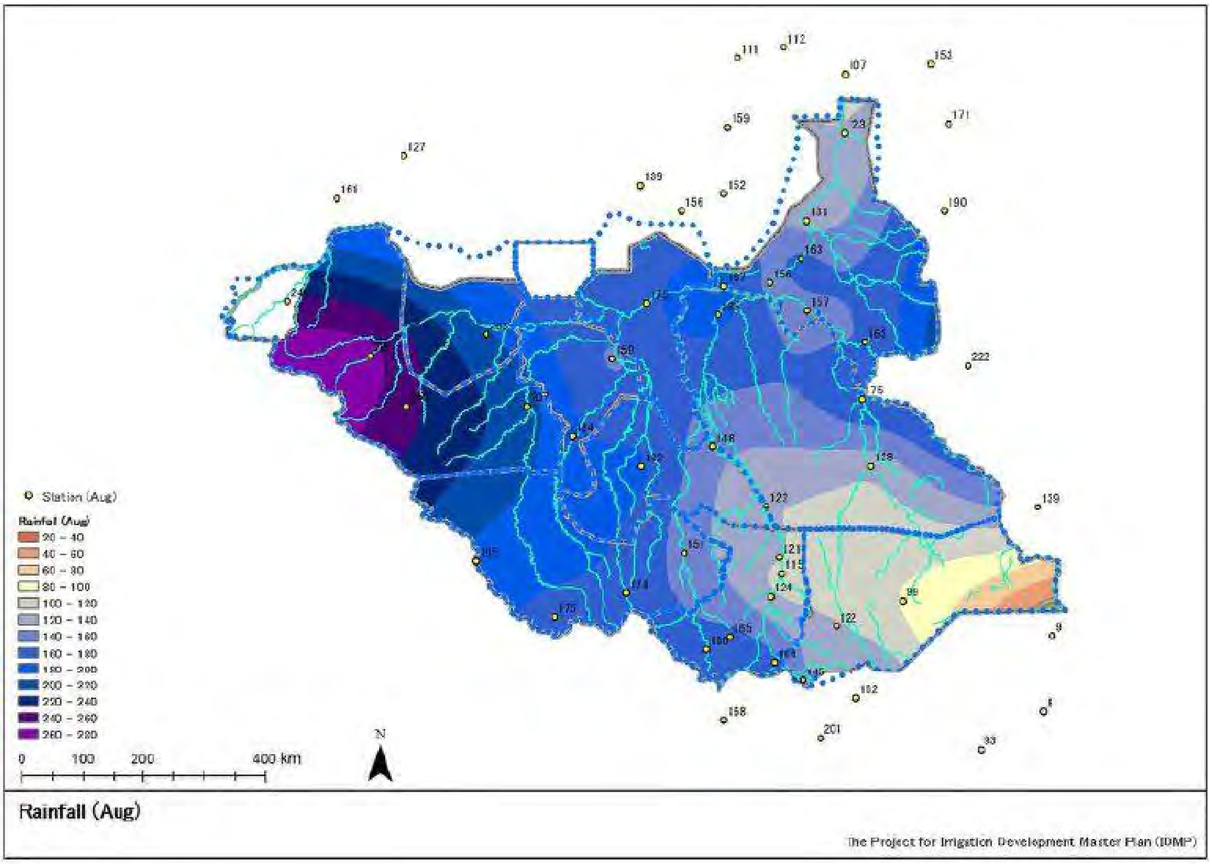
The Project for Irrigation Development Master Plan (IDMP)

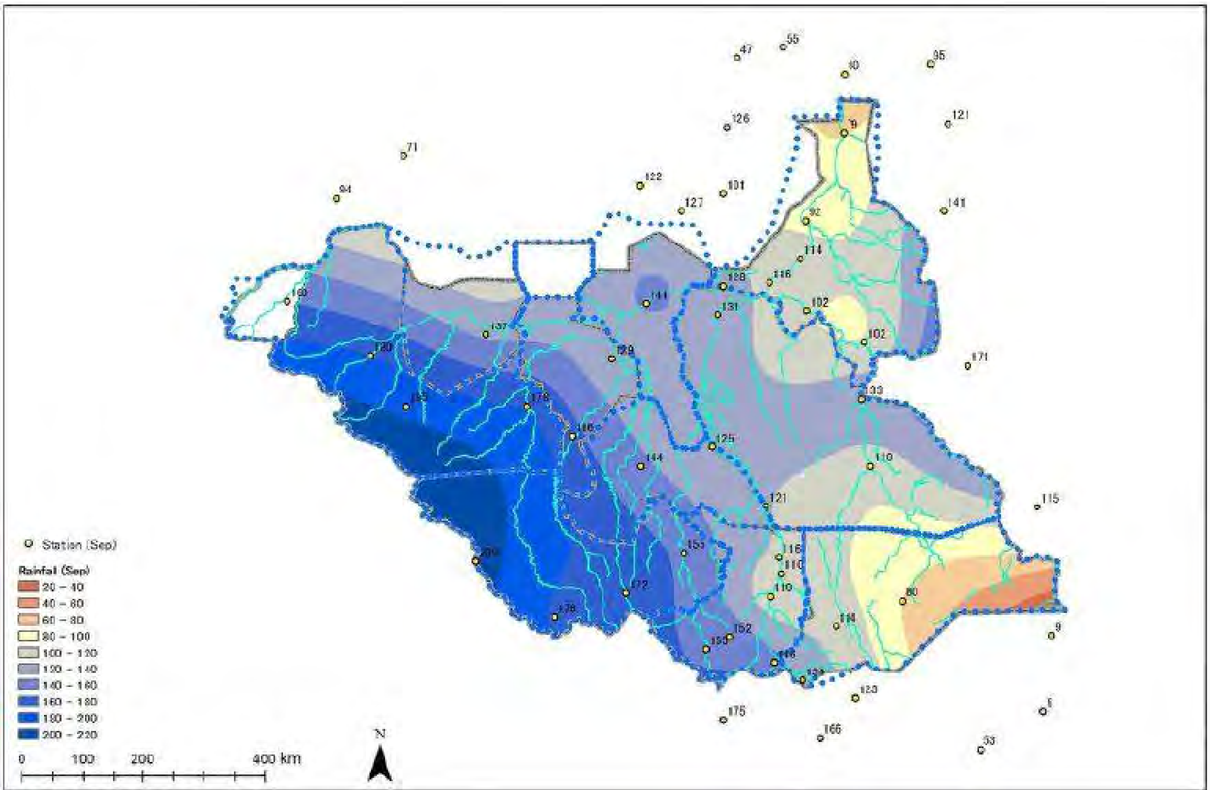


Rainfall (Jun)

The Project for Irrigation Development Master Plan (IDMP)

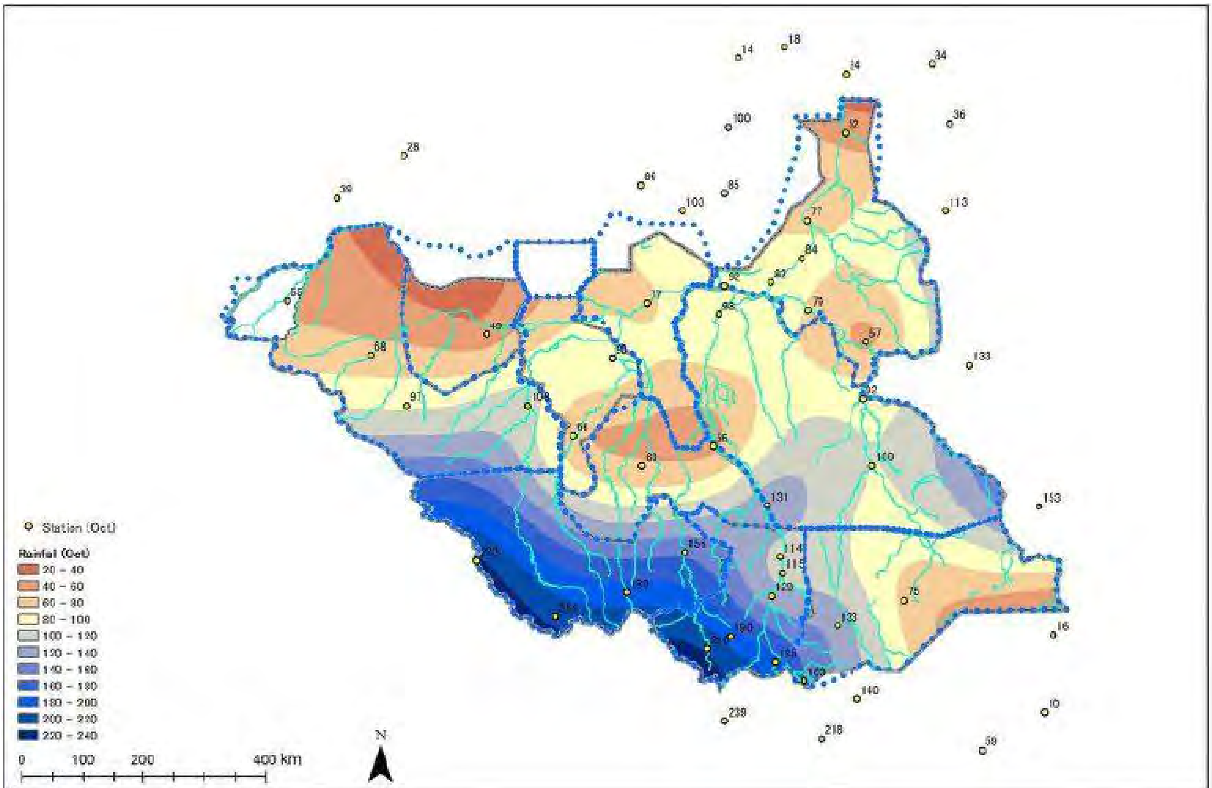

Station (Jul)
Rainfall (Jul)
40 - 60
60 - 80
80 - 100
100 - 120
120 - 140
140 - 160
160 - 180
180 - 200
200 - 220
220 - 240
240 - 260
0 100 200 400 km
N
Rainfall (Jul)
The Project for Irrigation Development Master Plan (IDMP)


Station (Aug)
Rainfall (Aug)
20 - 40
40 - 60
60 - 80
80 - 100
100 - 120
120 - 140
140 - 160
160 - 180
180 - 200
200 - 220
220 - 240
240 - 260
260 - 280
0 100 200 400 km
N
Rainfall (Aug)
The Project for Irrigation Development Master Plan (IDMP)



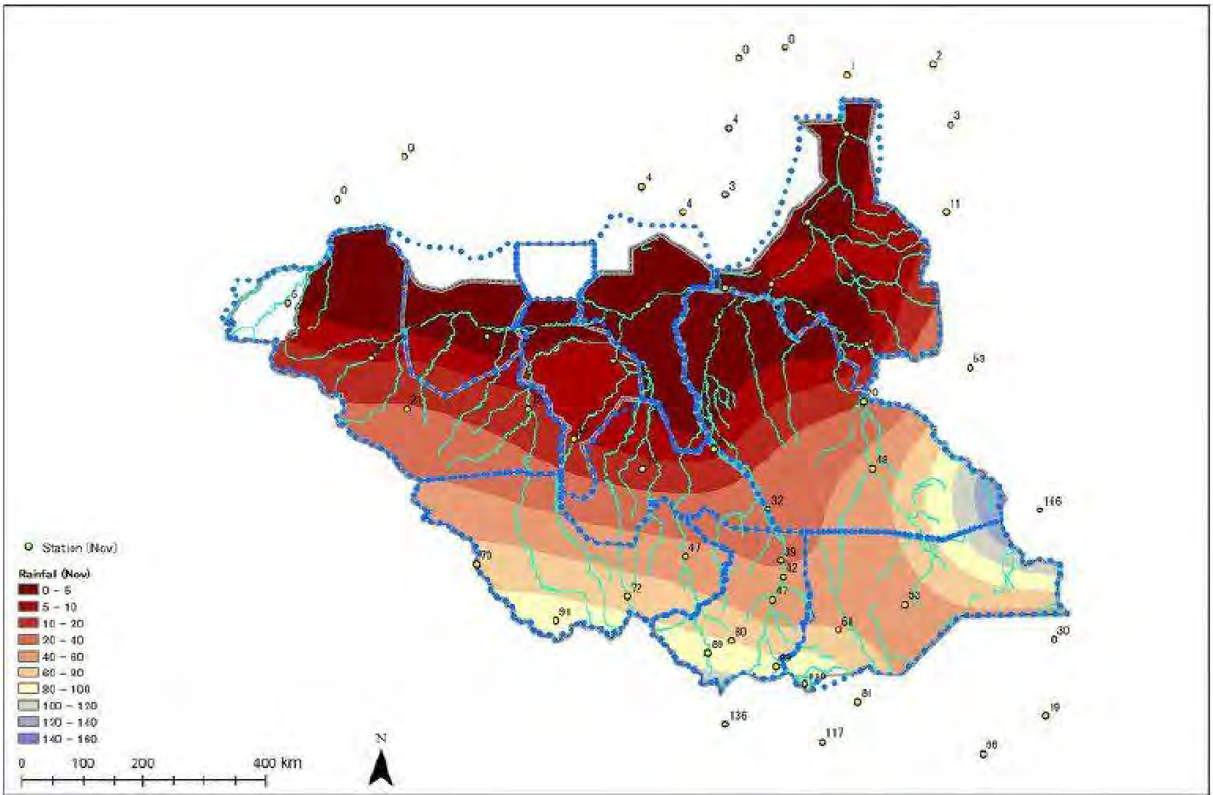
Rainfall (Sep)

The Project for Irrigation Development Master Plan (IDMP)



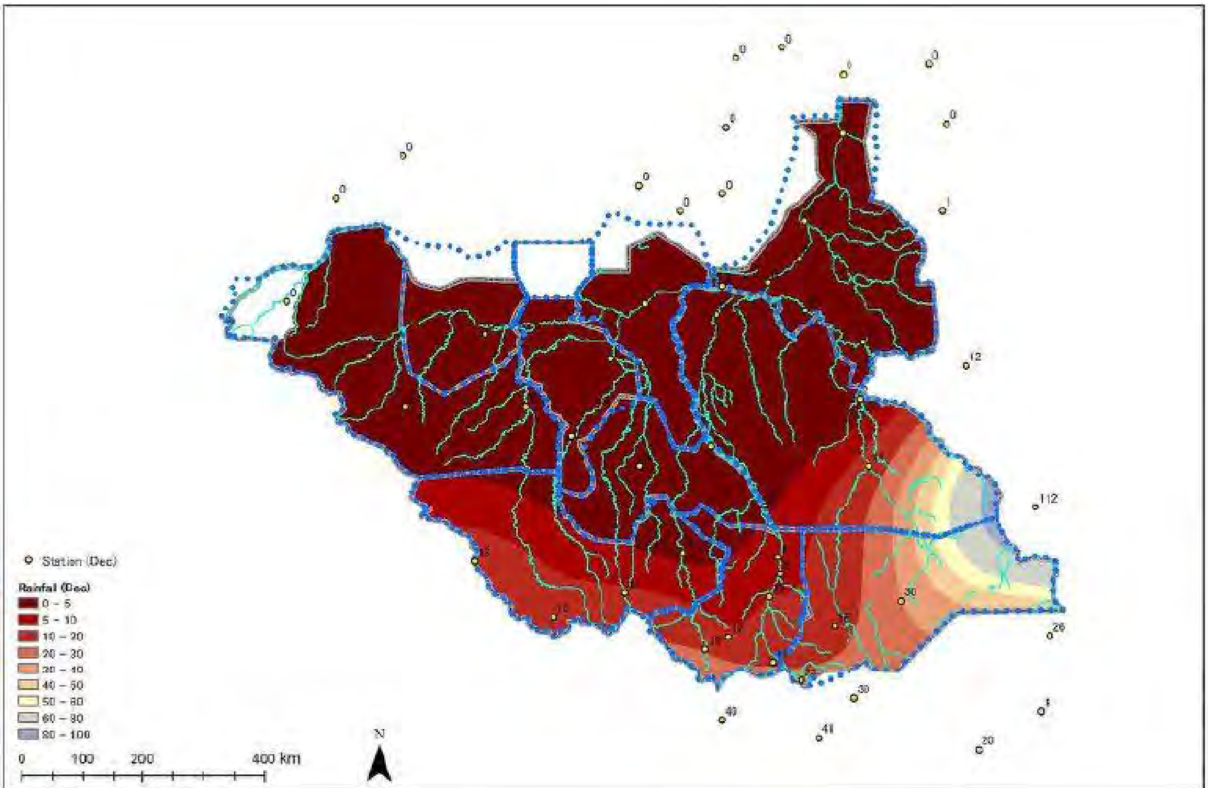
Rainfall (Oct)

The Project for Irrigation Development Master Plan (IDMP)



Rainfall (Nov)

The Project for Irrigation Development Master Plan (IDMP)



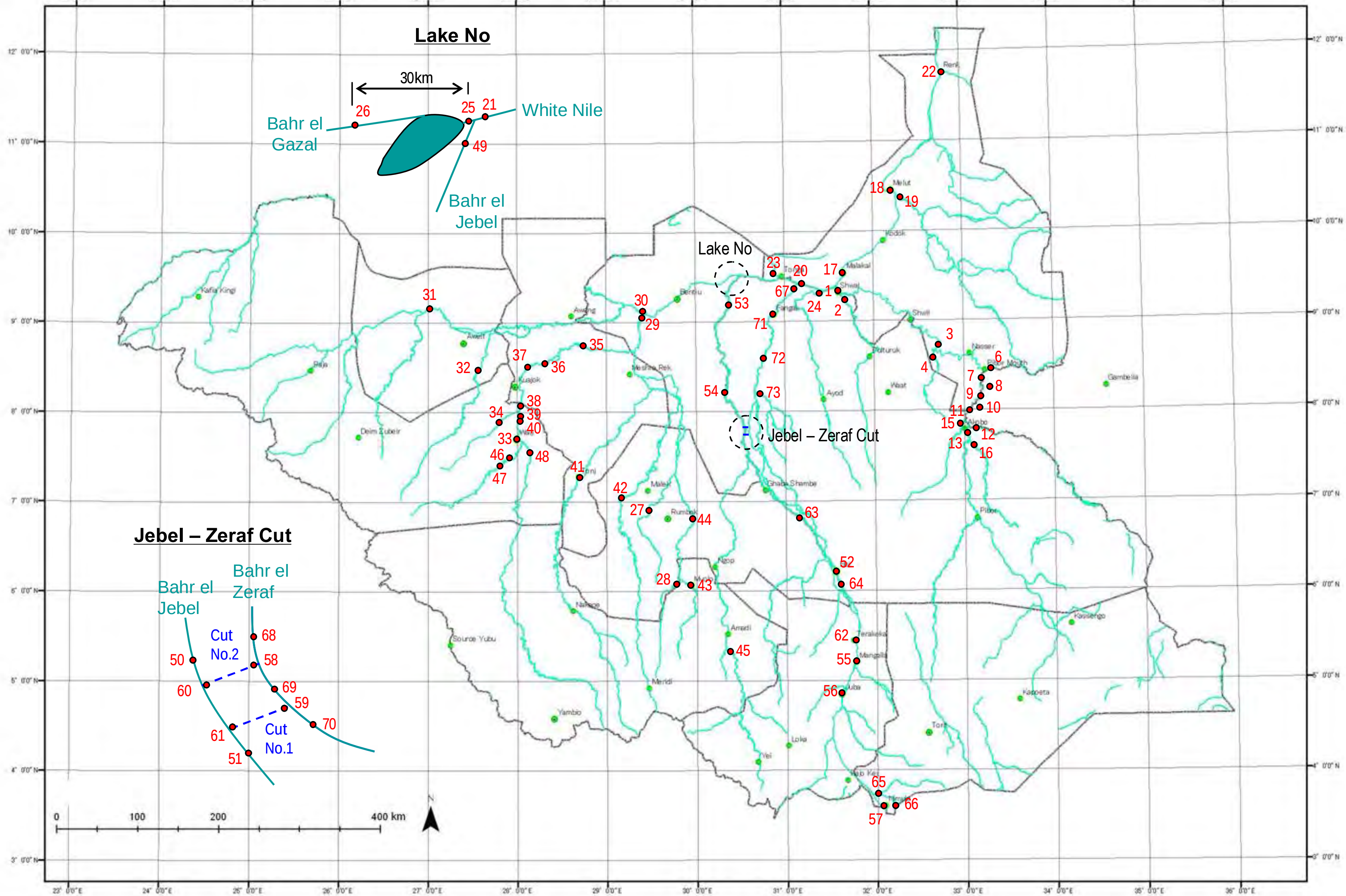
Rainfall (Dec)

The Project for Irrigation Development Master Plan (IDMP)

APPENDIX - 2-2

River Discharge Analysis
(Maps & Tables)

Location map of selected stations



Sobat River
01. Hillet Doleib
02. Khor Fullus at its Mouth
03. D.S. Khor Nyanding
04. Nyanding Mouth
05. -

Baro River
06. US the Baro-Pibor Junction

Pibor River
07. US the Baro-Pibor Junction
08. Khor Makwai at its Mouth
09. U.S. Khor Makwai
10. Gilo at Mouth
11. U.S. River Gilo
12. Akobo at Mouth
13. U.S. River Akobo
14. -
15. Khor Geni at its Mouth
16. River Agwei at its Mouth

White Nile
17. Malakal
18. Melut
19. Khor Adar
20. Abu Tong
21. D.S.Lake No
22. Renk
23. Tonga at Mouth
24. Khor Attar at mouth

Bahr el Ghazal
25. Bahr el Ghazal at mouth
26. D.S. Khor Doleib
27. River Gulham at New Road Bridge
28. River Wonko at Road Bridge
29. U.S. Bahr el Arab Mouth

Bahr el Arab
30. Bahr el Arab Mouth

Lol River
31. Nyamlell

Pongo River
32. 60m D.S. Road Bridge

Jur River
33. Wau
34. Geti at Road Bridge
35. Ghabat el Warrana
36. Deim Beshir
37. Gogrial
38. D.S. River Geti
39. U.S. River Geti
40. Nyinakoi

Tonj River
41. Tonj

Gel River
42. At New Road Bridge

Naam River
43. Mvolo
44. Rumbek

Yei river
45. Mundri

Bussere River
46. Nago Halima
47. Akanda

Sue River
48. 7k U.S. Mouth

Bahr el Jebel
49. Bahr el Jebel (near Mouth)
50. D.S. Head of Cut No.2
51. U.S. Head of Cut No.1
52. Bor
53. Buffalo Cape
54. Hillet Nuer
55. Mongalla
56. Juba
57. Nimule & Meshra Surrour
58. Jebel-Zeraf Cut No.2 at Tail
59. Jebel-Zeraf Cut No.1 at Tail
60. Jebel-Zeraf Cut No.2 at Head
61. Jebel-Zeraf Cut No.1 at Head
62. Terrakekka
63. Kenisa
64. Malek

