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SOIL AND WATER CHARACTERIZATION IN THE SELECTED SITES OF SOUTH SUDAN

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REHABILITATION AND MANAGEMENT OF SALT-AFFECTED SOILS TO IMPROVE AGRICULTURAL PRODUCTIVITY (RAMSAP) IN ETHIOPIA AND SOUTH SUDAN

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Rehabilitation and management of salt-affected soils to improve agricultural productivity in Ethiopia and South Sudan

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This study has been possible with the generous financial support of the International Fund for Agricultural Development (IFAD) within the ICBA-led project on "Rehabilitation and management of salt-affected soils to improve agricultural productivity (RAMSAP)" in Ethiopia and South Sudan (Grant No. 2000001100). This publication is the result of a comprehensive soil and water quality survey of nine selected areas in South Sudan to estimate the extent of saline lands and their impact on the livelihood of farming communities, as well as identification of limitations and constraints in the adoption of innovative technologies and approaches for improving agricultural productivity in the target areas of South Sudan. This project report series documents the ongoing work of the RAMSAP project in Ethiopia and South Sudan.

This project is led by the International Center for Biosaline Agriculture (ICBA), Dubai, and is being implemented with the collaboration of the Ministry of Agriculture, Ethiopia; Ethiopian Agricultural Research Institute (EIAR) and Directorate of Research and Training (DRT), South Sudan. The authors are highly grateful to Dr. Tarifa A. Alzaabi, Acting Director-General-ICBA, for her overall leadership and Ms. Seta Tutundjian, Director of Programs-ICBA, for her guidance during the execution of this project. We are thankful to H.E. Dr. Kaba Urgessa, State Minister of Agriculture, Ethiopia, Mr. Tefera Solomon, Director of Soil Fertility, Ministry of Agriculture, Ethiopia, and Dr. Victor Bennet, Director General, DRT-South-Sudan for their continued support during the implementation of this project. The hard work and dedication of the research and field staff in South Sudan is highly appreciated.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Agriculture is the backbone of the economy of South Sudan, like many other Sub-Saharan African countries. In South Sudan, agriculture accounts for 36% of the non-oil GDP, with 80% of the population living in rural areas largely dependent on subsistence farming and 75% of the households consuming cereals as a central part of their daily diet. Despite abundant water supplies, only 5% of the total 30 million ha arable land is cultivated. Crop yields are meager, which negatively affects the incomes and livelihood of poor farmers. Significant barriers are lack of agricultural inputs such as seed and fertilizer, poor advisory services, and inefficient irrigation management. The salt-affected lands in South Sudan are in the White Nile irrigation schemes. The agricultural potential of these areas has hardly been utilized despite having freshwater availability from the Nile River. Therefore, bringing back degraded lands into acceptable production levels is essential to ensure food security and social stability in South Sudan.

To address the massive land degradation and low agricultural productivity challenges, the International Center for Biosaline Agriculture (ICBA), with the financial assistance of the International Fund for Agricultural Development (IFAD), launched a project, “Rehabilitation and Management of Salt-Affected Soils to Improve Agricultural Productivity (RAMSAP)” in Ethiopia and South Sudan. This project was intended to investigate the extent of the problem and develop strategies to rehabilitate and manage salt-affected lands through improved soil, water, and crop management practices.

During 2018, large-scale investigations were started for qualitative and quantitative analysis of the selected areas in different parts of the country. A total of 375 composite samples were collected from the nine regions targeted at three different depths, i.e., 0-30, 30-60, and 60-90 cm. The soil samples were analyzed in Uganda due to the lack of analytical facilities in South Sudan. The results of soil sample analysis were used to generate GIS maps. The results show that soil texture at these locations is mainly silt loam (SL), silty clay loam (SCL), and clay loam (Cl). The average profile salinity values at all depths are low. However, due to the presence of clay, they have workability and permeability problems causing low crop production. The Ca, Mg, and Na values are low, reducing any chances of sodicity in these soils.

This study used remote sensing and GIS approaches to collect and process the soil quality data to develop spatial distribution maps of the target areas. The RAMSAP project field team did field measurements to validate the results achieved using remote sensing data for the nine target areas. The results of this study were compared with the FAO soil data. It was found that there is a close relationship between the FAO soil data and the RAMSAP soil work (R2 = 76.6).