Assua River
65. River Assua at Mouth

Unyama River
66. River Unyama at Mouth

Bahr el Zeraf
67. Bahr el Zeraf (near Mouth)
68. D.S. Tail of Cut No.2
69. D.S. Tail of Cut No.1
70. U.S. Tail of Cut No.1
71. Fangak
72. Meshra Kwach
73. Khor Jurwell at its Mouth

Data availability of River Discharge Data

Volume II	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15		
1869-1927	28-32	33-37	38-42	43-47	48-52	53-57	58-62	63-67	68-72	73-77	78-82	83-87	88-92	93-97	98-02	03-07	08-12

Basin	River	No. (in this survey)	Discharge Station	Remarks
Ethiopian Plateau	Sobat	001	Hillet Doleib 9km from its Sobat mouth	
		002	Khor Fullus at its mouth 15km from the mouth of river sobat	
		003	D.S. Khor Nyanding 2km D.S. Khor Nhyanding Mouth	
		004	Nyanding Mouth 239km from mouth of river Sobat	
	Baro	006	US the Baro-pipor Junction (River Baro Mouth)	
		024	Khor Attar at Mouth Khor Attar joins the White Nile 108km from Lake No *the same as 105	
	Pibor	007	US the Baro-pipor Junction	
		008	Khor Makwai at its Mouth 366km from the mouth of river Sobat	
		009	U.S. Khor Makwai 366km from the mouth of river Sobat	
		010	Gila at Mouth 401km from the mouth of river Sobat	
		011	U.S. River Gila 401km from the mouth of river Sobat	
		012	Akobo at Mouth 465km from the mouth of river Sobat	
		013	U.S. River Akobo 6km US the mouth of river Akobo, 471km from the mouth of rifer Sobat	
		015	Khor Geni at its Mouth	
		016	River Agwei at its Mouth	
	White Nile	017	Malakal 811km from junction of the Blue and White Nile	
		018	Melut 669km US junction of Blue and White Nile	
		019	Khor Adar 12km US Melut, 1.54km US its Mouth (Gauge only)	
		020	Abu tong 6km US of the Mouth of Bahr el Zeraf	
		021	Lake No 957km from the junction of the Blue and White Nile	
		022	Renk	
		023	Tonga at Mouth Tonga cut joinst the White Nile in its left bank at 62km from Lake No	
		024	Khor Attar Tail *the same as 063	
	Bahr el Ghazal	025	Bahr el Ghazal at Mouth	
		025	Exit from Lake No	
		026	D.S. Khor Doleib 29km from Ghazal mouth	
		027	River Gulmar at New Road B. Juba-Wau main road	

Basin	River	No. (in this survey)	Discharge Station	Volume II 1869-1927	S1 28-32	S2 33-37	S3 38-42	S4 43-47	S5 48-52	S6 53-57	S7 58-62	S8 63-67	S9 68-72	S10 73-77	S11 78-82	S12 83-87	S13 88-92	S14 93-97	S15 98-02	03-07	08-12	Remarks
Bahr el Ghazal Plateau		028	River Wokko at Road Bridge									Gauge only										
		029	US Bahr el Arab Mouth																			
	Bahr el Arab	030	Bahir el Arab Mouth						Gauge only													
	Lol	031	Nyamlell																			
	Pongo	032	60m D.S. Road Bridge Juba-Aweil main road		Location is not clear																	
	Jur	033	Wau																			
		034	Geti at Road Bridge																			
		035	Ghabat el Warrana																			
		036	Deim Beshir																			
		037	Gogrial																			
		038	D.S. River Geti 60km DS river Geti																			
		039	U.S. River Geti																			
		040	Nyinakoi																			
	Tonj	041	Tonj											Location is not clear Location is not clear								
	Gel	042	at New Road Bridge Juba-Wau main road		Location is not clear																	
	Naam	043	Mvolo																			
		044	Rumbek Rumgek-Yerol road																			
	Yei	045	Mundri																			
	Busseri	046	Nago Halima																			
		047	Akanda																			
	Sue	048	7k U.S. Mouth																			
		049	Bahr el Jebel (near Mouth)																			
		050	D.S. Head of Cut No.2																			
		051	U.S. Head of Cut No.1																			

Basin	River	No. (in this survey)	Discharge Station	Volume II 1869-1927	S1 28-32	S2 33-37	S3 38-42	S4 43-47	S5 48-52	S6 53-57	S7 58-62	S8 63-67	S9 68-72	S10 73-77	S11 78-82	S12 83-87	S13 88-92	S14 93-97	S15 98-02	03-07	08-12	Remarks
Equatorial Plateau	Bahr el Gebel	052	Bor RP124																			
		053	Buffalo Cape 51km from Lake No																			
		054	Hillet Nuer 222km from Lake No																			
		055	Mongalla 765km from Lake No PR142																			
		056	Juba																			
		057	Nimule				Combined record with Meshra Surror															
		058	Jebel-Zeraf Cut No.2 at Tail 289km from Zeraf Mouth																			
		059	Jebel-Zeraf Cut No.1 at Tail 293km from Zeraf Mouth																			
		060	Jebel-Zeraf Cut No.2 at Head 298km from Lake No																			
		061	Jebel-Zeraf Cut No.1 at Head 305km from Lake No																			
		062	Terrakekka																			
		063	Kenisa 504km from Lake No Pole 99																			
		064	Malek 648km from Lake No PR128																			
		057	Meshra Surrour 976km from Lake No				Combined record with Nimule		Combined record with Nimule													
	Assua	065	River Assua at Mouth																			
	Unyama	066	River Unyama at Mouth 979km from Lake No																			
	Bahr el Zaraf	067	Bahr el Zeraf (near Mouth) 3km from its mouth																			
		068	D.S. Tail of Cut No.2 285km from Zeraf mouth																			
		069	D.S. Tail of Cut No.1																			
		070	U.S. Tail of Cut No.1																			
		071	Fangak 73km US Zeraf Mouth																			
		072	Meshra Kwach 196km US Zeraf Mouth																			
		073	Khor Jurwell at its Mouth Khor Jurwell joins Bahr el Zeraf at 228km US Zeraf Mouth																			

: 10day mean and Montly discharge (The Nile Basin)

: Daily Discharge and Gauge reading (The Nile Basin)

: 10 day mean and monthly Discharge (Nile DST)

: Daily Discharge and Gauge reading (MWRI branch offce in Wau)

: Daily Discharge created using Daily Gauge reading and H-Q curve(MWRI branch offce in Wau)

: Daily discharge and gauge reading (MWRI)

: Daily Discharge created using Daily Gauge reading and H-Q curve(MWRI)

: Daily discharge and gauge reading (Egyptian office in Malakal)

Data availability of River Discharge Data after compilation

Basin	River	No. (in this survey)	Discharge Station	Volume II 1869-1927	S1 28-32	S2 33-37	S3 38-42	S4 43-47	S5 48-52	S6 53-57	S7 58-62	S8 63-67	S9 68-72	S10 73-77	S11 78-82	S12 83-87	S13 88-92	S14 93-97	S15 98-02	03-07	08-12	Remarks
Ethiopian Plateau		001	Hillet Doleib																			
	Sobat	002	Khor Fullus at its mouth																			
		003	D.S. Khor Nyanding																			
		004	Nyanding Mouth																			
	Baro	006	US the Baro-pipor Junction																			
	Pibor	007	US the Baro-pipor Junction																			
		008	Khor Makwai at its Mouth																			
		009	U.S. Khor Makwai																			
		010	Gila at Mouth																			
		011	U.S. River Gila																			
		012	Akobo at Mouth																			
		013	U.S. River Akobo																			
		015	Khor Geni at its Mouth																			
		016	River Agwei at its Mouth																			
	White Nile	017	Malakal																			
		018	Melut																			
		019	Khor Adar																			
		020	Abu tong																			
		021	Lake No																			
		022	Renk																			
		023	Tonga at Mouth																			
		024	Khor Attar Tail																			
Bahr el Ghazal Plateau	Bahr el Ghazal	025	Bahr el Ghazal at Mouth																			
		026	D.S. Khor Doleib																			
		027	River Gulmar at New Road B.																			
		028	River Wokko at Road Bridge																			
		029	US Bahr el Arab Mouth																			
	Bahr el Arab	030	Bahir el Arab Mouth																			
	Lol	031	Nyamlell																			
	Pongo	032	60m D.S. Road Bridge																			
	Jur	033	Wau																			
		034	Geti at Road Bridge																			
		035	Ghabat el Warrana																			
		036	Deim Beshir																			
		037	Gogrial																			
		038	D.S. River Geti																			
		039	U.S. River Geti																			
		040	Nyinakoi																			
	Tonj	041	Tonj																			
	Gel	042	at New Road Bridge																			
	Naam	043	Mvolo																			
		044	Rumbek																			
	Yei	045	Mundri																			
	Busseri	046	Nago Halima																			
		047	Akanda																			
	Sue	048	7k U.S. Mouth																			

Basin	River	No. (in this survey)	Discharge Station	Volume II 1869-1927	S1 28-32	S2 33-37	S3 38-42	S4 43-47	S5 48-52	S6 53-57	S7 58-62	S8 63-67	S9 68-72	S10 73-77	S11 78-82	S12 83-87	S13 88-92	S14 93-97	S15 98-02	03-07	08-12	Remarks
Equatorial Plateau	Bahr el Gebel	049	Bahr el Jebel (near Mouth)																			
		050	D.S. Head of Cut No.2																			
		051	U.S. Head of Cut No.1																			
		052	Bor																			
		053	Buffalo Cape																			
		054	Hillet Nuer																			
		055	Mongalla																			
		056	Juba																			
		057	Nimule																			
		058	Jebel-Zeraf Cut No.2 at Tail																			
		059	Jebel-Zeraf Cut No.1 at Tail																			
		060	Jebel-Zeraf Cut No.2 at Head																			
		061	Jebel-Zeraf Cut No.1 at Head																			
		062	Terrakekka																			
		063	Kenisa																			
		064	Malek																			
	Assua	065	River Assua at Mouth																			
	Unyama	066	River Unyama at Mouth																			
	Bahr el Zaraf	067	Bahr el Zeraf (near Mouth)																			
		068	D.S. Tail of Cut No.2																			
		069	D.S. Tail of Cut No.1																			
		070	U.S. Tail of Cut No.1																			
		071	Fangak																			
		072	Meshra Kwach																			
		073	Khor Jurwell at its Mouth																			

: 10day mean and Montly discharge (The Nile Basin)
: Daily Discharge and Gauge reading (The Nile Basin)
: Daily Discharge and Gauge reading (MWRI branch office in Wau)
: Daily discharge and gauge reading (MWRI)
: Daily discharge and gauge reading (Egyptian office in Malakal)

River Numbering Tables

G:Bahr el Ghazal River basin

Primary tributary		2nd tributary		3rd tributary		4th tributary	
Code	Name of River	Code	Name of River	Code	Name of River	Code	Name of River
1	Bahr el Ghazal	11	Jur	111	Geti		
				112	Bussere		
				113	Sue		
		12	Bahr el Arab	121	Lol	1211	Pongo
						1212	Kuru
						1213	Sopo
						1214	Raga
						1215	Boro
		13	Tonj	131	Gel		
				132	Lesi		
				133	Ibba		
		14	Naam	141	Gulham		
				142	Zoggo		
				143	Wonko		

: All the discharge evaporate at the swamps located at the exit of river. (Not connect to any rivers)

J:Bahr el Jebel River Basin

Primary tributary		2nd tributary		3rd tributary	
Code	Name of River	Code	Name of River	Code	Name of River
1	Bahr el Zeraf	11	Jurwell	111	Tem
		12	Magwong		
2	Atem				
3	Yei	31	Bostaki		
		32	Bibi		
		33	Tori		
4	Gal	41	Anok		
		42	Awong		
		43	Tatan		
5	Gwir				
6	Ugurro				
7	Luli				
8	Kii	81	Lefuleur		
9	Kaya				
10	Assua	10-1	Ateppi		
		10-2	Nyimur		
		10-3	Unyama		

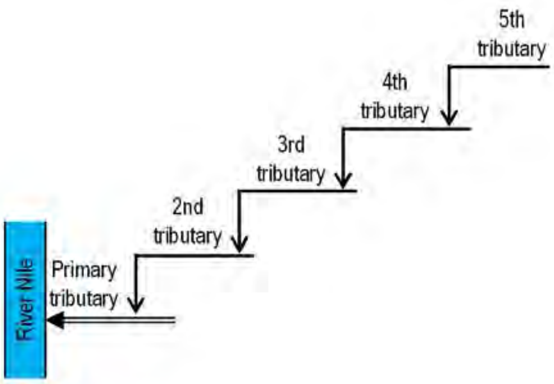
S:Sobat River Basin

Primary tributary		2nd tributary		3rd tributary		4th tributary		5th tributary	
Code	Name of River	Code	Name of River	Code	Name of River	Code	Name of River	Code	Name of River
1	Sobat	11	Fullus						
		12	Nyanding						
		13	Pibor	131	Baro				
				132	Makwai				
				133	Gilo				
				134	Geni				
				135	Akobo				
				136	Agwei	1361	Abana		
						1362	Kong kong		
				137	Kangen	1371	Lotifa	13711	Medikireit
								13712	Koss
						1372	Morech	13721	Lelazat
						1373	Kondech	13731	Tingayta
								13732	Kidepe
						1374	Chabong		
						1375	Lotilet		
						1376	Kakua		
2	Atar								

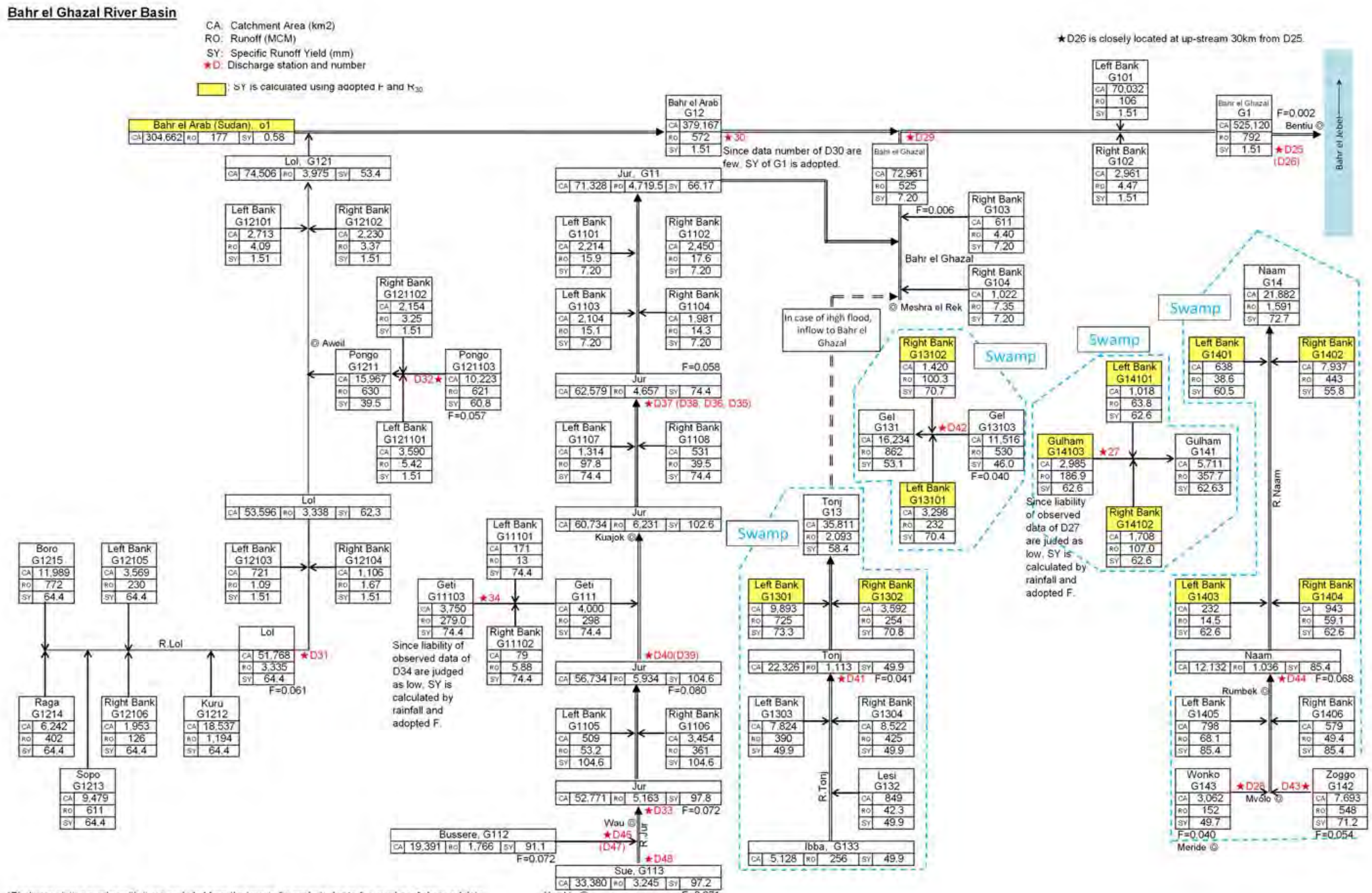
: All the discharge evaporate at the swamps located at the exit of river. (Not connect to any rivers)

W:White Nile River Basin

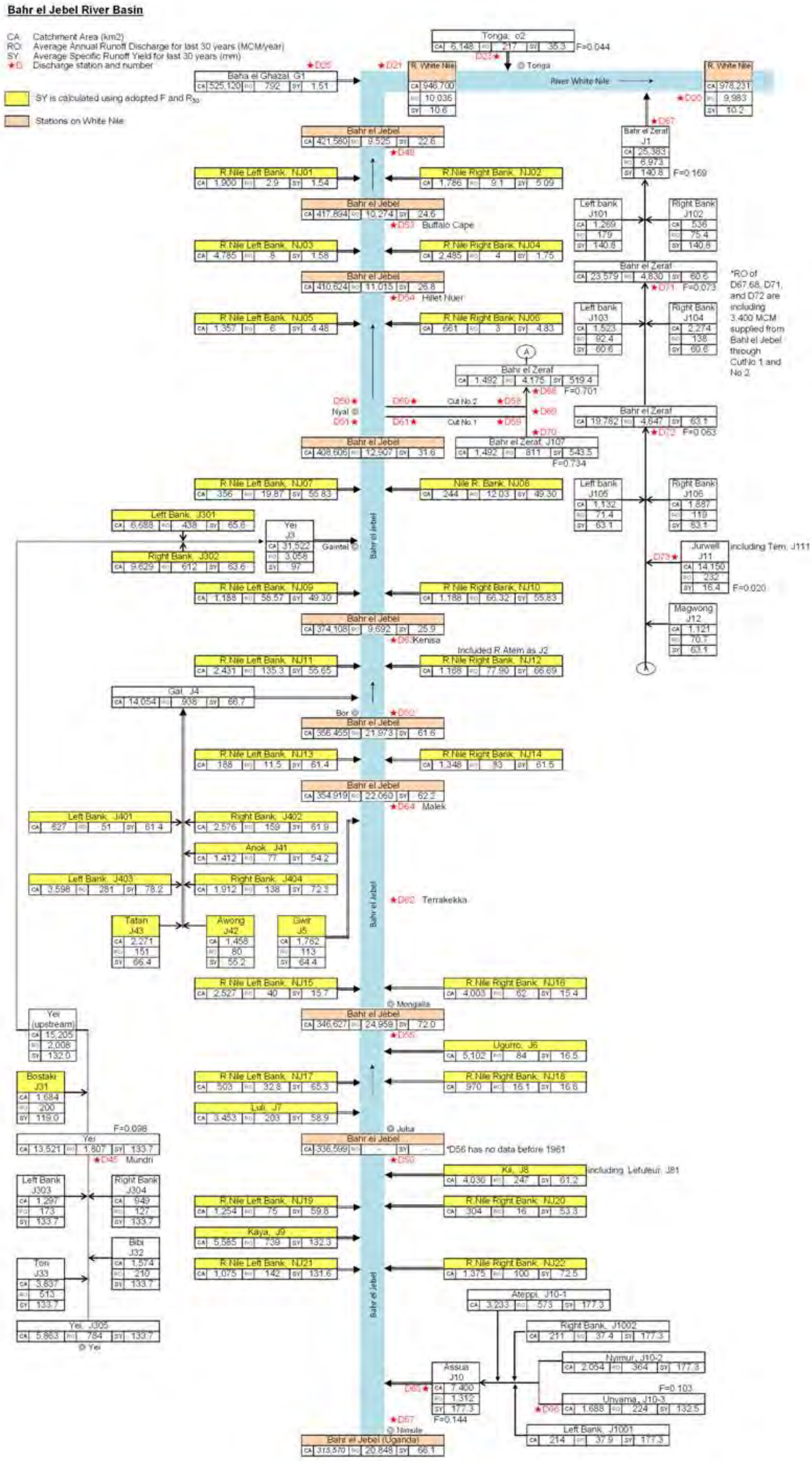
Primary tributary		2nd tributary		3rd tributary	
Code	Name of River	Code	Name of River	Code	Name of River
1	Adar	11	Tombao		
		12	Doga	121	Yabus
2	Birbari	21	Es Samaa		
		22	Chifayaca		
3	Doleib				