The land use and land cover map of South Sudan show that the biggest cropland is in Renk (42.9%), followed by Kapoeta (7.9%), Bor (3.9%), Torit (3.1%), Aweil (2.6%), Wau (0.8%) and Yambio (0.2%). However, there is a high potential to transform shrub and grasslands into farmlands if land transformation policy is implemented correctly. The results revealed that most areas could be brought under cultivation by providing irrigation water and training farmers on improved on-farm water management strategies. It is anticipated that the results of this study will help decision-makers to make timely policy decisions.

01

BACKGROUND

South Sudan is in East Africa, covering an area of 640,000 km2. Geographically, the country expands on the clay plains that extend southward with gradual uphill slopes to the mountains on the Sudan frontier with Ethiopia, Kenya, and Uganda. The water divide represents the southern boundary with Democratic Republic of Congo Central African Republic. It also expands from the borders with the Central African Republic in the west, passing through the lowlands of the White Nile Valley and the Sudd wetland to the Ethiopian highlands in the east. Most of the country has a sub-humid climate. The western Equatoria and highland parts of Eastern Equatorial receive 1,200 to 2,200 mm of rainfall annually. The lowland areas of Eastern Equatoria, Jonglei, Upper Nile, and Bahr El Ghazal receive 700 and 1,300 mm of rain annually.

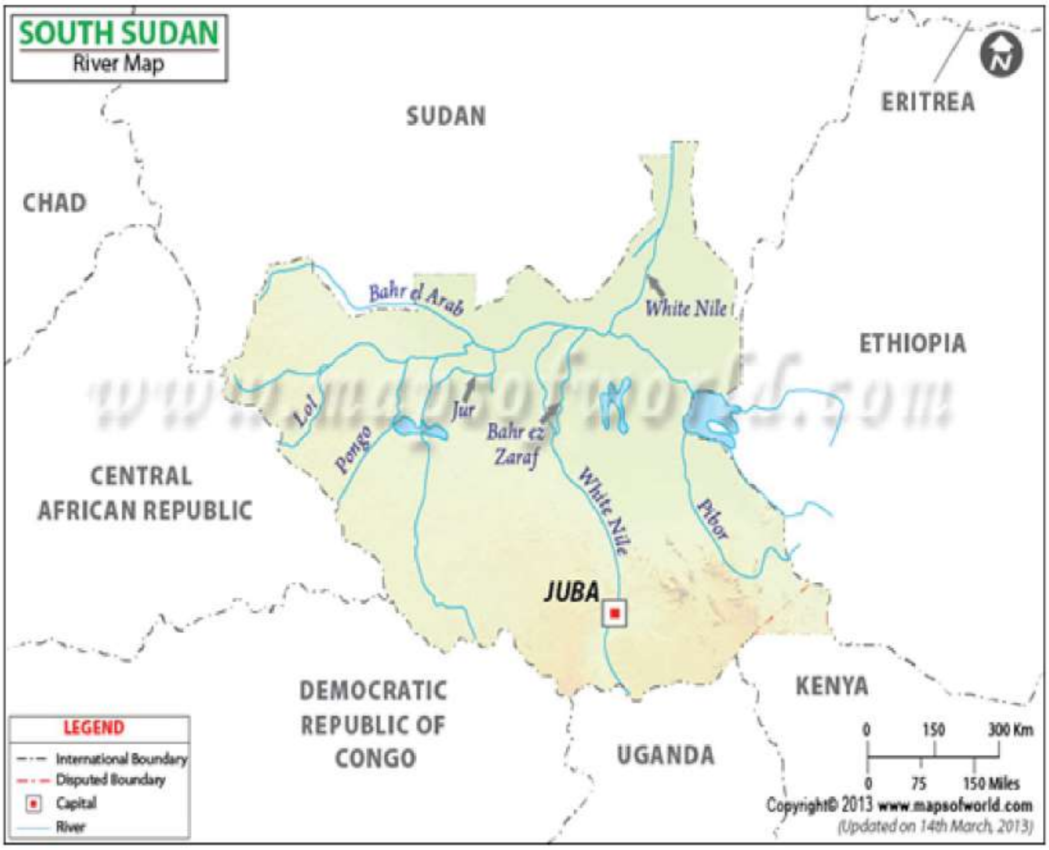


Figure 1. Map of South Sudan with main water supplying rivers.

1.1 Surface water and groundwater resources

South Sudan is rich in water resources. The primary water resources are the Nile, its tributaries, and groundwater. The lowlands of the White Nile Valley have great potential for irrigation due to the availability of fresh water from the Nile River but have hardly been utilized for agricultural production. Groundwater is found in the Um Ruwaba, Nubian, and basement complex formations. However, some reports of punctual salinity problems in the groundwater around Malakal and some isolated villages. The Blue Nile and its tributaries flow down from the highlands of Ethiopia. In contrast, the White Nile and its tributaries flow from Uganda and the Central African Republic into the low clay basin to form the world's largest contiguous swamp on their way to Sudan and Egypt (The Sudd Region).

The annual rainfall pattern is zone-dependent ranging from 500-2000 mm, which provides 130-300 days growing season. The temperatures are too variable and typically above 25°C, and 35°C, during the dry months: January to April. The dry, hot conditions trigger human and livestock migrations to more permanent water sources, which serve as dry season grazing and fishing areas. South-Sudan vegetation belts run in succession from northwest to southeast, mostly in coincidence with rainfall patterns. They are low-rainfall savanna (grassland), high-rainfall savanna, both with inland oodplains, and mountain vegetation regions Savanna vegetation during the rainy season. Low-rainfall savannas consist of grasses and thorny trees. Acacia trees dominate these savannas, with one species, A. Senegal, yielding gum Arabic, one of Sudan's principal exports for a long time. The high-rainfall savannas of the south-central part of the country are lusher, with rich grasses along the Nile that support a large cattle population. The intermittent woodlands dotting this belt merge southward with the actual rainforest found only in remnants in the southernmost portions of the country.