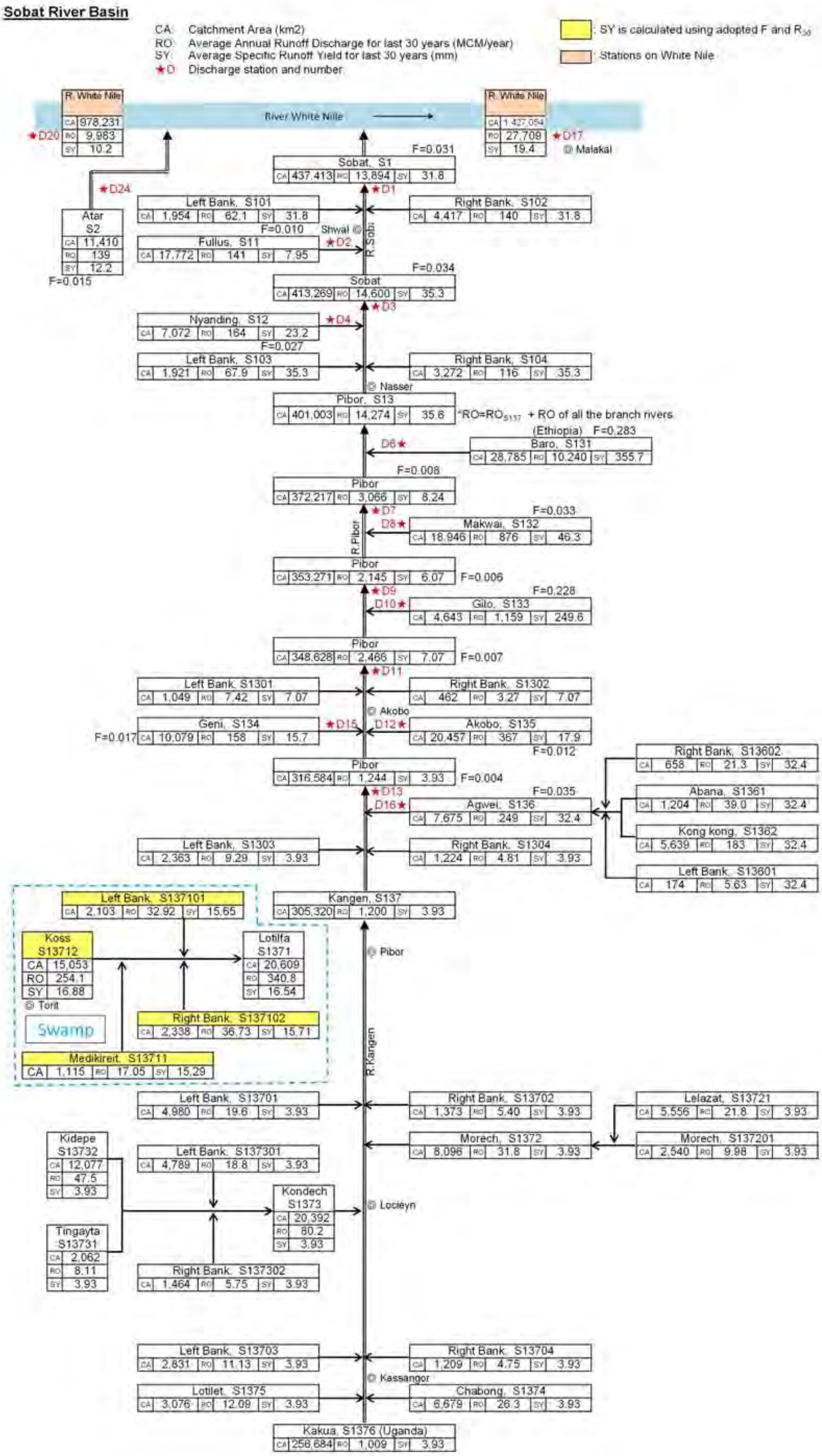


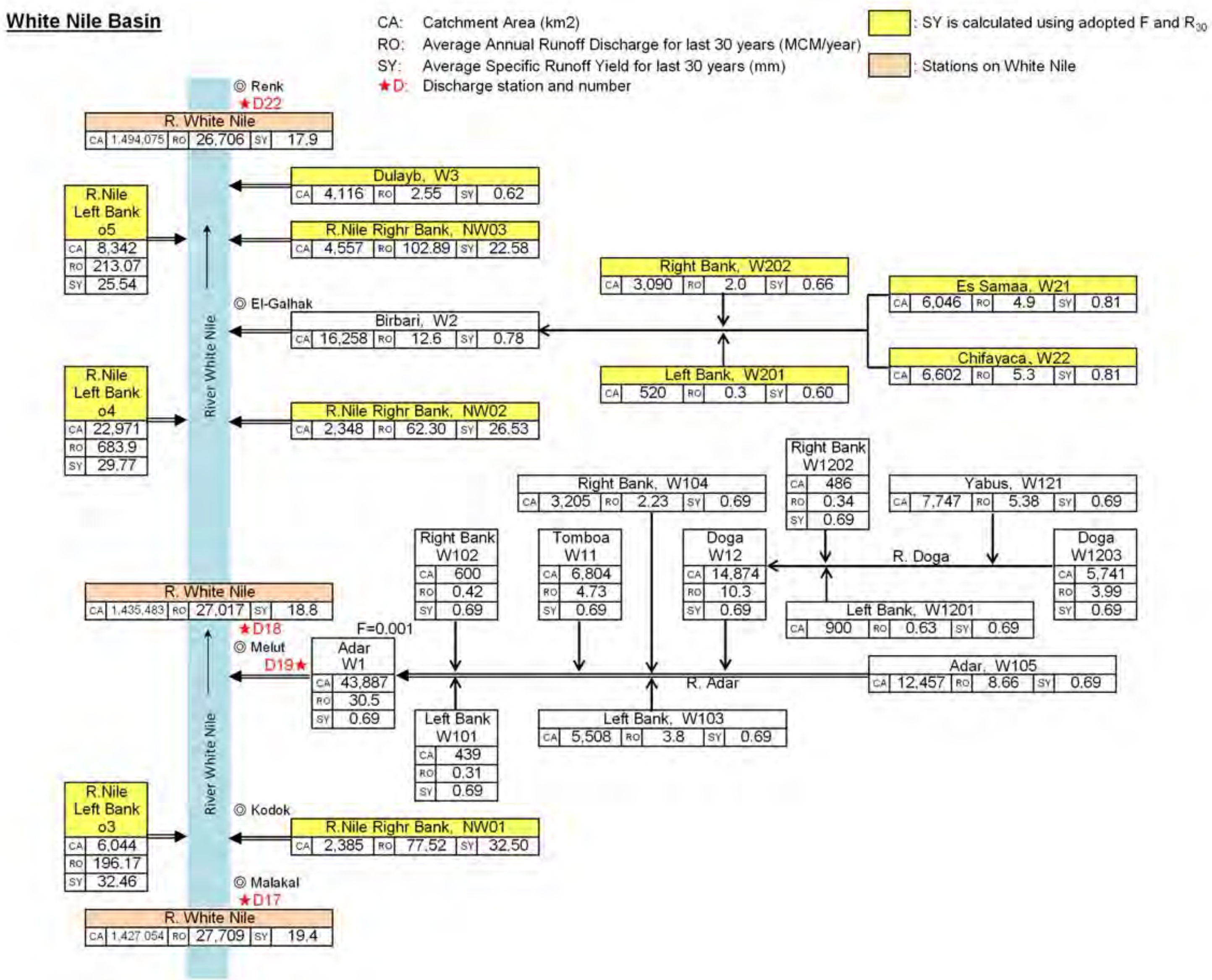
River Network Diagrams

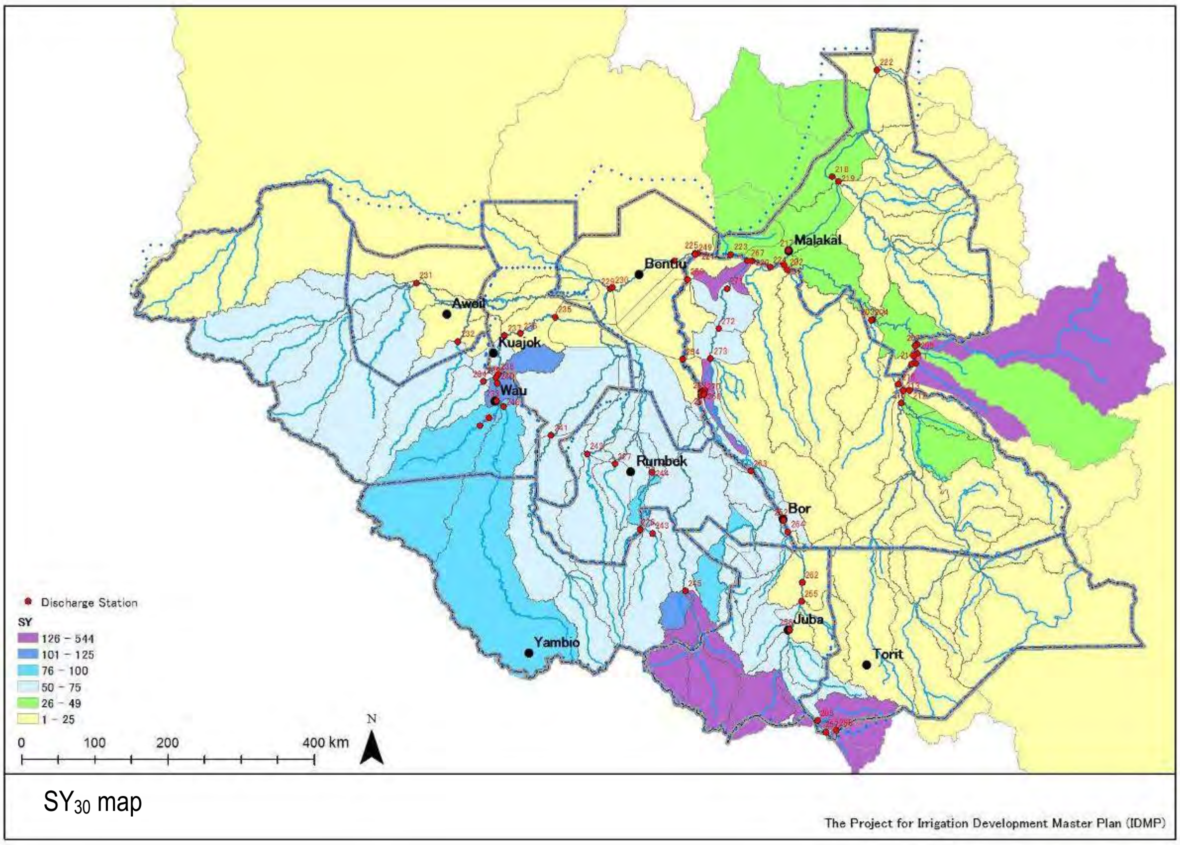


*Discharge station number with () are excluded from the targets for analysis due to few number of observed data

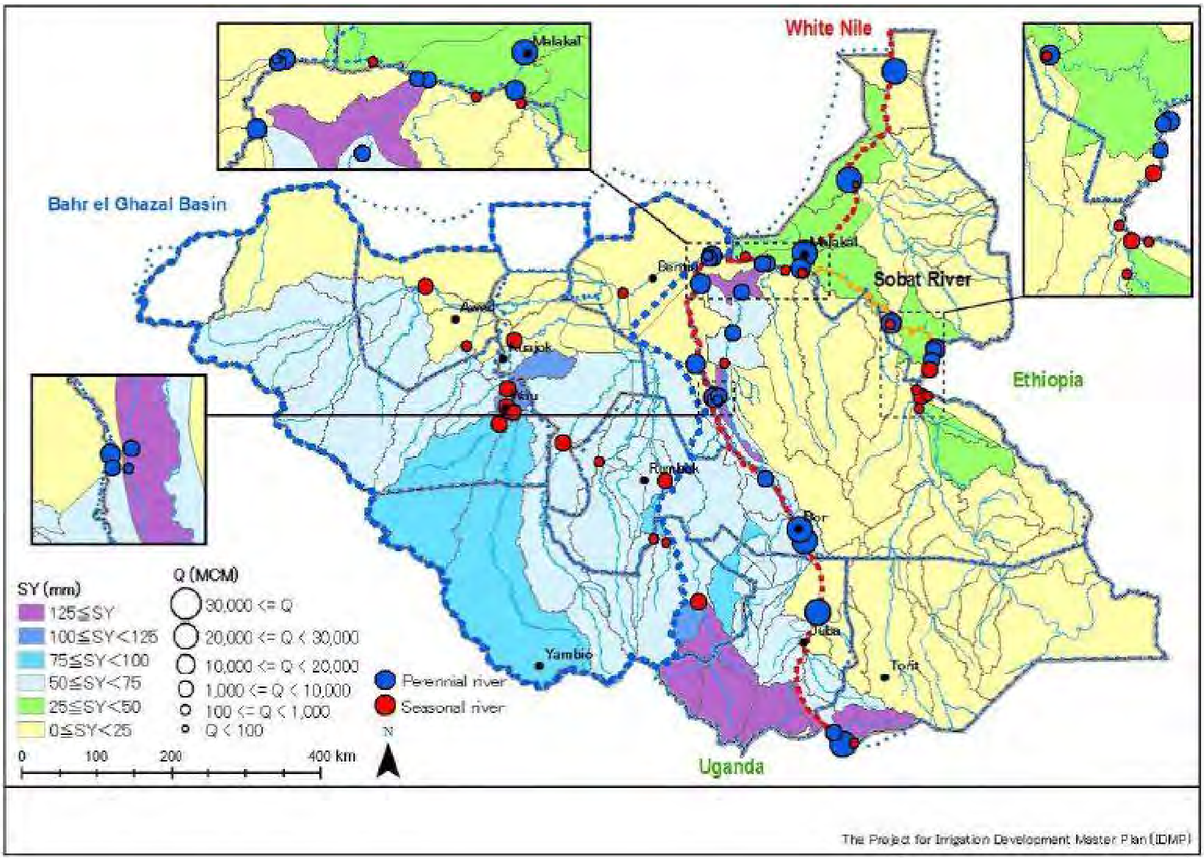

Bahr el Jebel River Basin
CA Catchment Area (km2)
RO Average Annual Runoff Discharge for last 30 years (MCM/year)
SY Average Specific Runoff Yield for last 30 years (mm)
★D Discharge station and number
SY is calculated using adopted F and R30
Stations on White Nile
River White Nile
Bahr el Jebel
Bahr el Zeraf
Tonga
Nyal
Gaintel
Bor
Mongalla
Juba
Nimule
Buffalo Cape
Hillet Nuer
Kenisa
Malek
Terrakekka
Mundri
Cut No.1
Cut No.2
*D56 has no data before 1961
Bahr el Jebel (Uganda)


Sobat River Basin
CA: Catchment Area (km2)
RO: Average Annual Runoff Discharge for last 30 years (MCM/year)
SY: Average Specific Runoff Yield for last 30 years (mm)
★D Discharge station and number
SY is calculated using adopted F and R
Stations on White Nile
River White Nile
R. White Nile CA 978,231 RO 9,983 SY 10.2 ★D20
R. White Nile CA 1,427,054 RO 27,709 SY 19.4 ★D17 Malakal
Sobat, S1 CA 437,413 RO 13,894 SY 31.8 F=0.031 ★D1
★D24
Atar S2 CA 11,410 RO 139 SY 12.2 F=0.015
Left Bank, S101 CA 1,954 RO 62.1 SY 31.8
Right Bank, S102 CA 4,417 RO 140 SY 31.8
F=0.010 Shwal ★D2
Fullus, S11 CA 17,772 RO 141 SY 7.95
R. Sobat
Sobat CA 413,269 RO 14,600 SY 35.3 F=0.034 ★D3
Nyanding, S12 CA 7,072 RO 164 SY 23.2 ★D4 F=0.027
Left Bank, S103 CA 1,921 RO 67.9 SY 35.3
Right Bank, S104 CA 3,272 RO 116 SY 35.3
Nasser
Pibor, S13 CA 401,003 RO 14,274 SY 35.6
*RO=RO S137 + RO of all the branch rivers
(Ethiopia) F=0.283
D6★ Baro, S131 CA 28,785 RO 10,240 SY 355.7
F=0.008
Pibor CA 372,217 RO 3,066 SY 8.24 ★D7
F=0.033 D8★ Makwai, S132 CA 18,946 RO 876 SY 46.3
R. Pibor
Pibor CA 353,271 RO 2,145 SY 6.07 F=0.006 ★D9
F=0.228 D10★ Gilo, S133 CA 4,643 RO 1,159 SY 249.6
Pibor CA 348,628 RO 2,466 SY 7.07 F=0.007 ★D11
Left Bank, S1301 CA 1,049 RO 7.42 SY 7.07
Right Bank, S1302 CA 462 RO 3.27 SY 7.07
Akobo
F=0.017 Geni, S134 CA 10,079 RO 158 SY 15.7 ★D15
D12★ Akobo, S135 CA 20,457 RO 367 SY 17.9 F=0.012
Pibor CA 316,584 RO 1,244 SY 3.93 F=0.004 ★D13
F=0.035 D16★ Agwei, S136 CA 7,675 RO 249 SY 32.4
Right Bank, S13602 CA 658 RO 21.3 SY 32.4
Abana, S1361 CA 1,204 RO 39.0 SY 32.4
Kong kong, S1362 CA 5,639 RO 183 SY 32.4
Left Bank, S13601 CA 174 RO 5.63 SY 32.4
Left Bank, S1303 CA 2,363 RO 9.29 SY 3.93
Right Bank, S1304 CA 1,224 RO 4.81 SY 3.93
Left Bank, S137101 CA 2,103 RO 32.92 SY 15.65
Kangen, S137 CA 305,320 RO 1,200 SY 3.93
Koss S13712 CA 15,053 RO 254.1 SY 16.88
Lotilfa S1371 CA 20,609 RO 340.8 SY 16.54
Pibor
Torit
Swamp
Right Bank, S137102 CA 2,338 RO 36.73 SY 15.71
Medikireit, S13711 CA 1,115 RO 17.05 SY 15.29
R. Kangen
Left Bank, S13701 CA 4,980 RO 19.6 SY 3.93
Right Bank, S13702 CA 1,373 RO 5.40 SY 3.93
Lelazat, S13721 CA 5,556 RO 21.8 SY 3.93
Morech, S1372 CA 8,096 RO 31.8 SY 3.93
Morech, S137201 CA 2,540 RO 9.98 SY 3.93
Kidepe S13732 CA 12,077 RO 47.5 SY 3.93
Left Bank, S137301 CA 4,789 RO 18.8 SY 3.93
Kondech S1373 CA 20,392 RO 80.2 SY 3.93
Lociyen
Tingayta S13731 CA 2,062 RO 8.11 SY 3.93
Right Bank, S137302 CA 1,464 RO 5.75 SY 3.93
Left Bank, S13703 CA 2,831 RO 11.13 SY 3.93
Right Bank, S13704 CA 1,209 RO 4.75 SY 3.93
Kassangor
Lotilet, S1375 CA 3,076 RO 12.09 SY 3.93
Chabong, S1374 CA 6,679 RO 26.3 SY 3.93
Kakua, S1376 (Uganda) CA 256,684 RO 1,009 SY 3.93


White Nile Basin
CA: Catchment Area (km2)
RO: Average Annual Runoff Discharge for last 30 years (MCM/year)
SY: Average Specific Runoff Yield for last 30 years (mm)
★D: Discharge station and number
: SY is calculated using adopted F and R_{30}
: Stations on White Nile
Renk
★D22
R. White Nile CA 1,494,075 RO 26,706 SY 17.9
Dulayb, W3 CA 4,116 RO 2.55 SY 0.62
R.Nile Left Bank o5 CA 8,342 RO 213.07 SY 25.54
R.Nile Righr Bank, NW03 CA 4,557 RO 102.89 SY 22.58
Right Bank, W202 CA 3,090 RO 2.0 SY 0.66
Es Samaa, W21 CA 6,046 RO 4.9 SY 0.81
El-Galhak
Birbari, W2 CA 16,258 RO 12.6 SY 0.78
Left Bank, W201 CA 520 RO 0.3 SY 0.60
Chifayaca, W22 CA 6,602 RO 5.3 SY 0.81
River White Nile
R.Nile Left Bank o4 CA 22,971 RO 683.9 SY 29.77
R.Nile Righr Bank, NW02 CA 2,348 RO 62.30 SY 26.53
Right Bank W1202 CA 486 RO 0.34 SY 0.69
Right Bank, W104 CA 3,205 RO 2.23 SY 0.69
Yabus, W121 CA 7,747 RO 5.38 SY 0.69
Right Bank W102 CA 600 RO 0.42 SY 0.69
Tomboa W11 CA 6,804 RO 4.73 SY 0.69
Doga W12 CA 14,874 RO 10.3 SY 0.69
R. Doga
Doga W1203 CA 5,741 RO 3.99 SY 0.69
Left Bank, W1201 CA 900 RO 0.63 SY 0.69
R. White Nile CA 1,435,483 RO 27,017 SY 18.8
★D18
F=0.001
Melut
D19★
Adar W1 CA 43,887 RO 30.5 SY 0.69
R. Adar
Adar, W105 CA 12,457 RO 8.66 SY 0.69
Left Bank W101 CA 439 RO 0.31 SY 0.69
Left Bank, W103 CA 5,508 RO 3.8 SY 0.69
River White Nile
R.Nile Left Bank o3 CA 6,044 RO 196.17 SY 32.46
Kodok
R.Nile Righr Bank, NW01 CA 2,385 RO 77.52 SY 32.50
Malakal
★D17
R. White Nile CA 1,427,054 RO 27,709 SY 19.4