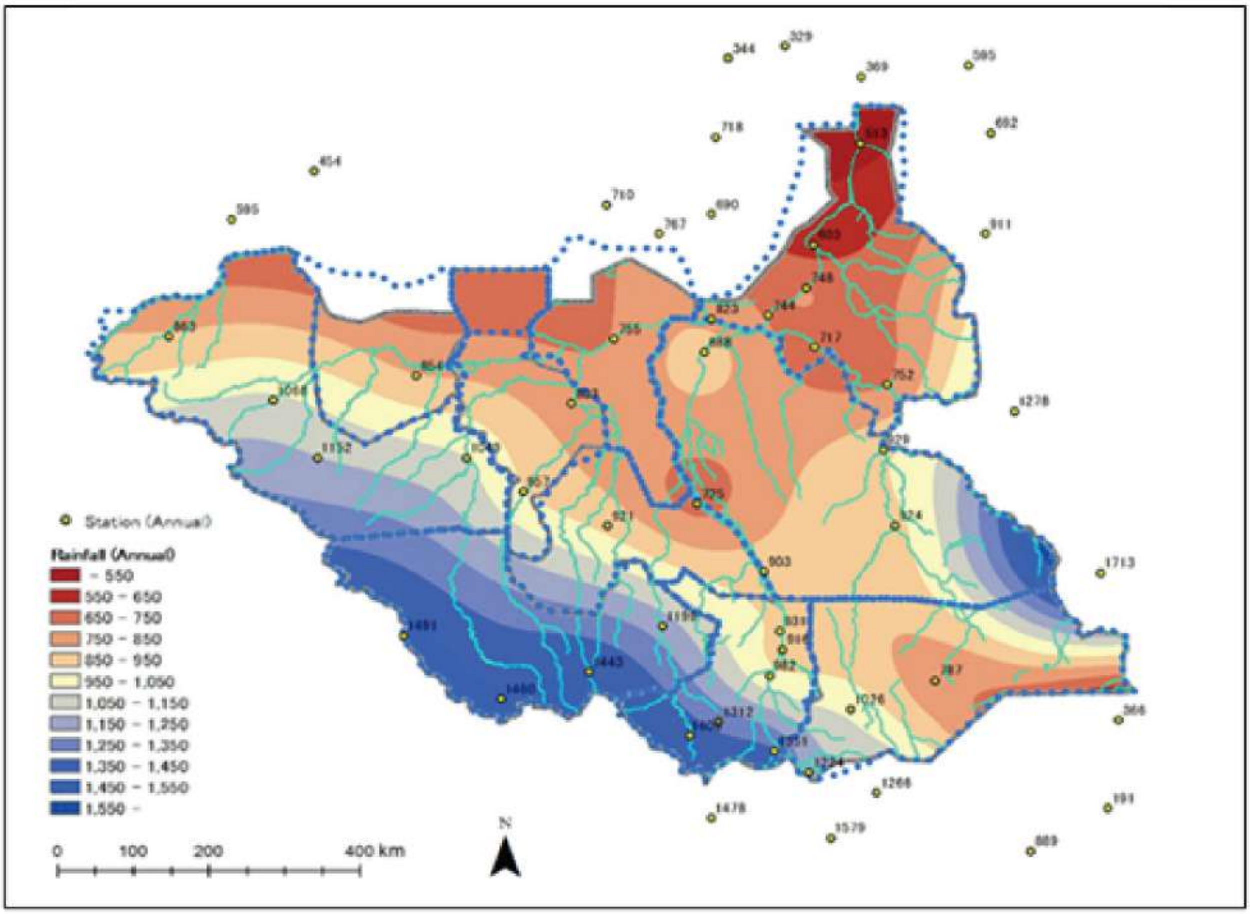
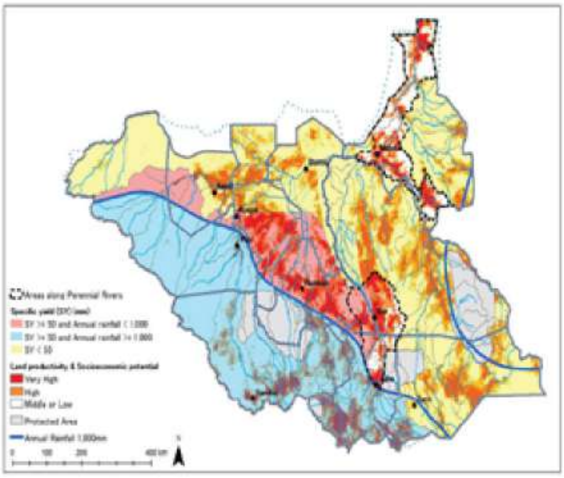


Figure 2. Rainfall contour map of South Sudan.

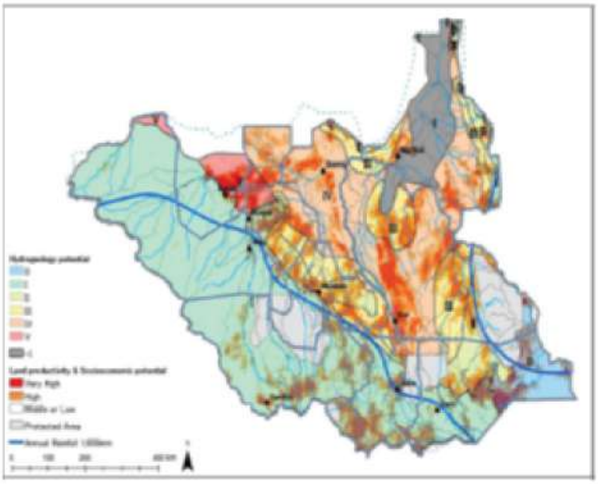
The primary water resources of South Sudan are the Nile, its tributaries, and groundwater. The lowlands of the White Nile Valley have great potential for irrigation due to the availability of fresh water from the Nile River but have hardly been utilized for agricultural production. Groundwater is found in the Um Ruwaba, Nubian, and basement complex formations. However, salinity problems in the groundwater around Malakal and some isolated villages have been reported (WB, 2011). The Blue Nile and its tributaries ow down from the highlands of Ethiopia. In contrast, the White Nile and its tributaries ow from Uganda and the Central African Republic into the low clay basin to form the world's largest contiguous swamp on their way to Sudan and Egypt (The Sudd Region).