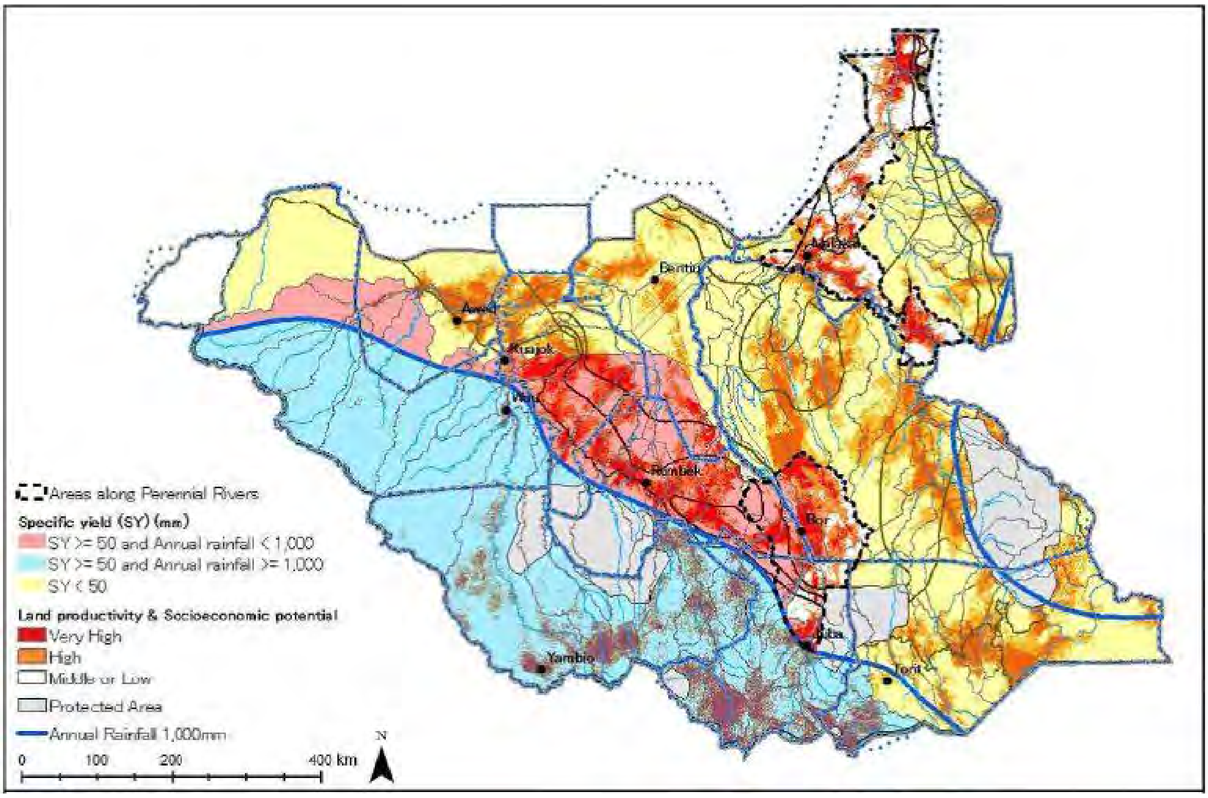
SY_{30} map



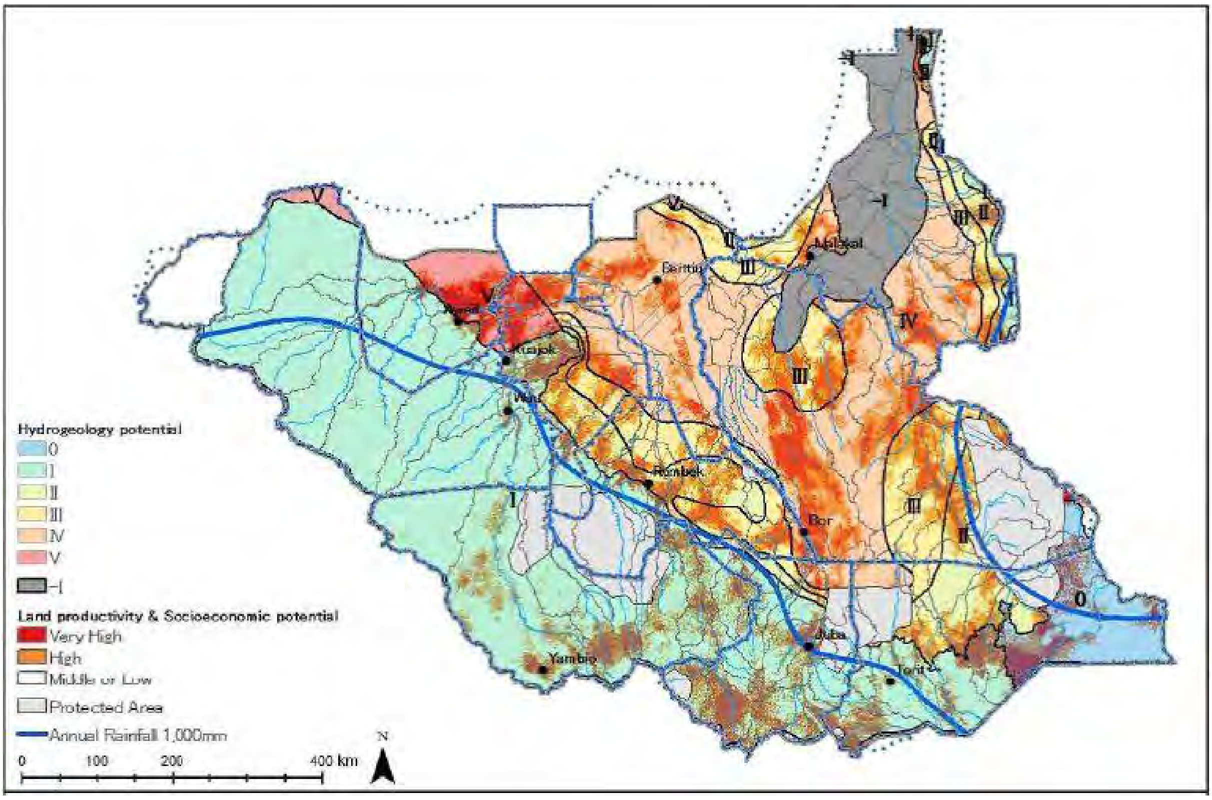
Surface water potential map (SY_{30} + Q_{30} map)

APPENDIX - 2-3

Irrigation Development Potential Map



Irrigation Development Potential Map (with Surface Water Potential)



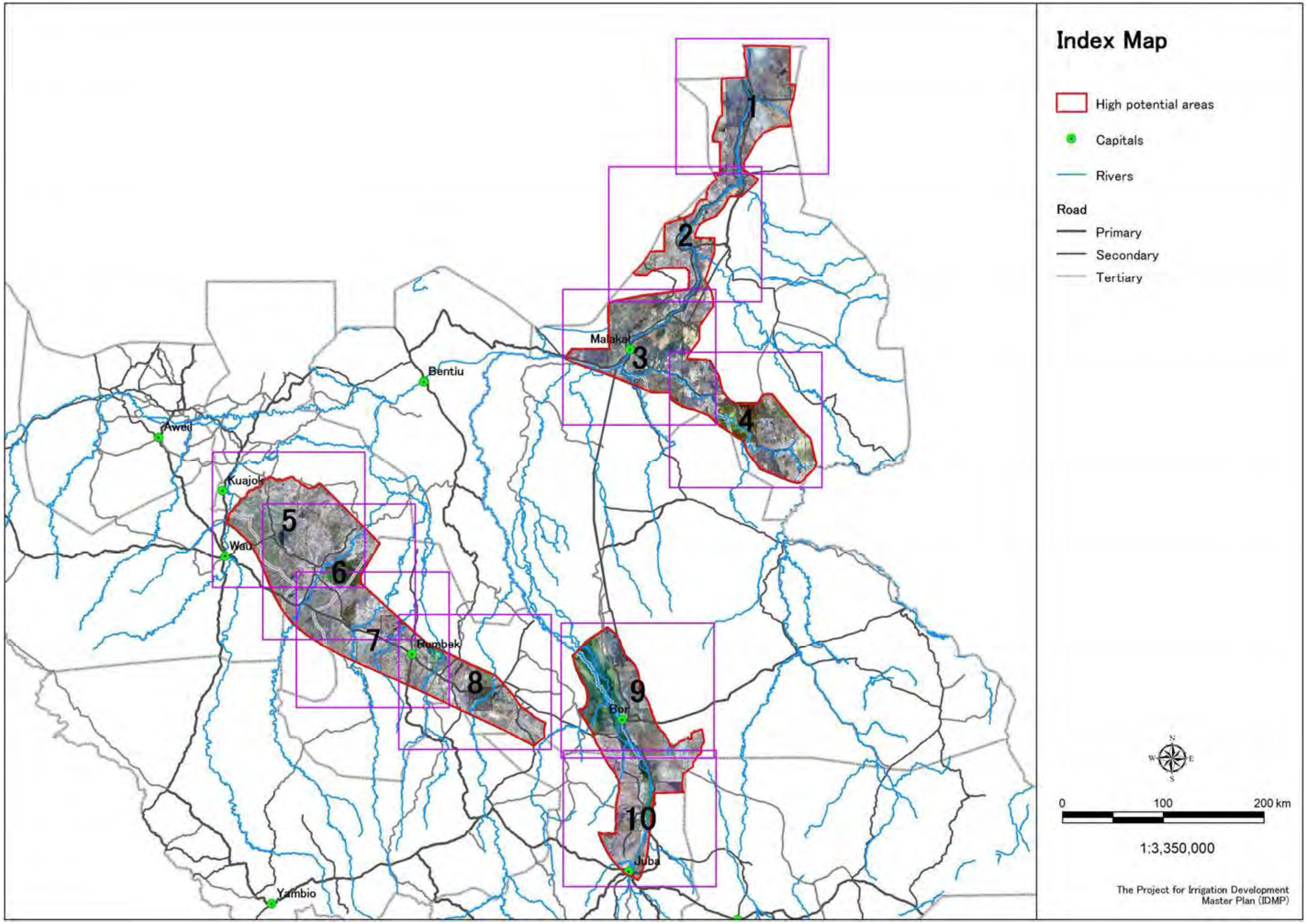
Irrigation Development Potential Map (with Groundwater Potential

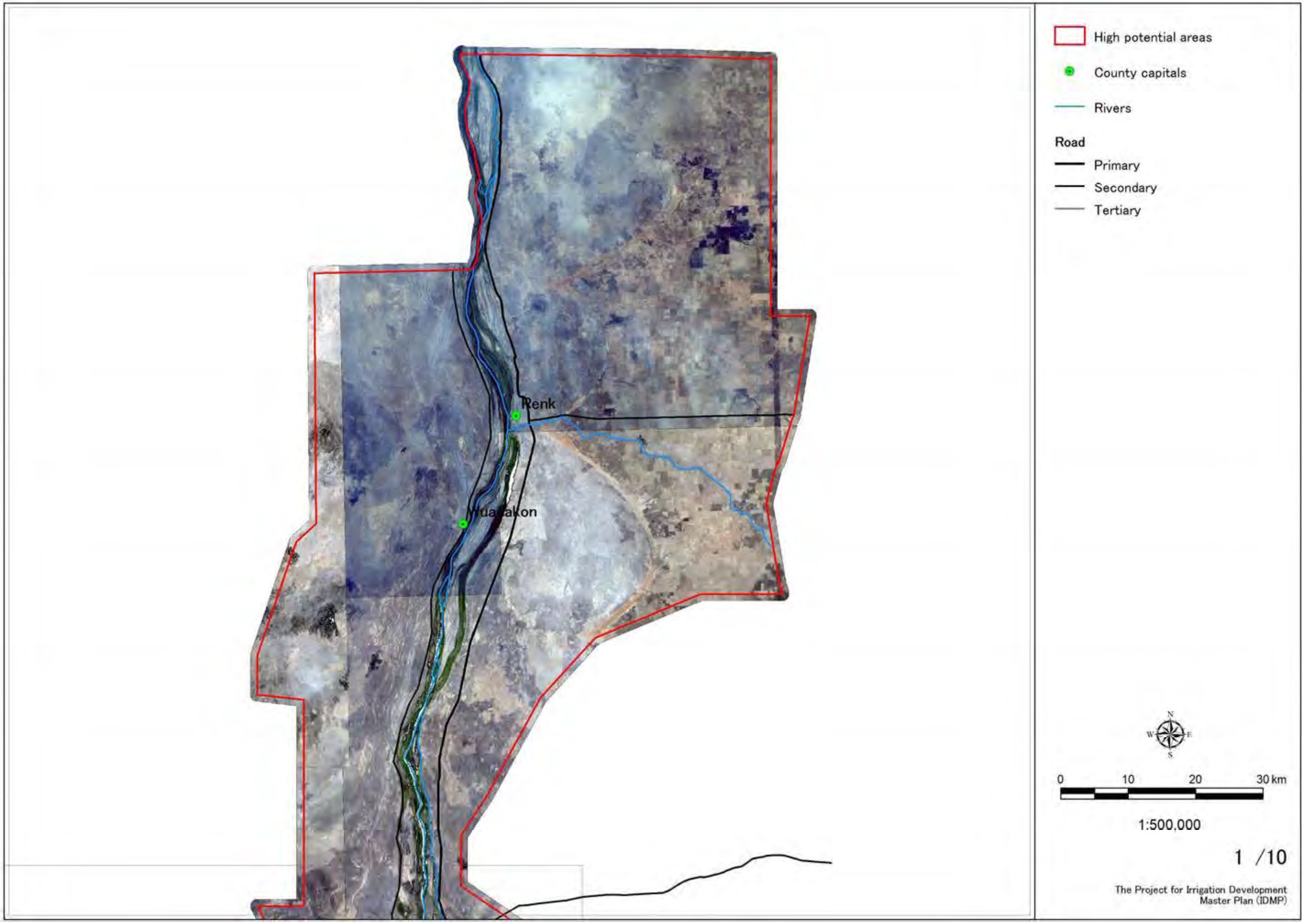
APPENDIX - 3

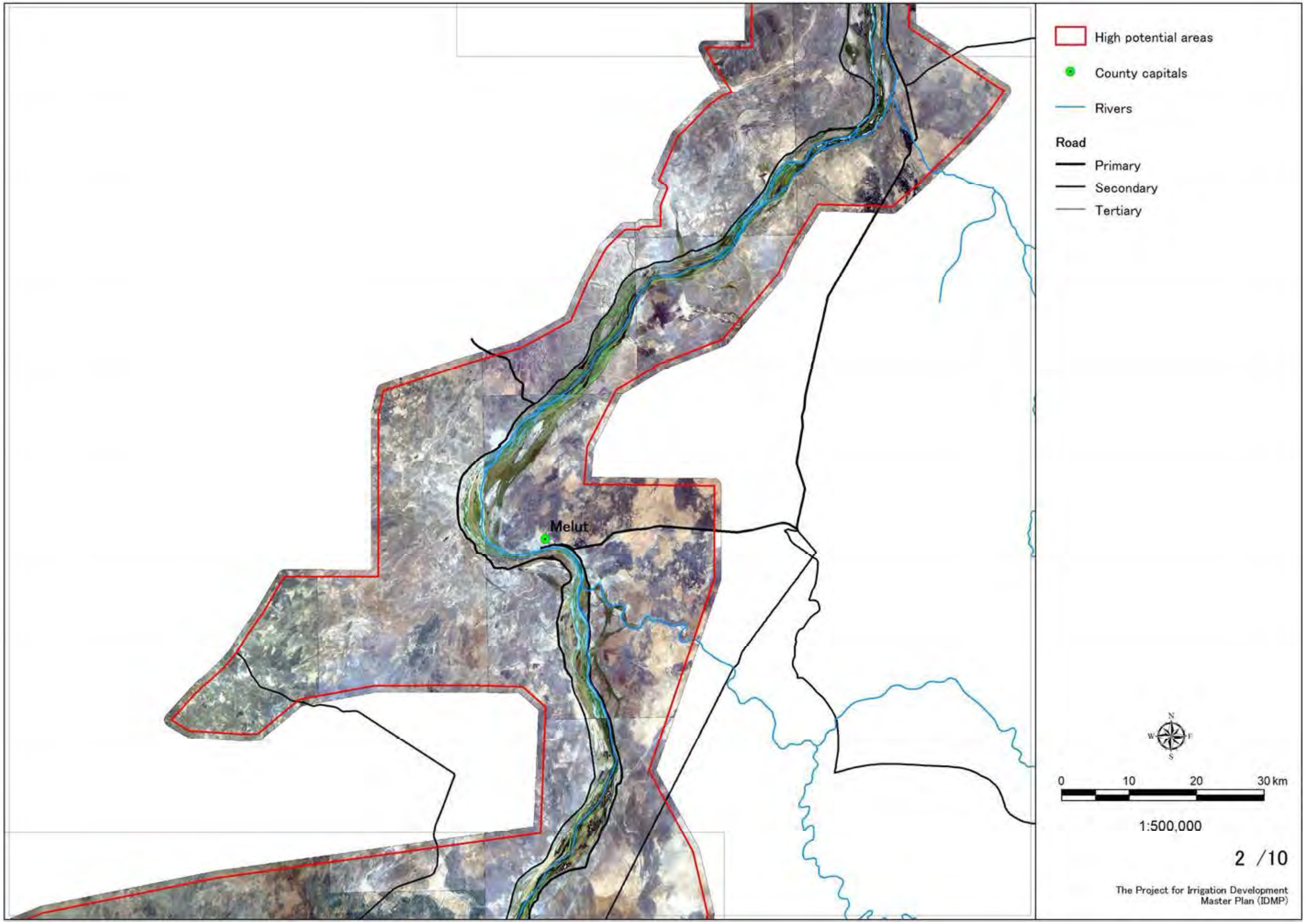
DETAILED ASSESSMENT ANALYSIS (HIGH RESOLUTION MAPS)

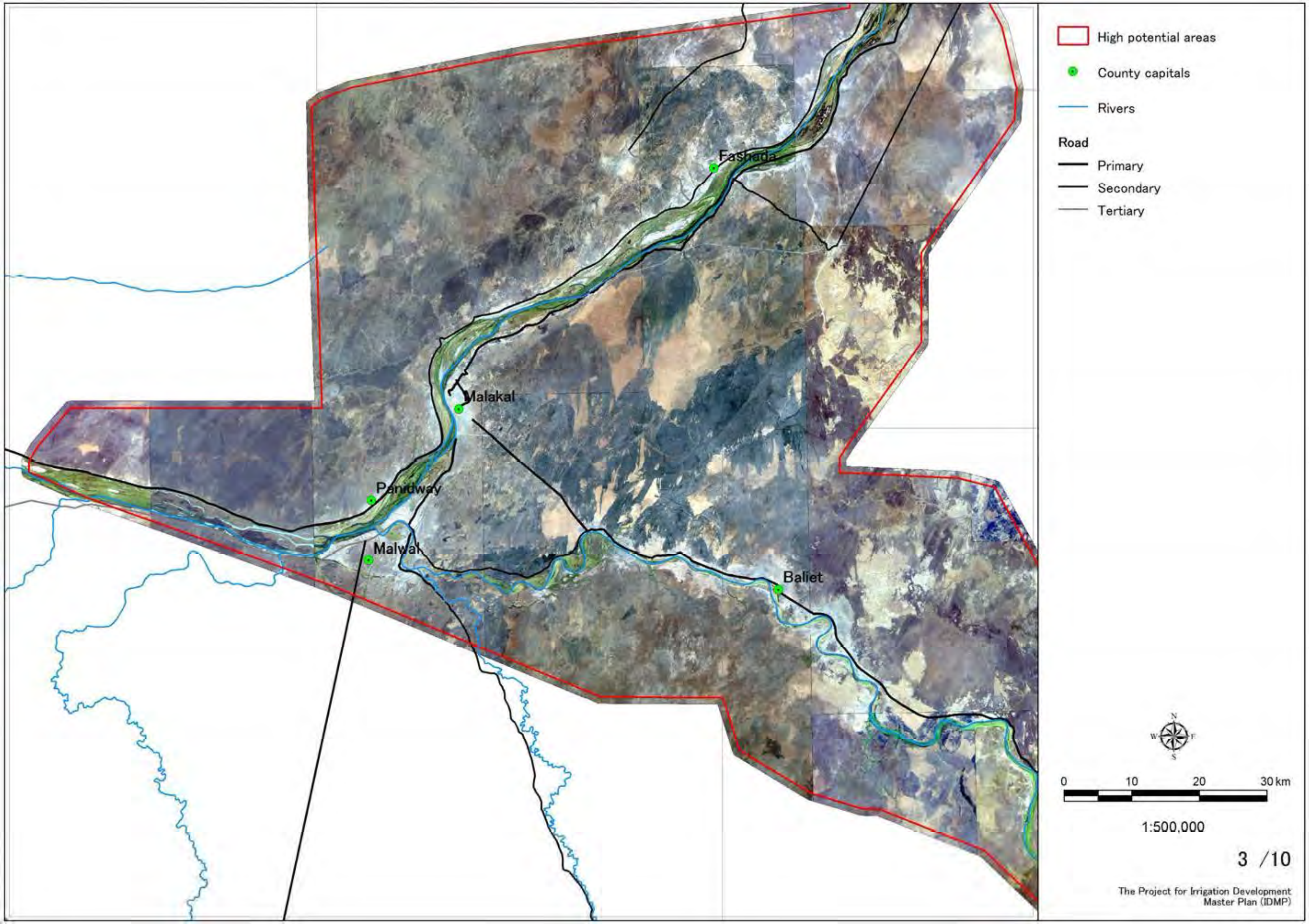
APPENDIX - 3-1

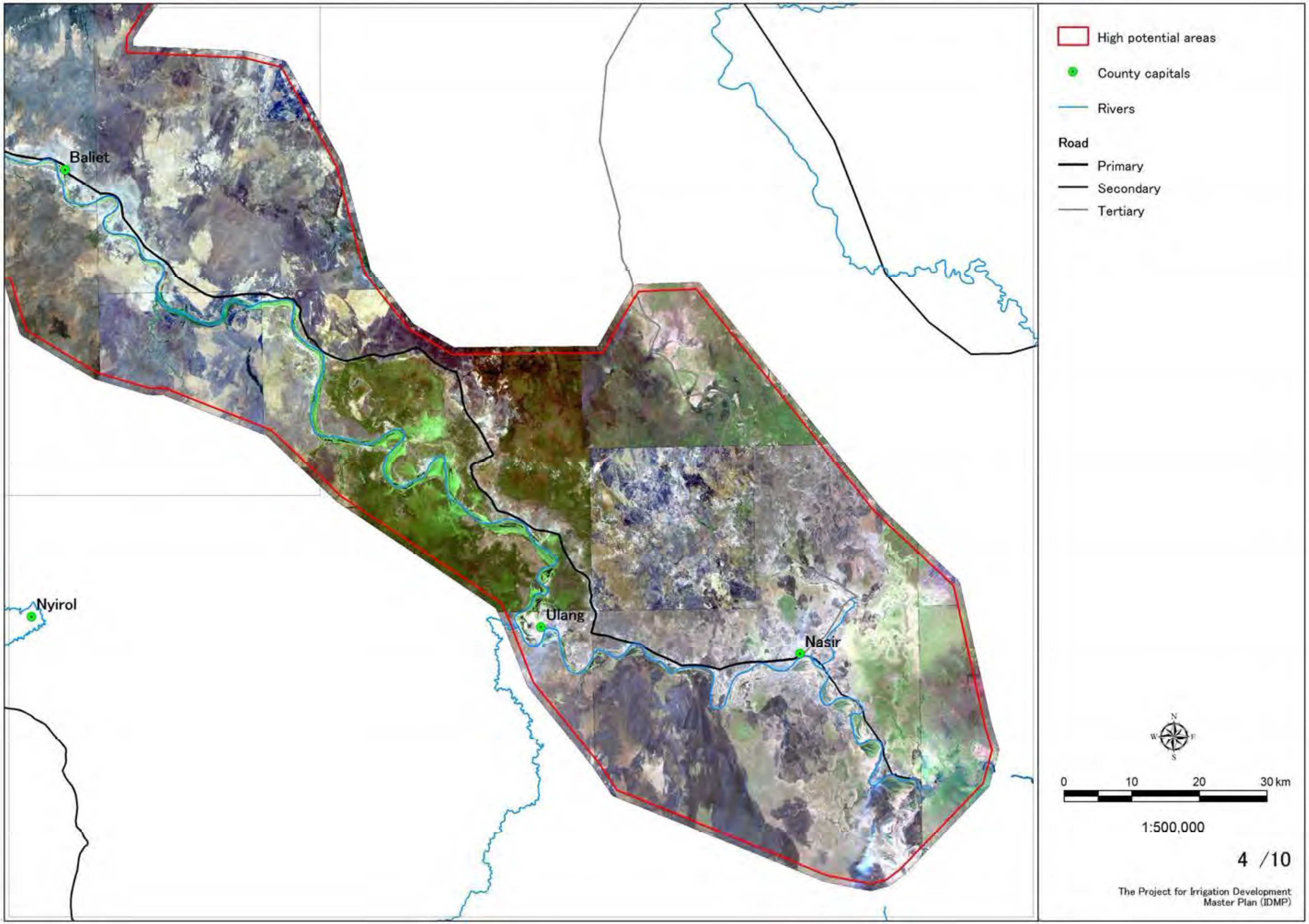
High Resolution Maps
(Ortho Photo Imagery)