Despite rich water resources, only 5% of the total area is irrigated due to a lack of irrigation infrastructure. Irrigation is mainly done using surface irrigation methods, and irrigation efficiencies are as low as 30-35%. There is a great potential to increase irrigated areas if the proper irrigation infrastructure is provided. The primary reasons for low land and water productivities are described as follows:

1. Poor agronomic and irrigation practices resulting in land degradation.
2. Costly land reclamation.
3. Deforestation because of logging and charcoal burning.
4. Overgrazing and bush burning.
5. Lack of adequate quality seeds and improved farm technologies, etc.
6. Climate variability e.g., rampant oods and drought.
7. Lack of infrastructure/equipped central soil and water laboratory.



Irrigation potential with surface water resources



Irrigation potential with groundwater resources

Figure 3. Irrigation potential with surface water and groundwater resources.

1.2 Agriculture

In South Sudan, about 95% of the land is suitable for agriculture, out of which 50% has high production potential. The country has the highest per capita livestock population in Africa. The livestock sector accounts for 15% of the total GDP. Forest cover is about 30% of the entire area. The fertile lands are suitable to grow all sorts of crops. However, land productivity is generally low due to a lack of agricultural inputs such as seeds, fertilizer, pesticides, agricultural machinery, and higher labor costs. Farmers use traditional seed and grain storage methods, which increases post-harvest losses and results in poor seed quality. The timely availability of labor at reasonable prices is another major issue limiting crop production. Energy for cooking is one of the most challenging things for farmers. The use of animal waste (Cow dung) to produce biogas needs to be encouraged to reduce the negative impact of deforestation. This will contribute to waste management and create a healthy and disease-free environment.



1.3 Challenges faced by agriculture in South-Sudan

In South Sudan, agriculture accounts for 36% of the non-oil GDP, with 80% of the population living in rural areas dependent on subsistence farming and 75% of the households consuming cereals as a central part of their daily diet. Despite abundant water supplies, only 5% of the total 30 million ha arable land is cultivated. Crop yields are generally low, which negatively affects the incomes and livelihood of farmers. Lack of inputs such as seed and fertilizer, poor advisory services, and inefficient irrigation management are significant barriers. Although South Sudan has the highest livestock per capita globally, with 23 million head of cattle, sheep, and goats, there is little use of improved varieties of seed or breeds of livestock. There is a strong need for salt-tolerant forage varieties to improve livestock productivity. The salt-affected lands are in the White Nile irrigation schemes. The agricultural potential of these areas has hardly been utilized despite having freshwater availability from the Nile River. Furthermore, poor groundwater quality around Malakal and isolated regions also cause salinity.

The land holdings in South Sudan are generally small, and not all land is cultivated simultaneously due to a shortage of water and other agricultural inputs. The baseline survey conducted by ICBA shows that 70% of the farmers have less than one ha of land, whereas 16% own less than 3 ha and 14% have more than 4 ha of land. Figure 4 shows that 42% of farmers grow vegetables and 28% legume crops to meet their household needs and earn little money by selling the excess produce in local markets. Cereals and oil crops are grown by 17.5% and 12.5% of farmers, respectively. Other crops are grown in small quantities and include groundnuts, vegetables, and cassava.

The average crop productivities in South Sudan are consistently low. The significant challenges perceived by farmers include poor land leveling of fields, lack of irrigation management, less irrigation time, loss of land due to salinity, and low water use efficiency due to seepage and runoff losses. Lack of agricultural inputs such as improved seed, fertilizer, farm machinery, shortage of arable land, lack of technical knowledge, shortage of irrigation water, and increasing salinity are the significant constraints for low productivity. The non-availability of pesticides results in the expansion of invasive weeds.

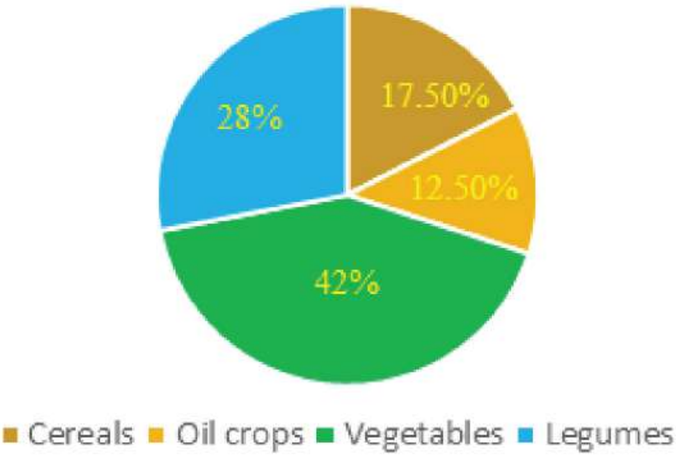


Figure 4. Commonly grown crops in South Sudan.