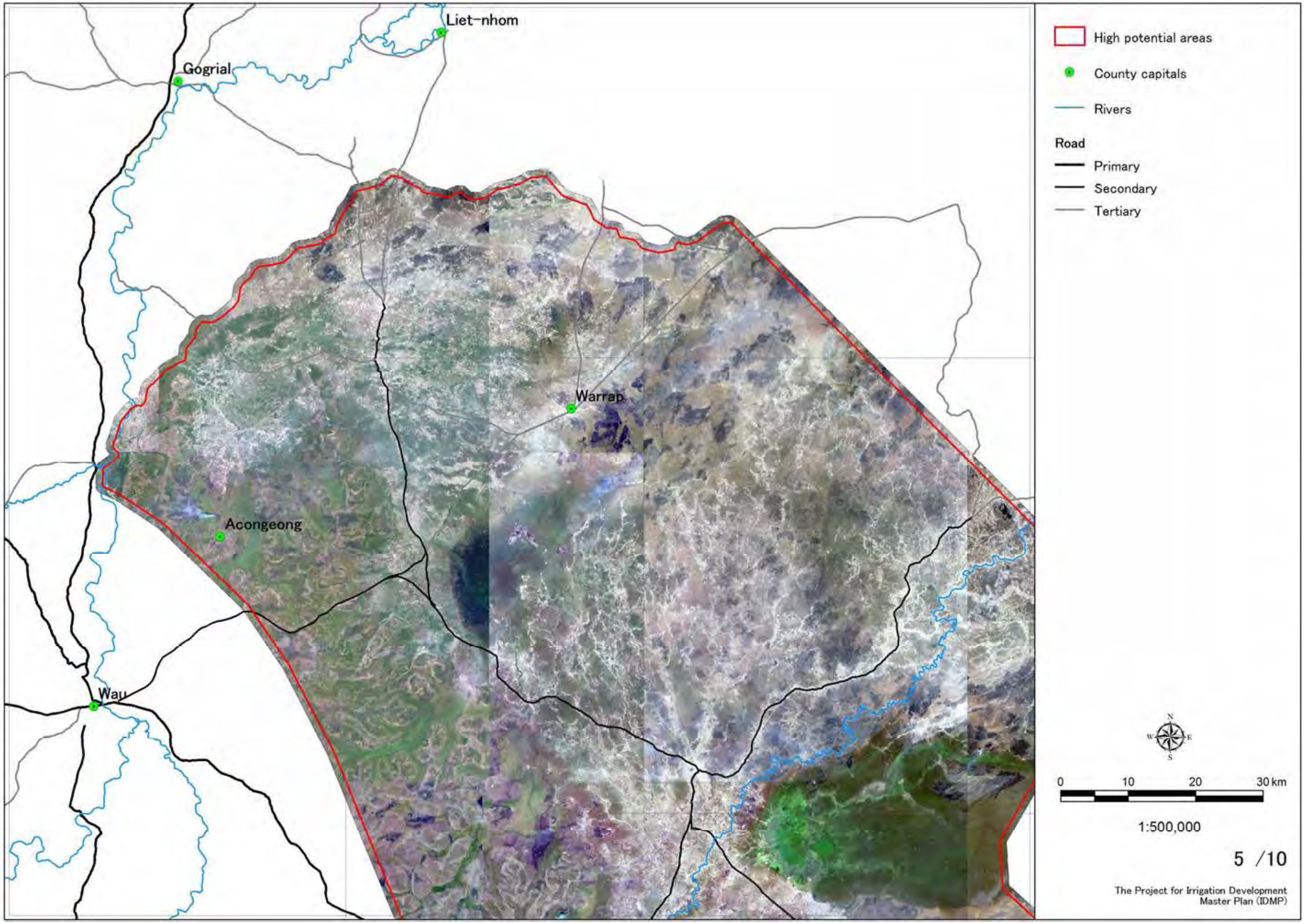

Index Map
High potential areas
Capitals
Rivers
Road
Primary
Secondary
Tertiary
1
2
3
4
5
6
7
8
9
10
Malakal
Bentiu
Aweil
Kuajok
Wau
Rumbek
Bor
Juba
Yambio
0
100
200 km
1:3,350,000
The Project for Irrigation Development Master Plan (IDMP)

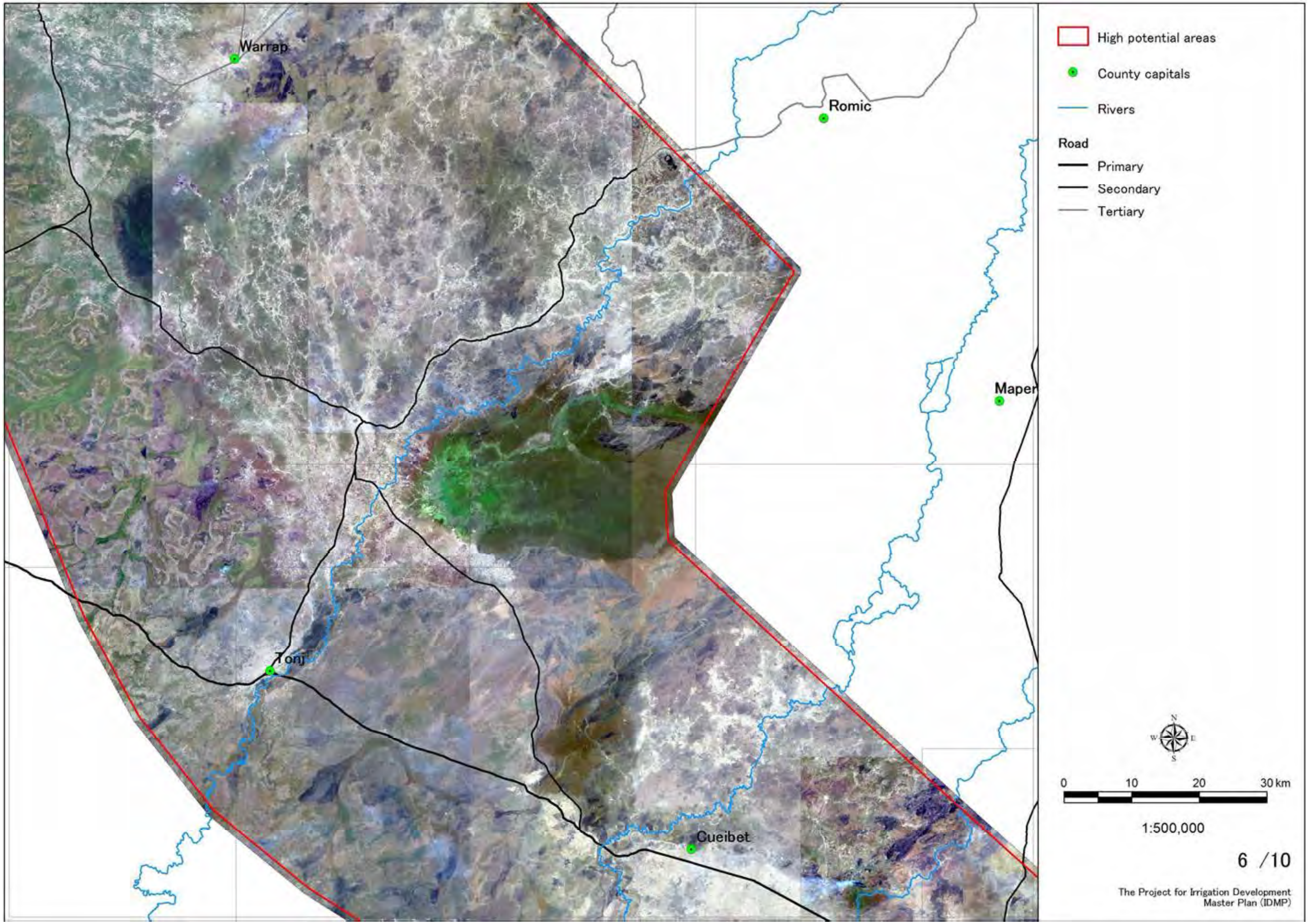

Renk
High potential areas
County capitals
Rivers
Road
Primary
Secondary
Tertiary
N
W
E
S
0
10
20
30 km
1:500,000
1 /10
The Project for Irrigation Development Master Plan (IDMP)

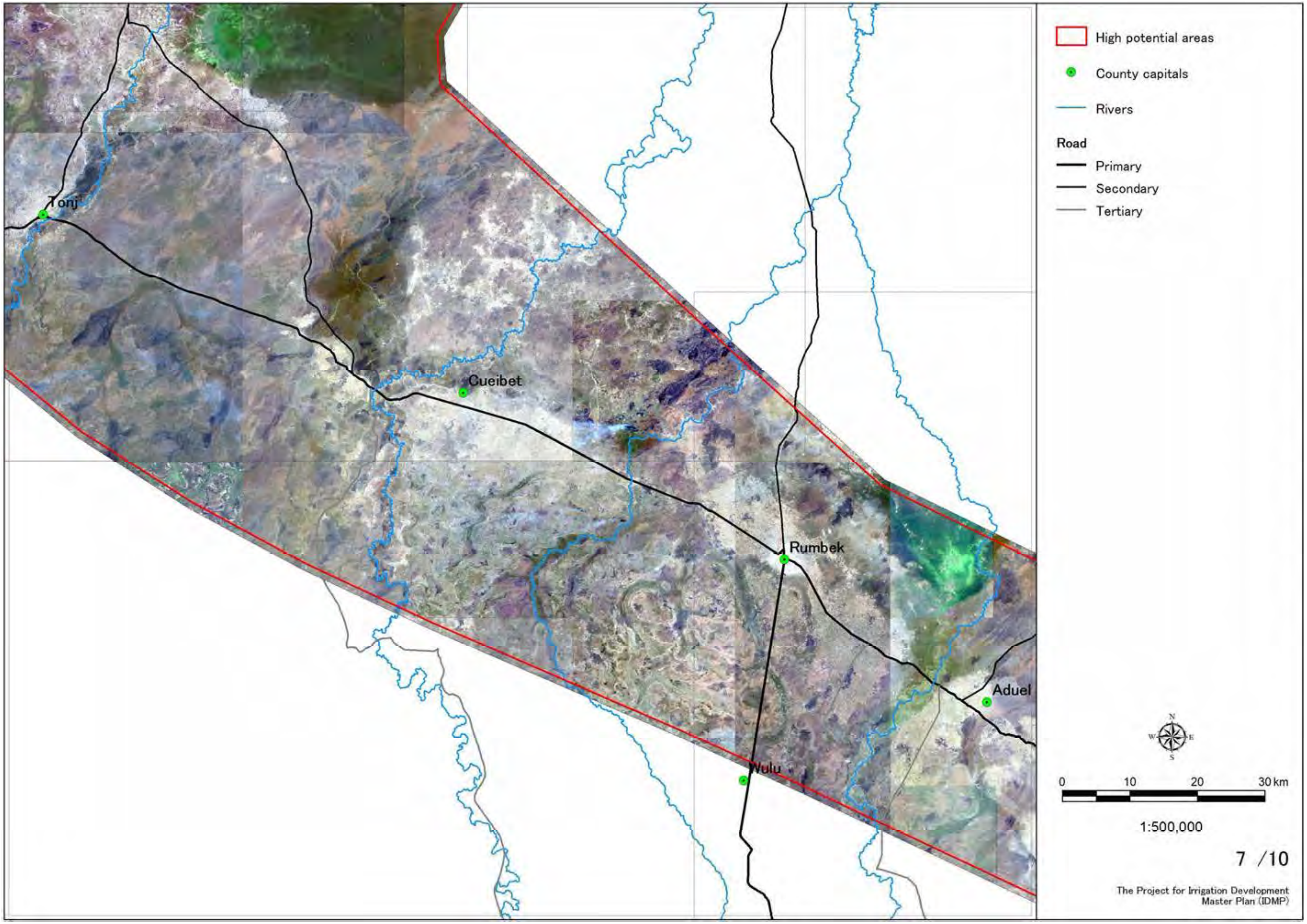

High potential areas
County capitals
Rivers
Road
Primary
Secondary
Tertiary
Melut
N
W
E
S
0
10
20
30 km
1:500,000
2 /10
The Project for Irrigation Development Master Plan (IDMP)


High potential areas
County capitals
Rivers
Road
Primary
Secondary
Tertiary
Fashoda
Malakal
Panidway
Malwal
Baliet
0
10
20
30 km
1:500,000
3 /10
The Project for Irrigation Development Master Plan (IDMP)

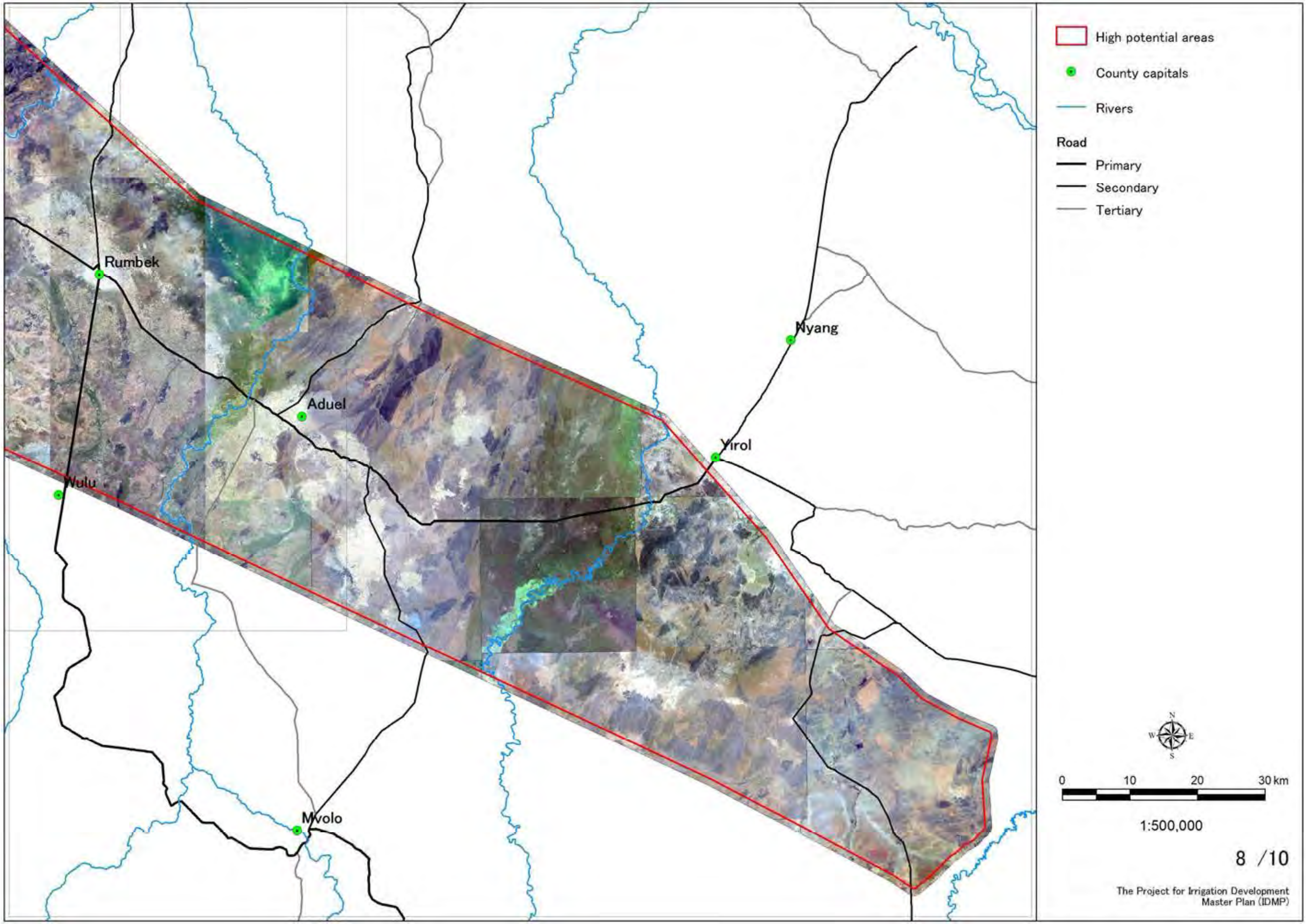

Baliet
Nyirol
Ulang
Nasir
High potential areas
County capitals
Rivers
Road
Primary
Secondary
Tertiary
N
W
E
S
0
10
20
30 km
1:500,000
4 /10
The Project for Irrigation Development Master Plan (IDMP)

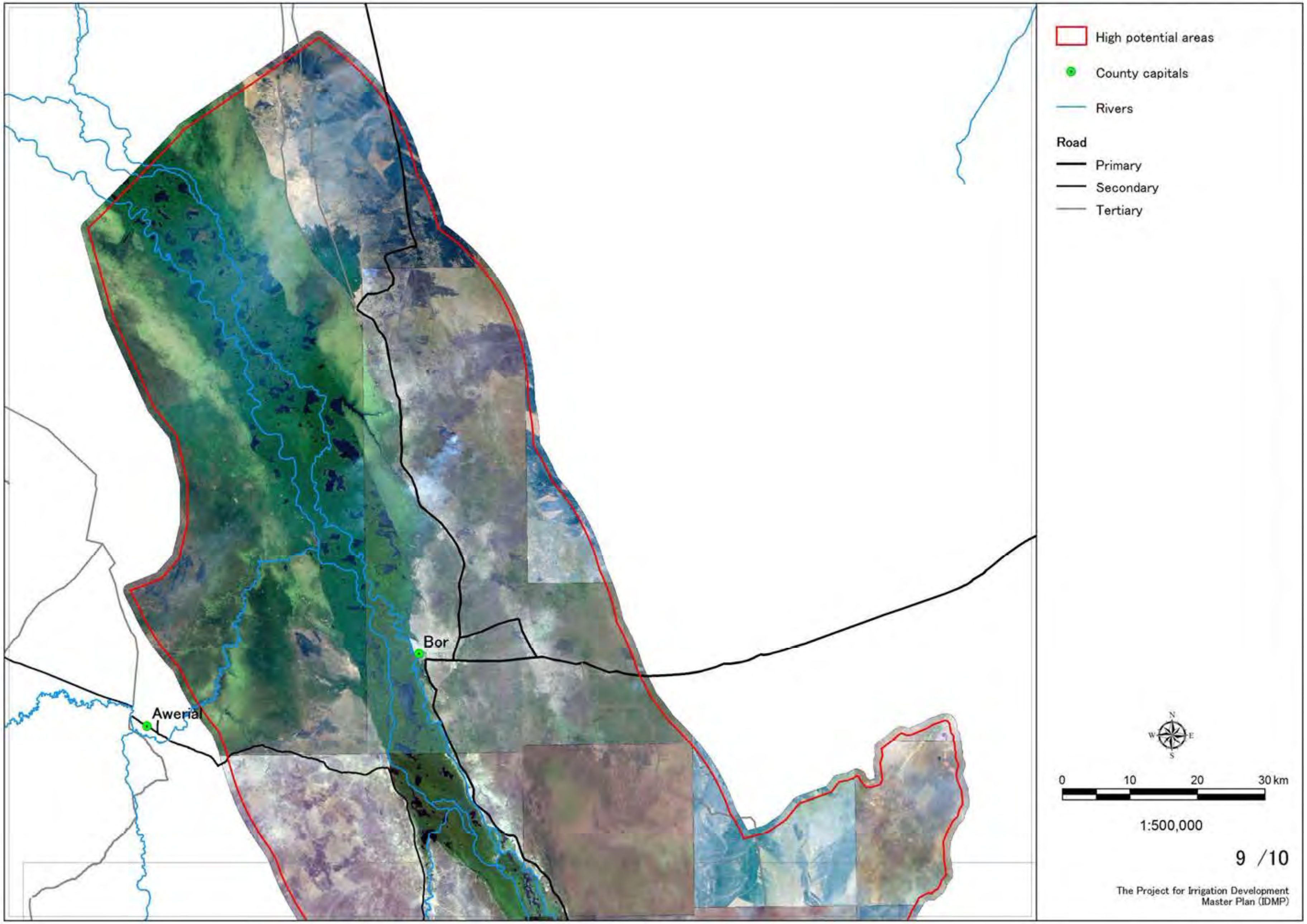

Liet-nhom
Gogrial
Warrap
Acongeong
Wau
High potential areas
County capitals
Rivers
Road
Primary
Secondary
Tertiary
N
W
E
S
0
10
20
30 km
1:500,000
5 /10
The Project for Irrigation Development Master Plan (IDMP)


Warrap
Romic
Maper
Tonj
Cueibet
High potential areas
County capitals
Rivers
Road
Primary
Secondary
Tertiary
N
W
E
S
0
10
20
30 km
1:500,000
6 /10
The Project for Irrigation Development Master Plan (IDMP)



High potential areas
County capitals
Rivers
Road
Primary
Secondary
Tertiary
Tonj
Cueibet
Rumbek
Aduel
Wulu
0
10
20
30 km
1:500,000
7 /10
The Project for Irrigation Development Master Plan (IDMP)


High potential areas
County capitals
Rivers
Road
Primary
Secondary
Tertiary
Rumbek
Aduel
Wulu
Nyang
Yirol
Mvolo
0
10
20
30 km
1:500,000
8 /10
The Project for Irrigation Development Master Plan (IDMP)


High potential areas
County capitals
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Road
Primary
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Awerial
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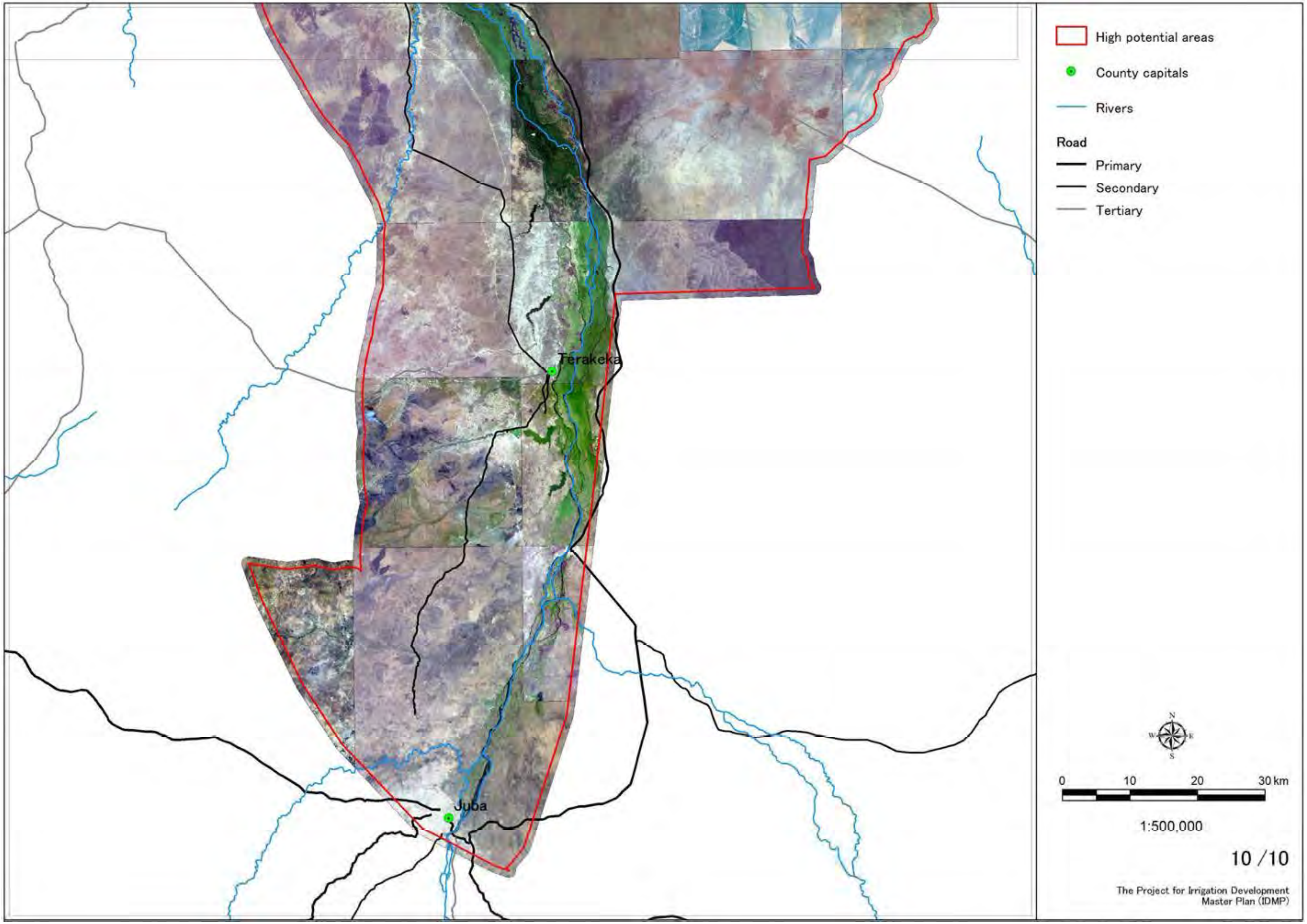
30 km
1:500,000
9 /10
The Project for Irrigation Development Master Plan (IDMP)


Terakeka
Juba
High potential areas
County capitals
Rivers
Road
Primary
Secondary
Tertiary
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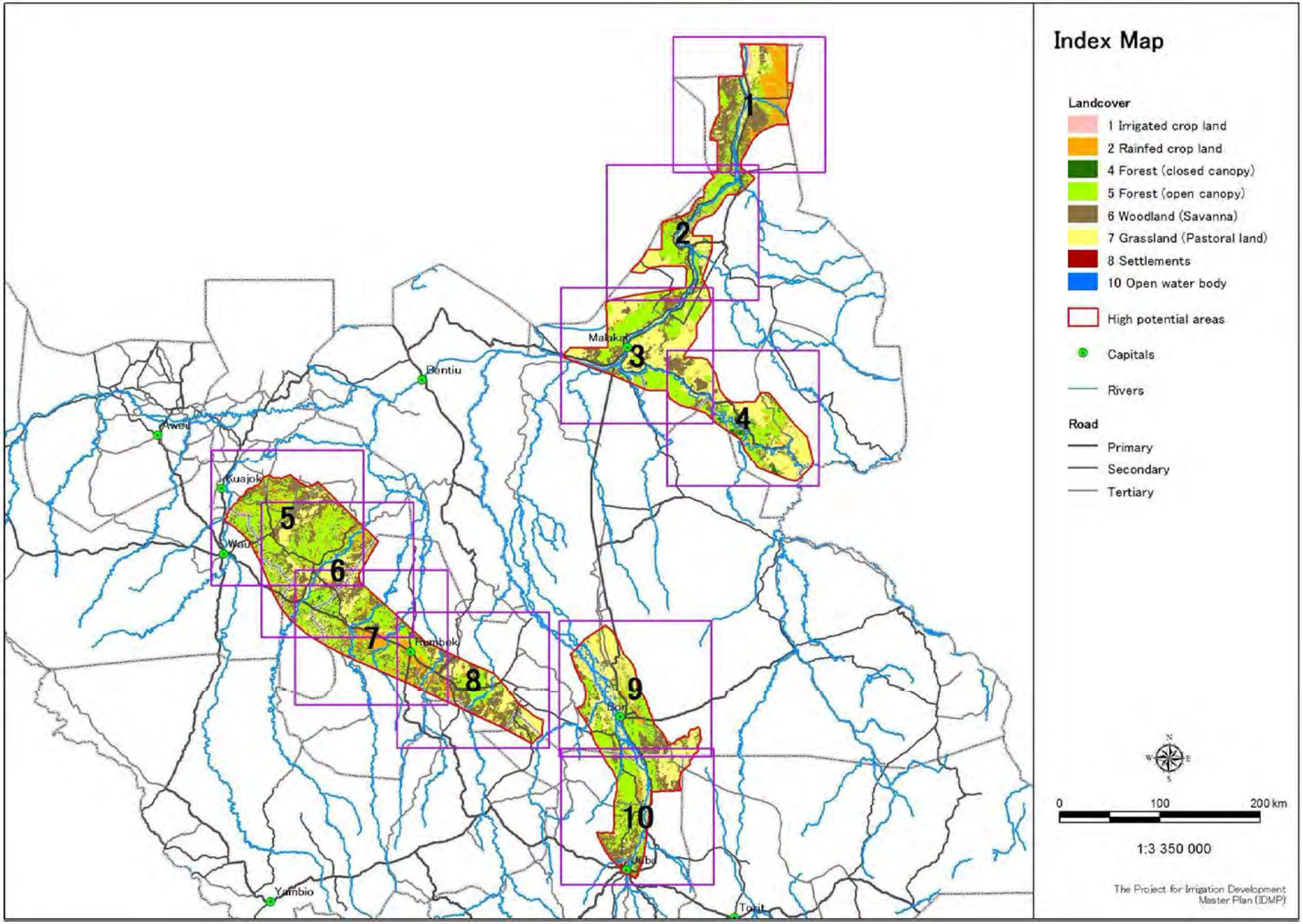
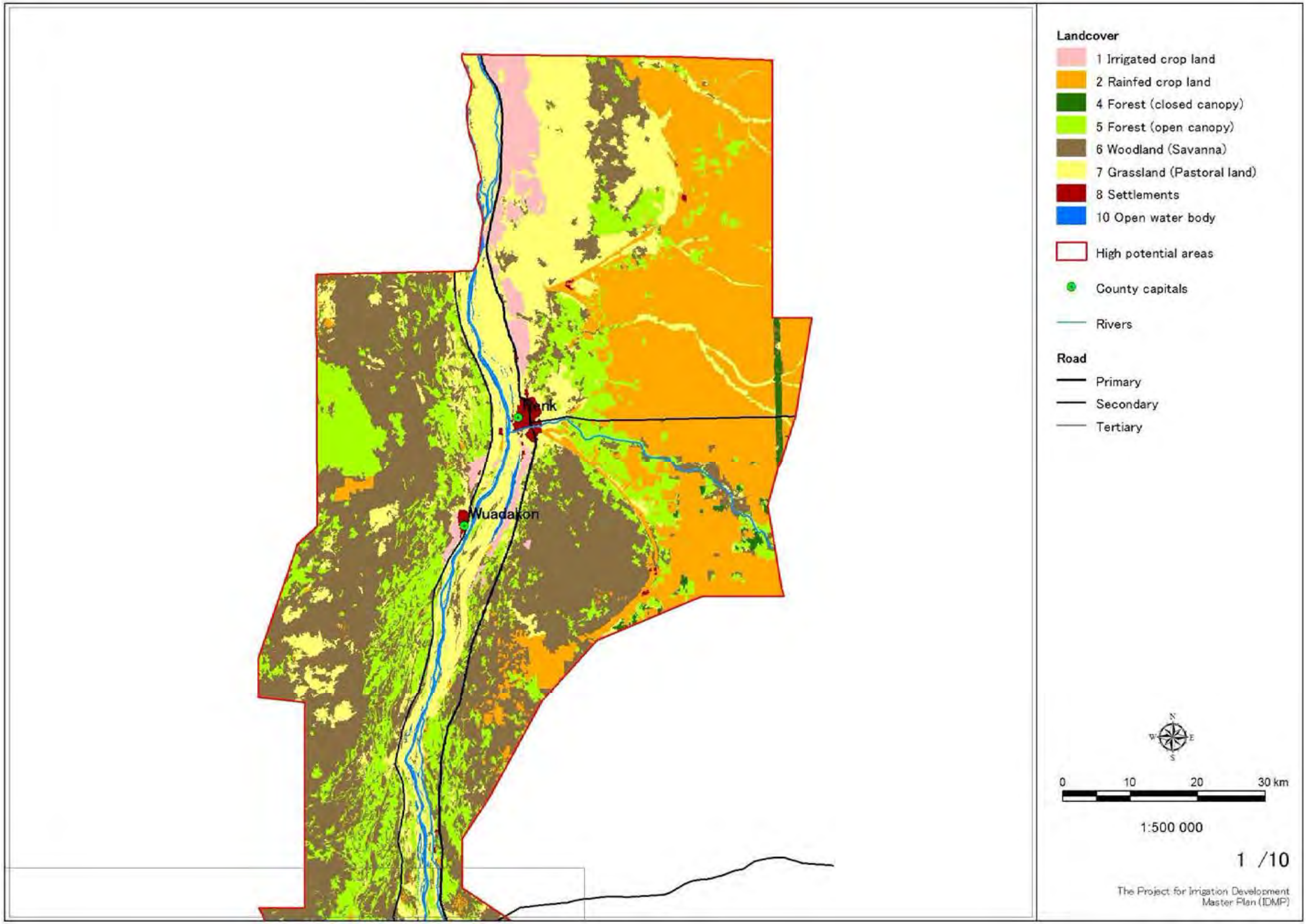
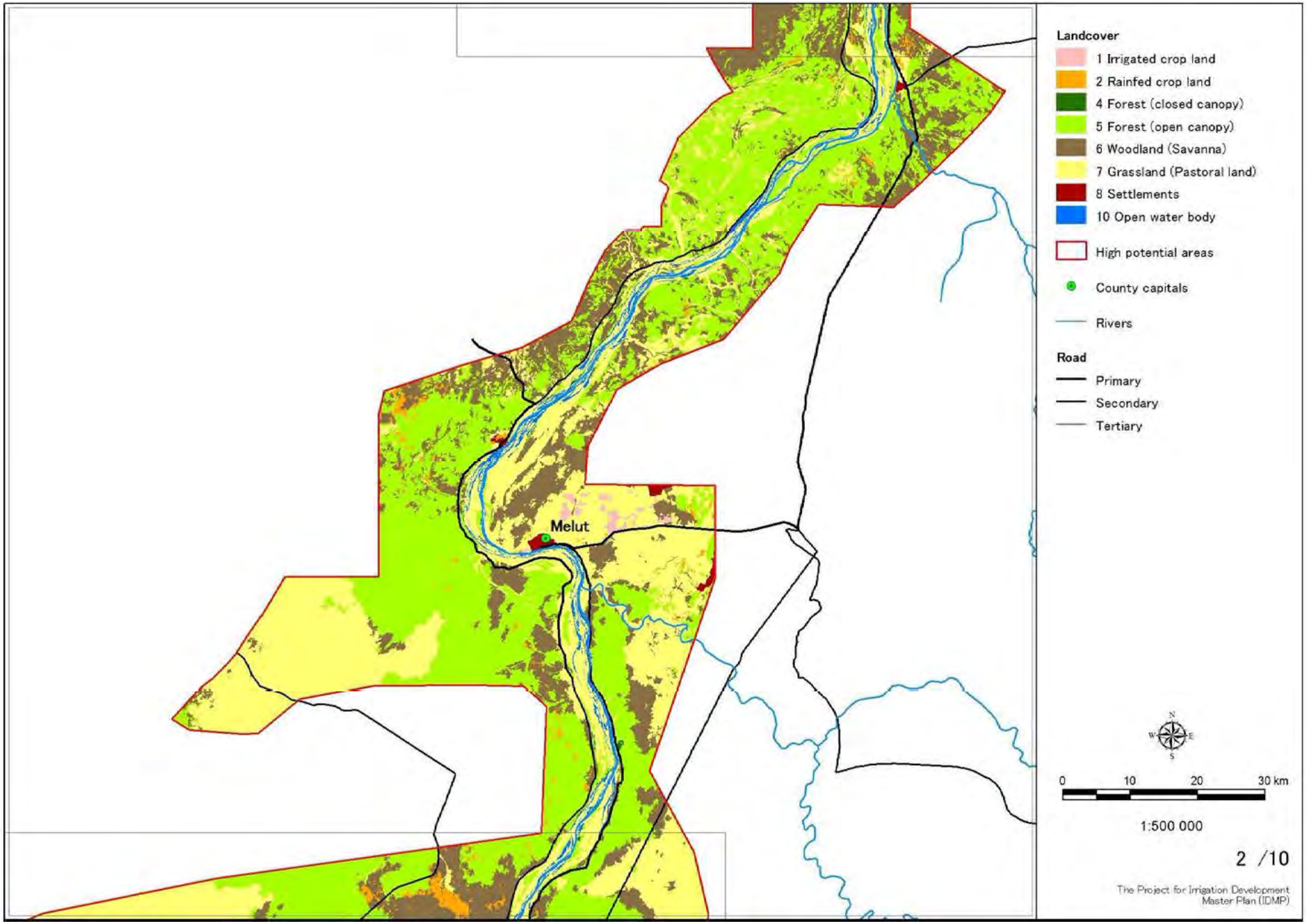
30 km
1:500,000
10 /10
The Project for Irrigation Development Master Plan (IDMP)

APPENDIX - 3-2

High Resolution Maps
(Landcover Map)


Index Map
Landcover
1 Irrigated crop land
2 Rainfed crop land
4 Forest (closed canopy)
5 Forest (open canopy)
6 Woodland (Savanna)
7 Grassland (Pastoral land)
8 Settlements
10 Open water body
High potential areas
Capitals
Rivers
Road
Primary
Secondary
Tertiary
0
100
200 km
1:3 350 000
The Project for Irrigation Development Master Plan (IDMP)
1
2
3
4
5
6
7
8
9
10
Malakal
Bentiu
Aweil
Kuajok
Wau
Rumbek
Bor
Juba
Yambio
Torit


Wuadakon
Landcover
1 Irrigated crop land
2 Rainfed crop land
4 Forest (closed canopy)
5 Forest (open canopy)
6 Woodland (Savanna)
7 Grassland (Pastoral land)
8 Settlements
10 Open water body
High potential areas
County capitals
Rivers
Road
Primary
Secondary
Tertiary
0 10 20 30 km
1:500 000
1 /10
The Project for Irrigation Development Master Plan (IDMP)


Landcover
1 Irrigated crop land
2 Rainfed crop land
4 Forest (closed canopy)
5 Forest (open canopy)
6 Woodland (Savanna)
7 Grassland (Pastoral land)
8 Settlements
10 Open water body
High potential areas
County capitals
Rivers
Road
Primary
Secondary
Tertiary
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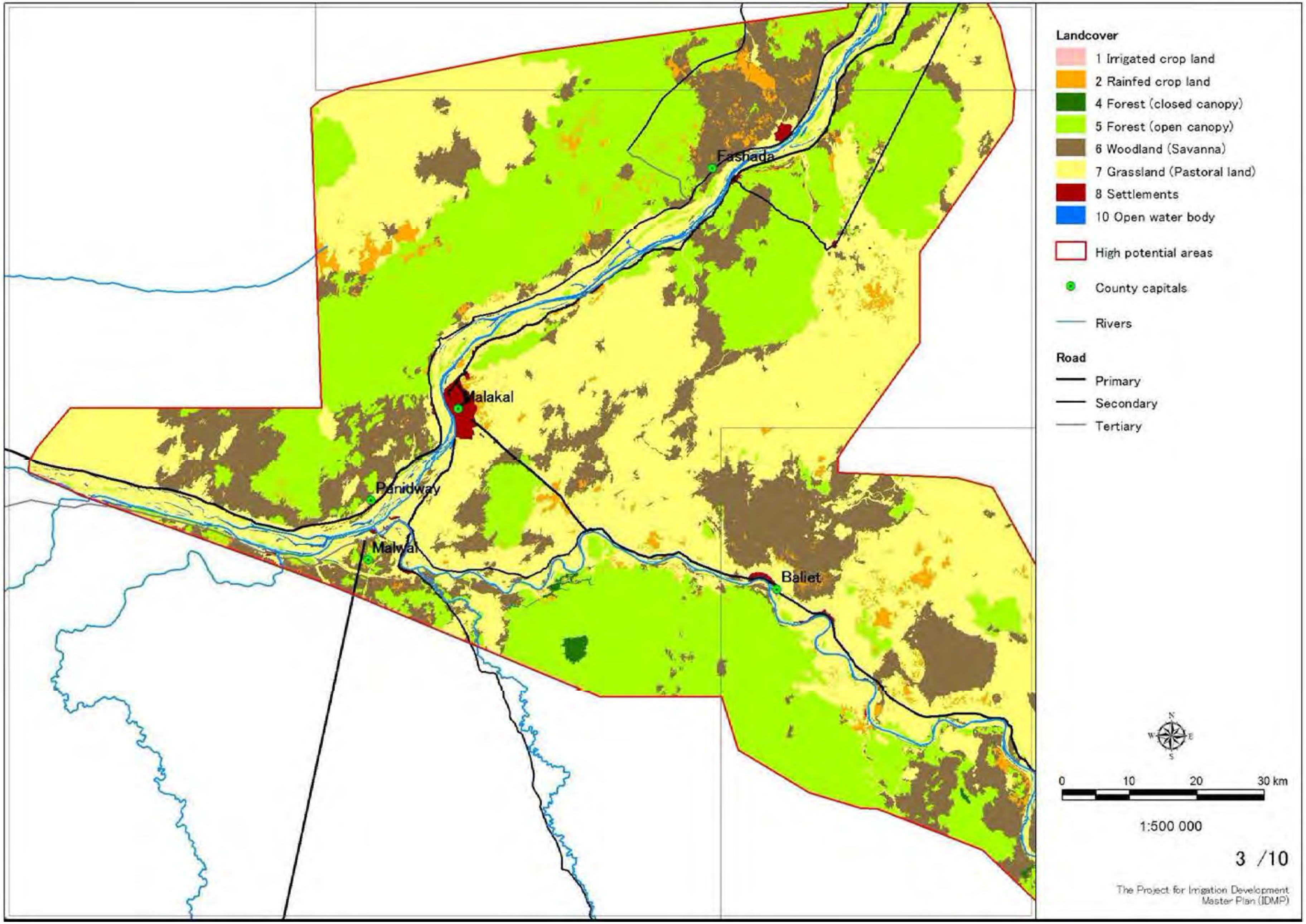
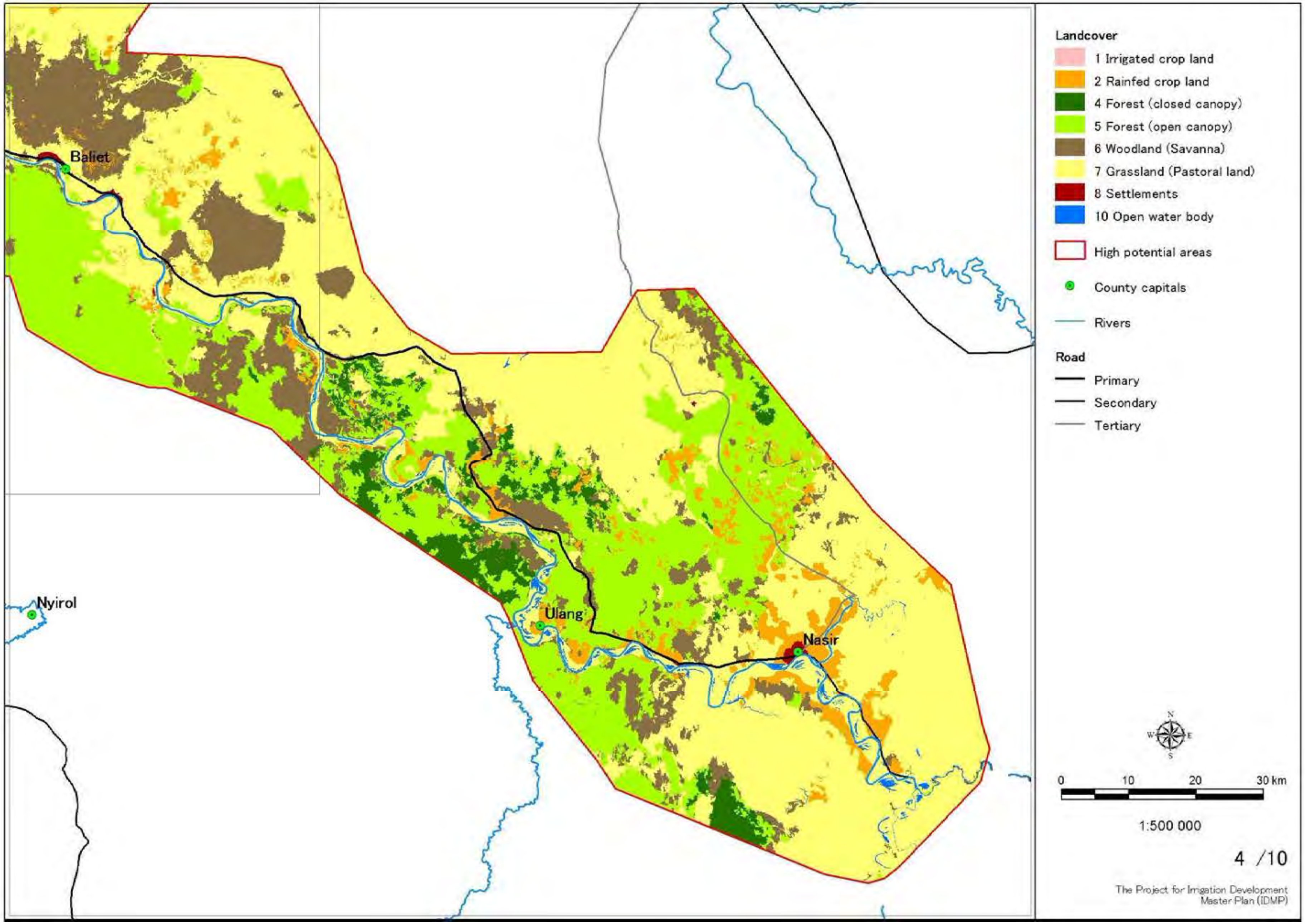
30 km
1:500 000
2 /10
The Project for Irrigation Development Master Plan (IDMP)


Landcover
1 Irrigated crop land
2 Rainfed crop land
4 Forest (closed canopy)
5 Forest (open canopy)
6 Woodland (Savanna)
7 Grassland (Pastoral land)
8 Settlements
10 Open water body
High potential areas
County capitals
Rivers
Road
Primary
Secondary
Tertiary
Fashoda
Malakal
Panidway
Malwal
Baliet
0
10
20
30 km
1:500 000
3 /10
The Project for Irrigation Development Master Plan (IDMP)


Baliet
Nyirol
Ulang
Nasir
Landcover
1 Irrigated crop land
2 Rainfed crop land
4 Forest (closed canopy)
5 Forest (open canopy)
6 Woodland (Savanna)
7 Grassland (Pastoral land)
8 Settlements
10 Open water body
High potential areas
County capitals
Rivers
Road
Primary
Secondary
Tertiary
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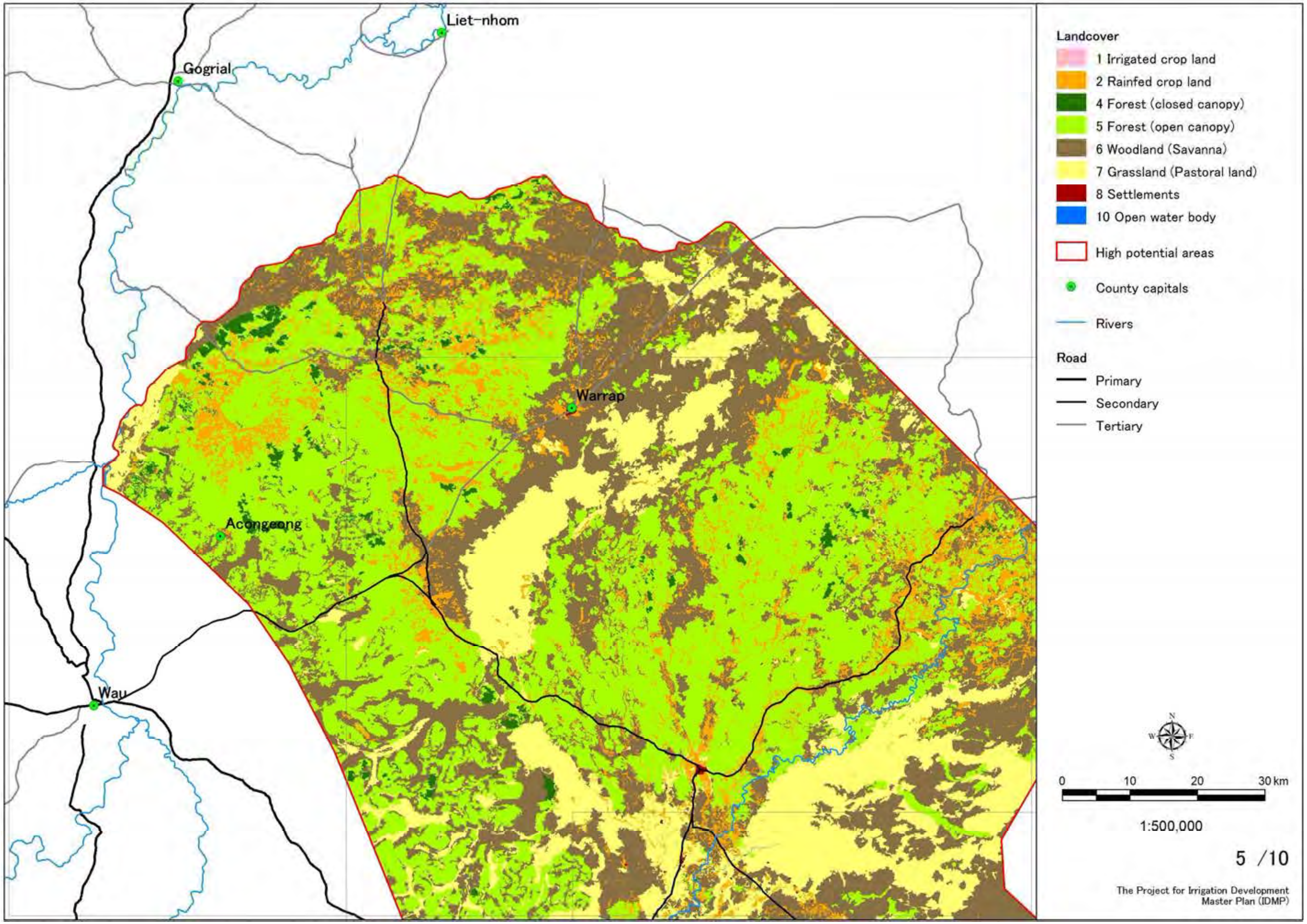
30 km
1:500 000
4 /10
The Project for Irrigation Development Master Plan (IDMP)


Liet-nhom
Gogrial
Warrap
Acongeong
Wau
Landcover
1 Irrigated crop land
2 Rainfed crop land
4 Forest (closed canopy)
5 Forest (open canopy)
6 Woodland (Savanna)
7 Grassland (Pastoral land)
8 Settlements
10 Open water body
High potential areas
County capitals
Rivers
Road
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Secondary
Tertiary
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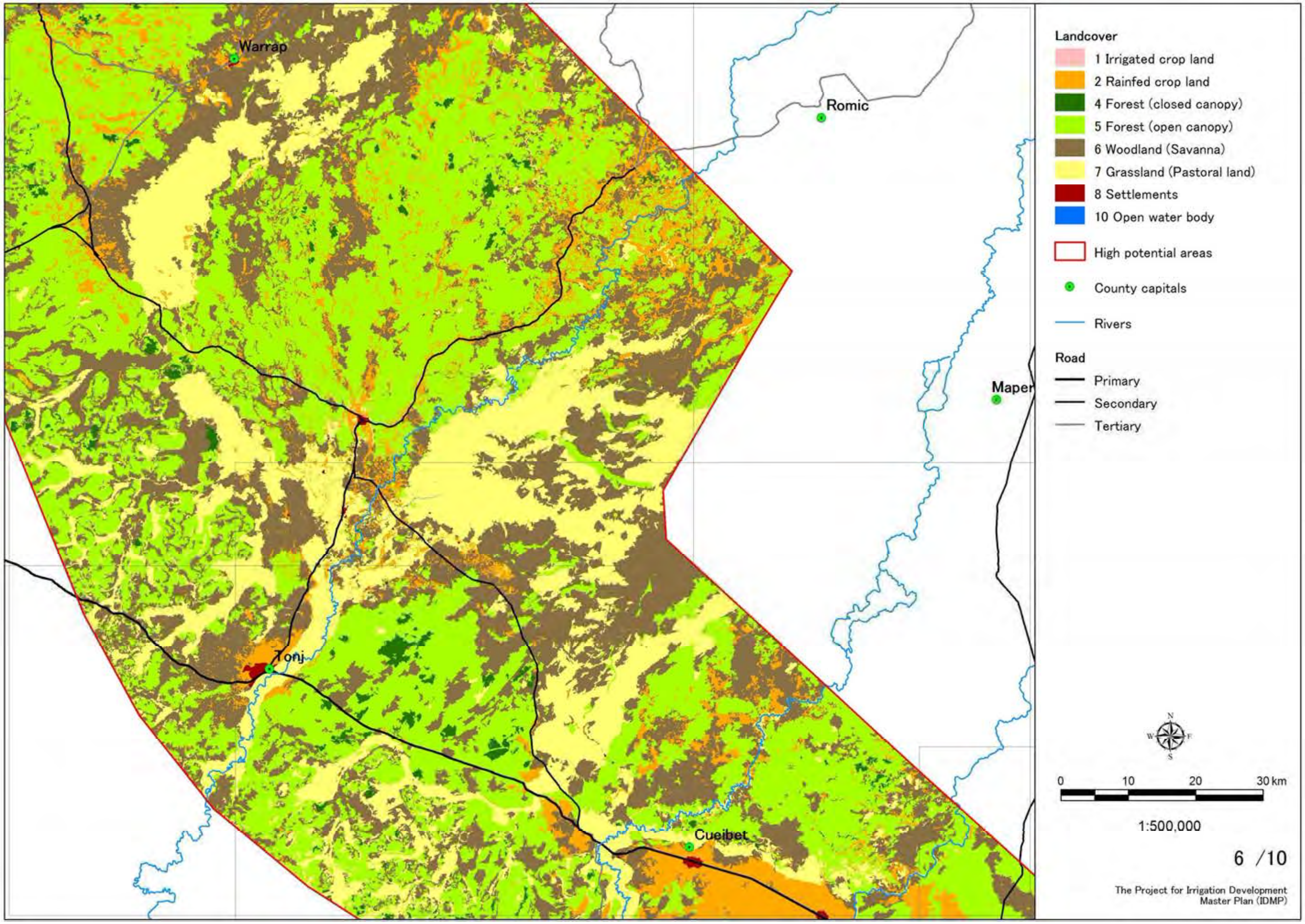
1:500,000
5 /10
The Project for Irrigation Development Master Plan (IDMP)


Warrap
Romic
Maper
Tonj
Cueibet
Landcover
1 Irrigated crop land
2 Rainfed crop land
4 Forest (closed canopy)
5 Forest (open canopy)
6 Woodland (Savanna)
7 Grassland (Pastoral land)
8 Settlements
10 Open water body
High potential areas
County capitals
Rivers
Road
Primary
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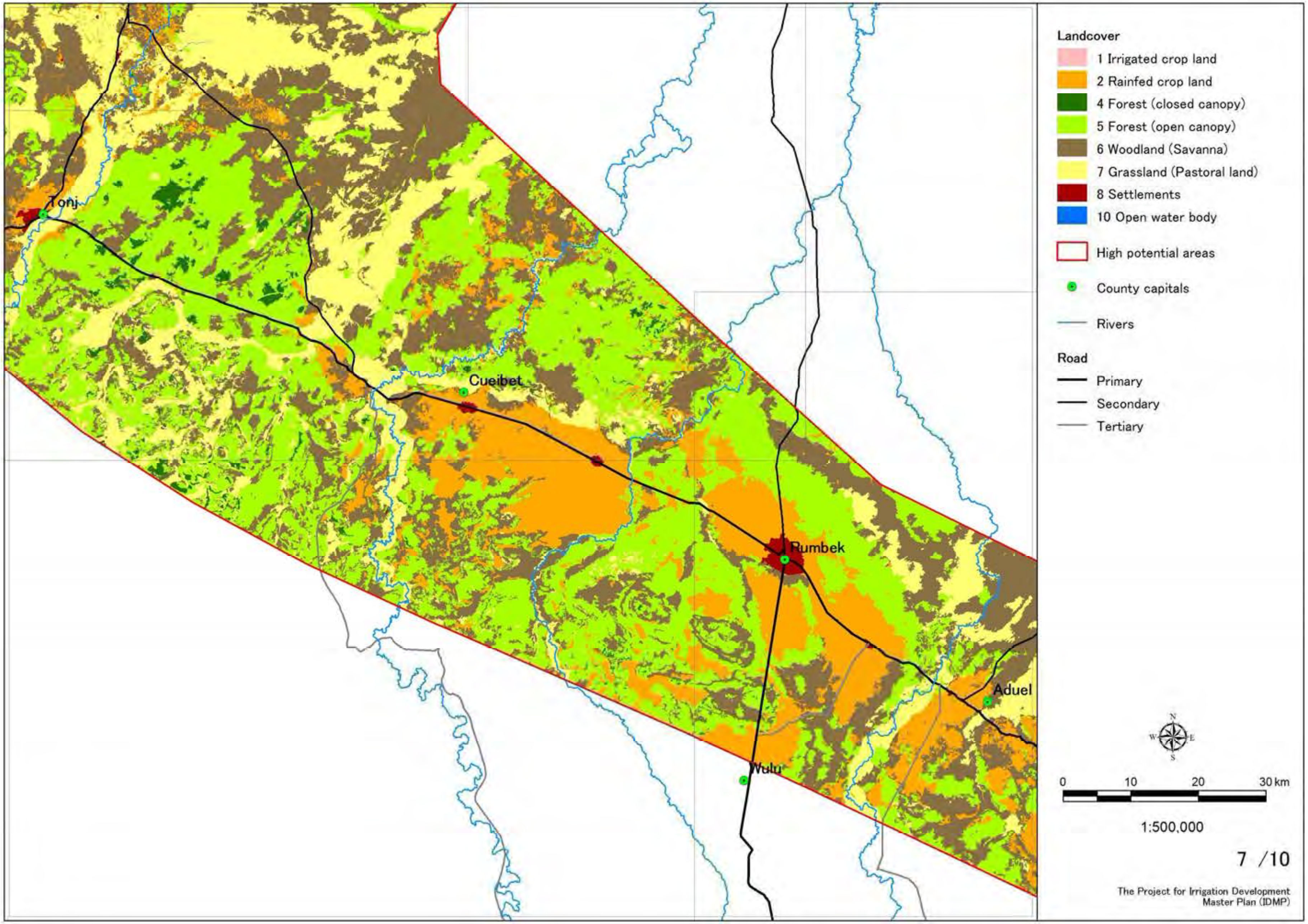
6 /10
The Project for Irrigation Development Master Plan (IDMP)



Tonj
Cueibet
Rumbek
Aduel
Wulu
Landcover
1 Irrigated crop land
2 Rainfed crop land
4 Forest (closed canopy)
5 Forest (open canopy)
6 Woodland (Savanna)
7 Grassland (Pastoral land)
8 Settlements
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High potential areas
County capitals
Rivers
Road
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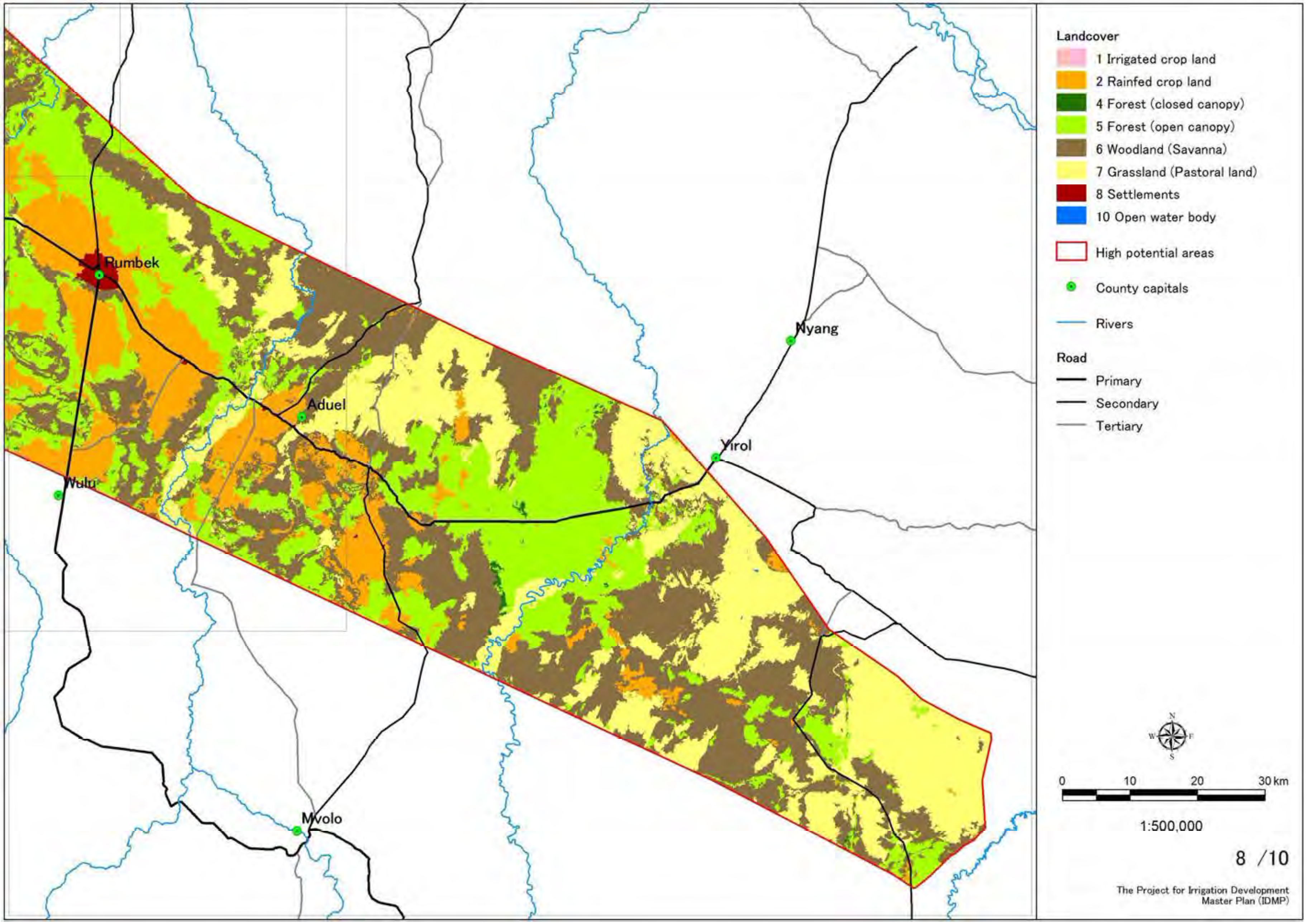
1:500,000
7 /10
The Project for Irrigation Development Master Plan (IDMP)


Rumbek
Aduel
Wulu
Mvolo
Yirol
Nyang
Landcover
1 Irrigated crop land
2 Rainfed crop land
4 Forest (closed canopy)
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High potential areas
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Rivers
Road
Primary
Secondary
Tertiary
0
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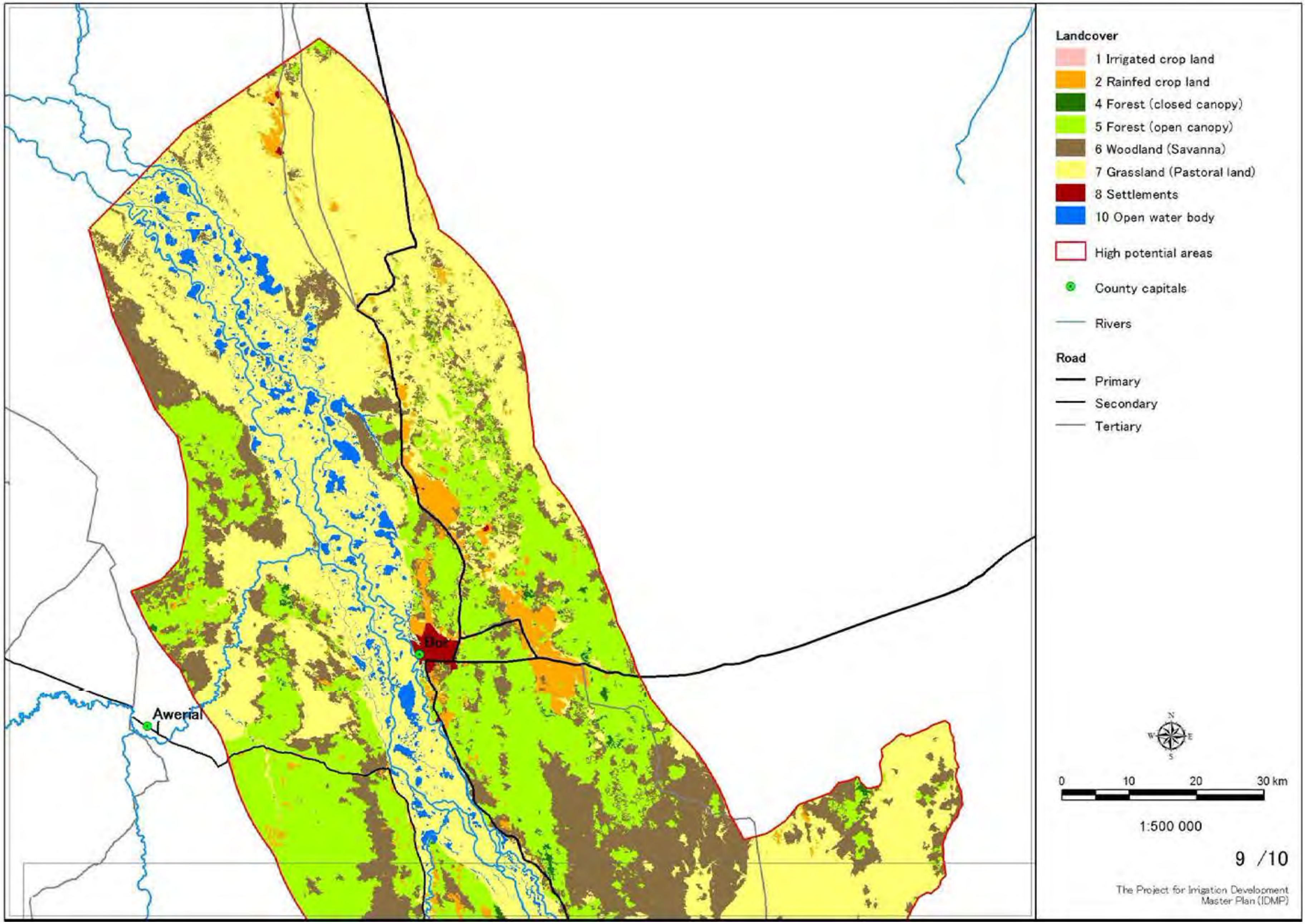
30 km
1:500,000
8 /10
The Project for Irrigation Development Master Plan (IDMP)


Landcover
1 Irrigated crop land
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4 Forest (closed canopy)
5 Forest (open canopy)
6 Woodland (Savanna)
7 Grassland (Pastoral land)
8 Settlements
10 Open water body
High potential areas
County capitals
Rivers
Road
Primary
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Tertiary
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Awerial
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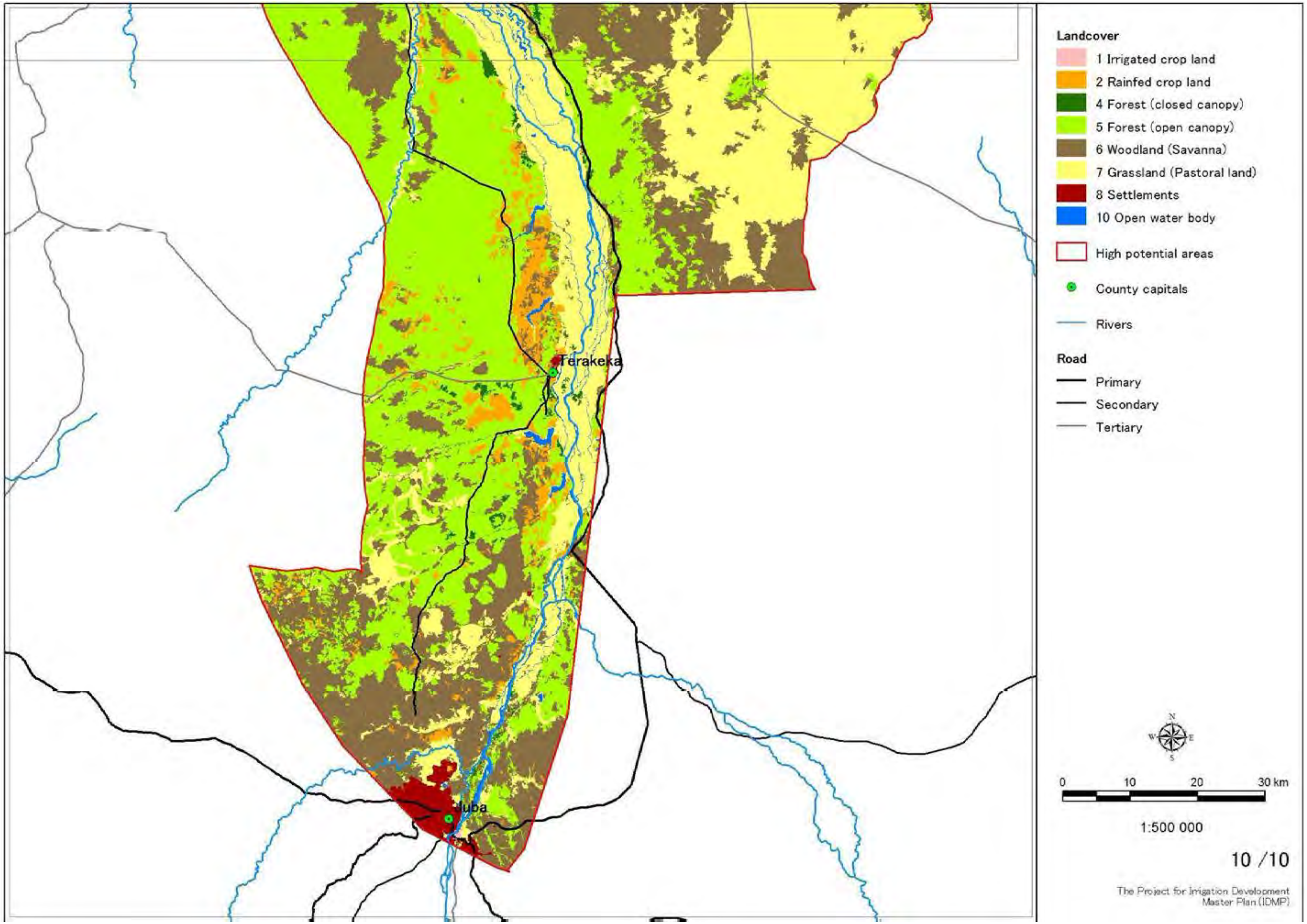
1:500 000
9 /10
The Project for Irrigation Development Master Plan (IDMP)


Landcover
1 Irrigated crop land
2 Rainfed crop land
4 Forest (closed canopy)
5 Forest (open canopy)
6 Woodland (Savanna)
7 Grassland (Pastoral land)
8 Settlements
10 Open water body
High potential areas
County capitals
Rivers
Road
Primary
Secondary
Tertiary
Terakeka
Juba
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30 km
1:500 000
10 /10
The Project for Irrigation Development Master Plan (IDMP)

APPENDIX - 4

SELECTION OF PRIORITY PROJECT AREAS
(SCORING OF CANDIDATE AREAS)

South Priority Area

Priority Area						South	South	South	South	South	South	South
No.						S-0	S-1	S-1'	S-2	S-2'	S-3	S-3'
Name of Candidate Area						Rejaf-East	Jebel Lado	Mongalla	Terekeka-South	Tali	Terekeka-North	Mingkaman
Score	1. Technical	(1) Water Availability	Perennial river		5	5	5	5	5	5	5	5
			Seasonal River*1	Jur	4							
				Yei	3							
				Naam, Tonj	2							
				Gel	1							
				Gulmam	0							
		(2) Main Land Cover*2	Irrigated Crop Land		5	5	3	1	3	4	4	3
			Consolidated Rainfed Crop Land		4							
			Fragmented Rainfed Crop		3							
			Grass Land & Woodland		1							
			Others		0							
		(3) Irrigable size	More than 50 Feddan		5	5	5	5	5	5	5	5
			Less than 50 Feddan		0							
	2. Socio Economic	(1) Physical accessibility	Road	0 - 10 km	4	4	4	4	4	4	4	4
				More than 10 km	2							
			County Capital*3	0 - 5 km	2	2	3	3	4	4	2	3
				5 - 10 km	4							
				More than 10 km	3							
			Water point	0 - 10 km	4	4	4	4	4	4	4	4
				More than 10 km	2							
		(2) Schemes with national Impact (Food security, income generation etc)	High		5	3	5	5	3	3	3	3
			Moderate		3							
			Low		2							
		(3) Conflict records over land use	Yes		0	4	4	4	4	4	4	4
			No		4							
	3. Government Plan	(1) Proposed/Agreed schemes by RSS Gov (National, State, County)	Yes		4	4	4	4	0	0	0	0
			No		0							
		(2) Previously proposed schemes by Sudan MP, IGAD, NBI etc	Yes		2	2	2	2	0	0	0	0
			No		0							
	Total Score					**32**	**39**	**37**	**32**	**33**	**31**	**31**
Rank in Each Priority Area						**5**	**1**	**2**	**5**	**4**	**7**	**7**

*1: Score is ranked based on annual discharge volume

*2: Rainfed Crop Land, Consolidated and Fragmented are judged based on the Land Cover Map.

*3: Since there has possibility to be occupied by residential area in future and become difficult to be farm lands, score of 0- 5km is lower than 5 - 10km .

Priority Area						South	South	South	South
No.						S-4	S-5	S-6	S-7
Name of Candidate Area						Bor-East	Bor-North	Twic-East	Wangule
Score	1. Technical	(1) Water Availability	Perennial river		5	5	5	5	5
			Seasonal River*1	Jur	4				
				Yei	3				
				Naam, Tonj	2				
				Gel	1				
				Gulmam	0				
		(2) Main Land Cover*2	Irrigated Crop Land		5	4	4	4	4
			Consolidated Rainfed Crop Land		4				
			Fragmented Rainfed Crop		3				
			Grass Land & Woodland		1				
			Others		0				
		(3) Irrigable size	More than 50 Feddan		5	5	5	5	5
			Less than 50 Feddan		0				
	2. Socio Economic	(1) Physical accessibility	Road	0 - 10 km	4	4	4	4	4
				More than 10 km	2				
			County Capital*3	0 - 5 km	2	4	2	3	3
				5 - 10 km	4				
				More than 10 km	3				
			Water point	0 - 10 km	4	2	4	4	2
				More than 10 km	2				
		(2) Schemes with national Impact (Food security, income generation etc)	High		5	3	3	3	3
			Moderate		3				
			Low		2				
		(3) Conflict records over land use	Yes		0	4	4	4	4
			No		4				
	3. Government Plan	(1) Proposed/Agreed schemes by RSS Gov (National, State, County)	Yes		4	0	0	4	0
			No		0				
		(2) Previously proposed schemes by Sudan MP, IGAD, NBI etc	Yes		2	0	0	0	0
			No		0				
	Total Score					**31**	**31**	**36**	**30**
Rank in Each Priority Area						**7**	**7**	**3**	**11**

*1: Score is ranked based on annual discharge volume

*2: Rainfed Crop Land, Consolidated and Fragmented are judged based on the Land Cover Map.

*3: Since there has possibility to be occupied by residential area in future and become difficult to be farm lands, score of 0- 5km is lower than 5 - 10km .

North Priority Area

Priority Area						North	North	North	North	North	North	North
No.						N-1	N-2	N-3	N-4	N-5	N-6	N-7
Name of Candidate Area						Renk-North	Renk-South-1	Manyo-North	Manyo-South	Manyo-West	Renk-South-2	Jelhak
Score	1. Technical	(1) Water Availability	Perennial river		5	5	5	5	5	5	5	5
			Seasonal River*1	Jur	4							
				Yei	3							
				Naam, Tonj	2							
				Gel	1							
				Gulmam	0							
		(2) Main Land Cover*2	Irrigated Crop Land		5	5	5	5	5	4	4	3
			Consolidated Rainfed Crop Land		4							
			Fragmented Rainfed Crop		3							
			Grass Land & Woodland		1							
			Others		0							
		(3) Irrigable size	More than 50 Feddan		5	5	5	5	5	5	5	5
			Less than 50 Feddan		0							
	2. Socio Economic	(1) Physical accessibility	Road	0 - 10 km	4	4	4	4	4	2	4	4
				More than 10 km	2							
			County Capital*3	0 - 5 km	2	2	2	2	2	3	3	3
				5 - 10 km	4							
				More than 10 km	3							
			Water point	0 - 10 km	4	4	4	4	4	2	4	4
				More than 10 km	2							
		(2) Schemes with national Impact (Food security, income generation etc)	High		5	5	5	5	5	3	3	3
			Moderate		3							
			Low		2							
		(3) Conflict records over land use	Yes		0	4	4	4	4	4	4	4
			No		4							
	3. Government Plan	(1) Proposed/Agreed schemes by RSS Gov (National, State, County)	Yes		4	4	4	4	4	0	0	4
			No		0							
		(2) Previously proposed schemes by Sudan MP, IGAD, NBI etc	Yes		2	2	2	2	2	0	0	2
			No		0							
	Total Score					**40**	**40**	**40**	**40**	**28**	**32**	**37**
Rank in Each Priority Area						**1**	**1**	**1**	**1**	**23**	**8**	**7**

*1: Score is ranked based on annual discharge volume

*2: Rainfed Crop Land, Consolidated and Fragmented are judged based on the Land Cover Map.

*3: Since there has possibility to be occupied by residential area in future and become difficult to be farm lands, score of 0- 5km is lower than 5 - 10km .

Priority Area						North	North	North	North	North	North	North
No.						N-8	N-9	N-10	N-11	N-12	N-13	N-14
Name of Candidate Area						Melut	Kaka-1	Kaka-2	Jelhak-South	Fashada	Akoka	Makal
Score	1. Technical	(1) Water Availability	Perennial river		5	5	5	5	5	5	5	5
			Seasonal River*1	Jur	4							
				Yei	3							
				Naam, Tonj	2							
				Gel	1							
				Gulmam	0							
		(2) Main Land Cover*2	Irrigated Crop Land		5	5	3	3	3	3	4	4
			Consolidated Rainfed Crop Land		4							
			Fragmented Rainfed Crop		3							
			Grass Land & Woodland		1							
			Others		0							
		(3) Irrigable size	More than 50 Feddan		5	5	5	5	5	5	5	5
			Less than 50 Feddan		0							
	2. Socio Economic	(1) Physical accessibility	Road	0 - 10 km	4	4	2	4	4	4	4	2
				More than 10 km	2							
			County Capital*3	0 - 5 km	2	2	3	3	3	2	3	3
				5 - 10 km	4							
				More than 10 km	3							
			Water point	0 - 10 km	4	4	2	4	4	4	2	2
				More than 10 km	2							
		(2) Schemes with national Impact (Food security, income generation etc)	High		5	5	3	3	3	3	3	3
			Moderate		3							
			Low		2							
		(3) Conflict records over land use	Yes		0	4	4	4	4	4	4	4
			No		4							
	3. Government Plan	(1) Proposed/Agreed schemes by RSS Gov (National, State, County)	Yes		4	4	0	0	0	0	0	0
			No		0							
		(2) Previously proposed schemes by Sudan MP, IGAD, NBI etc	Yes		2	2	0	0	0	0	0	0
			No		0							
	Total Score					**40**	**27**	**31**	**31**	**30**	**30**	**28**
Rank in Each Priority Area						**1**	**25**	**14**	**14**	**21**	**21**	**23**

*1: Score is ranked based on annual discharge volume

*2: Rainfed Crop Land, Consolidated and Fragmented are judged based on the Land Cover Map.

*3: Since there has possibility to be occupied by residential area in future and become difficult to be farm lands, score of 0- 5km is lower than 5 - 10km .

Priority Area						North	North	North	North	North	North	North
No.						N-15	N-16	N-17	N-18	N-19	N-20	N-21
Name of Candidate Area						Panyidway	Nakdeir	Baliet	Abong	Adong	Galacial	Doma
Score	1. Technical	(1) Water Availability	Perennial river		5	5	5	5	5	5	5	5
			Seasonal River*1	Jur	4							
				Yei	3							
				Naam, Tonj	2							
				Gel	1							
				Gulmam	0							
		(2) Main Land Cover*2	Irrigated Crop Land		5	4	4	4	4	3	4	3
			Consolidated Rainfed Crop Land		4							
			Fragmented Rainfed Crop		3							
			Grass Land & Woodland		1							
			Others		0							
		(3) Irrigable size	More than 50 Feddan		5	5	5	5	5	5	5	5
			Less than 50 Feddan		0							
	2. Socio Economic	(1) Physical accessibility	Road	0 - 10 km	4	4	4	4	4	4	4	4
				More than 10 km	2							
			County Capital*3	0 - 5 km	2	3	3	3	3	3	3	3
				5 - 10 km	4							
				More than 10 km	3							
			Water point	0 - 10 km	4	4	4	4	4	4	4	4
				More than 10 km	2							
		(2) Schemes with national Impact (Food security, income generation etc)	High		5	3	3	3	3	3	3	3
			Moderate		3							
			Low		2							
		(3) Conflict records over land use	Yes		0	4	4	4	4	4	4	4
			No		4							
	3. Government Plan	(1) Proposed/Agreed schemes by RSS Gov (National, State, County)	Yes		4	0	0	0	0	0	0	0
			No		0							
		(2) Previously proposed schemes by Sudan MP, IGAD, NBI etc	Yes		2	0	0	0	0	0	0	0
			No		0							
	Total Score					**32**	**32**	**32**	**32**	**31**	**32**	**31**
Rank in Each Priority Area						**8**	**8**	**8**	**8**	**14**	**8**	**14**

*1: Score is ranked based on annual discharge volume

*2: Rainfed Crop Land, Consolidated and Fragmented are judged based on the Land Cover Map.

*3: Since there has possibility to be occupied by residential area in future and become difficult to be farm lands, score of 0- 5km is lower than 5 - 10km .

Priority Area						North	North	North	North
No.						N-22	N-23	N-24	N-25
Name of Candidate Area						Ulong	Nasir-East	Nasir-West	Mohamad Ajak
Score	1. Technical	(1) Water Availability	Perennial river		5	5	5	5	5
			Seasonal River[*1]	Jur	4				
				Yei	3				
				Naam, Tonj	2				
				Gel	1				
				Gulmam	0				
		(2) Main Land Cover[*2]	Irrigated Crop Land		5	4	4	4	4
			Consolidated Rainfed Crop Land		4				
			Fragmented Rainfed Crop		3				
			Grass Land & Woodland		1				
			Others		0				
		(3) Irrigable size	More than 50 Feddan		5	5	5	5	5
			Less than 50 Feddan		0				
	2. Socio Economic	(1) Physical accessibility	Road	0 - 10 km	4	4	4	4	4
				More than 10 km	2				
			County Capital[*3]	0 - 5 km	2	2	2	2	2
				5 - 10 km	4				
				More than 10 km	3				
			Water point	0 - 10 km	4	4	4	4	4
				More than 10 km	2				
		(2) Schemes with national Impact (Food security, income generation etc)	High		5	3	3	3	5
			Moderate		3				
			Low		2				
		(3) Conflict records over land use	Yes		0	4	4	4	4
			No		4				
	3. Government Plan	(1) Proposed/Agreed schemes by RSS Gov (National, State, County)	Yes		4	0	0	0	4
			No		0				
		(2) Previously proposed schemes by Sudan MP, IGAD, NBI etc	Yes		2	0	0	0	2
			No		0				
	Total Score					**31**	**31**	**31**	**39**
Rank in Each Priority Area						**14**	**14**	**14**	**6**

*1: Score is ranked based on annual discharge volume

*2: Rainfed Crop Land, Consolidated and Fragmented are judged based on the Land Cover Map.

*3: Since there has possibility to be occupied by residential area in future and become difficult to be farm lands, score of 0- 5km is lower than 5 - 10km .

South-West Priority Area

Priority Area						South-West	South-West	South-West	South-West	South-West	South-West	South-West
No.						SW-1	SW-2	SW-3	SW-4	SW-5	SW-6	SW-7
Name of Candidate Area						Ngop	Payii	Aduel	Pacung	Malekajok	Cueibet-East	Cueibet-West
Score	1. Technical	(1) Water Availability	Perennial river		5	3	3	2	2	2	1	1
			Seasonal River[*1]	Jur	4							
				Yei	3							
				Naam, Tonj	2							
				Gel	1							
				Gulmam	0							
		(2) Main Land Cover[*2]	Irrigated Crop Land		5	4	3	4	4	4	4	3
			Consolidated Rainfed Crop Land		4							
			Fragmented Rainfed Crop		3							
			Grass Land & Woodland		1							
			Others		0							
		(3) Irrigable size	More than 50 Feddan		5	5	5	5	5	5	5	5
			Less than 50 Feddan		0							
	2. Socio Economic	(1) Physical accessibility	Road	0 - 10 km	4	2	4	4	4	4	4	4
				More than 10 km	2							
			County Capital[*3]	0 - 5 km	2	3	3	2	3	3	2	3
				5 - 10 km	4							
				More than 10 km	3							
			Water point	0 - 10 km	4	4	4	4	4	2	4	4
				More than 10 km	2							
		(2) Schemes with national Impact (Food security, income generation etc)	High		5	3	3	3	5	3	3	3
			Moderate		3							
			Low		2							
		(3) Conflict records over land use	Yes		0	4	4	4	4	4	4	4
			No		4							
	3. Government Plan	(1) Proposed/Agreed schemes by RSS Gov (National, State, County)	Yes		4	0	0	0	0	0	0	0
			No		0							
		(2) Previously proposed schemes by Sudan MP, IGAD, NBI etc	Yes		2	0	0	0	0	0	0	0
			No		0							
	Total Score					**28**	**29**	**28**	**31**	**27**	**27**	**27**
Rank in Each Priority Area						**4**	**2**	**4**	**1**	**8**	**8**	**8**

*1: Score is ranked based on annual discharge volume
*2: Rainfed Crop Land, Consolidated and Fragmented are judged based on the Land Cover Map.
*3: Since there has possibility to be occupied by residential area in future and become difficult to be farm lands, score of 0- 5km is lower than 5 - 10km .

Priority Area						South-West	South-West	South-West	South-West	South-West
No.						SW-8	SW-9	SW-10	SW-11	SW-12
Name of Candidate Area						Tonj-South	Tonj-North	Aconjeong-North	Toc	Cueibet-North
Score	1. Technical	(1) Water Availability	Perennial river		5	2	2	4	2	1
			Seasonal River*1	Jur	4					
				Yei	3					
				Naam, Tonj	2					
				Gel	1					
				Gulmam	0					
		(2) Main Land Cover*2	Irrigated Crop Land		5	3	3	3	3	3
			Consolidated Rainfed Crop Land		4					
			Fragmented Rainfed Crop		3					
			Grass Land & Woodland		1					
			Others		0					
		(3) Irrigable size	More than 50 Feddan		5	5	5	5	5	5
			Less than 50 Feddan		0					
	2. Socio Economic	(1) Physical accessibility	Road	0 - 10 km	4	4	4	2	4	2
				More than 10 km	2					
			County Capital*3	0 - 5 km	2	2	3	4	3	3
				5 - 10 km	4					
				More than 10 km	3					
			Water point	0 - 10 km	4	4	4	4	4	4
				More than 10 km	2					
		(2) Schemes with national Impact (Food security, income generation etc)	High		5	3	3	3	3	3
			Moderate		3					
			Low		2					
		(3) Conflict records over land use	Yes		0	4	4	4	4	4
			No		4					
	3. Government Plan	(1) Proposed/Agreed schemes by RSS Gov (National, State, County)	Yes		4	0	0	0	0	0
			No		0					
		(2) Previously proposed schemes by Sudan MP, IGAD, NBI etc	Yes		2	0	0	0	0	0
			No		0					
	Total Score					**27**	**28**	**29**	**28**	**25**
Rank in Each Priority Area						**8**	**4**	**2**	**4**	**12**

*1: Score is ranked based on annual discharge volume

*2: Rainfed Crop Land, Consolidated and Fragmented are judged based on the Land Cover Map.

*3: Since there has possibility to be occupied by residential area in future and become difficult to be farm lands, score of 0- 5km is lower than 5 - 10km .