The results of the baseline survey conducted by ICBA reveal that 38% of farmers consider lack of irrigation equipment as the major challenge for improving crop production followed by less irrigation time (27%), low water use efficiency (18%), poor land leveling (12%) and salinity problems (5%) (Figure 5). For the leveling of their fields, farmers must hire the services of companies as they do not have the skills and equipment to do it themselves. This makes this task difficult for them. Low water use efficiency is mainly caused by excessive seepage and surface runoff due to the use of the ooding method of irrigation. Salinity problems are not widespread in the study areas except in the Bore district.

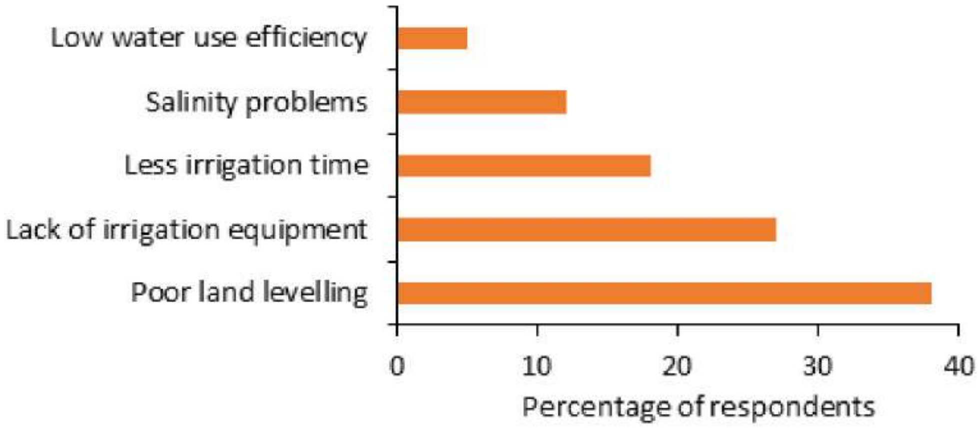


Figure 5. Challenges of low crop productivity as perceived by farmers.

In South Sudan, farmers hire annual labor for land preparation, planting, weeding, and harvesting purposes. The cost of hiring labor ranges from 200-1000ssp per day (IUS$ = 130 ssp). Meanwhile, the daily income from the sale of their farm products ranges from 1500-5000ssp per day. This shows that farmers earn a good income from irrigation farming to cover these costs. However, income levels are low without irrigation, and it becomes hard for them to cover these expenses. Farmers' first preference is to use surface water for irrigation because of its low cost and better quality. However, in the absence of surface water, their ultimate choice is groundwater for irrigation. Some farmers prefer groundwater because of its on-farm availability since surface water is far from their farming site.

02 SELECTED LOCATONS AND DATA COLLECTION

2.1 Site selection

Detailed soil and water analysis were conducted at nine sites in South Sudan. These sites were selected in collaboration with the Ministry of Agriculture and Food Security representatives, local research organizations, and research scientists. The selection criteria were based on geographical, climate, cultural, agricultural variations in different locations in South Sudan. The selected locations are, Awiel, Bor, Kapoeta, Renk, Torit, Wau, Yambio, Rumbek, and Jubek (Figure 6).

These sites were selected based on the following criterion.

- Marginal degraded lands with low due to poor agronomic and water management practices.
- They are characterized by many poor-resourced farm-households, including women and youth, mainly rare cattle and small ruminants.
- Accessibility to the selected sites.
- Availability of local partners and state government staff on ground.
- Shallow water levels and poor groundwater quality in Jonglei (Bor) and Unity (Bentiu) states.
- Overgrazing and deforestation have affected the soil structures of some of these sites.

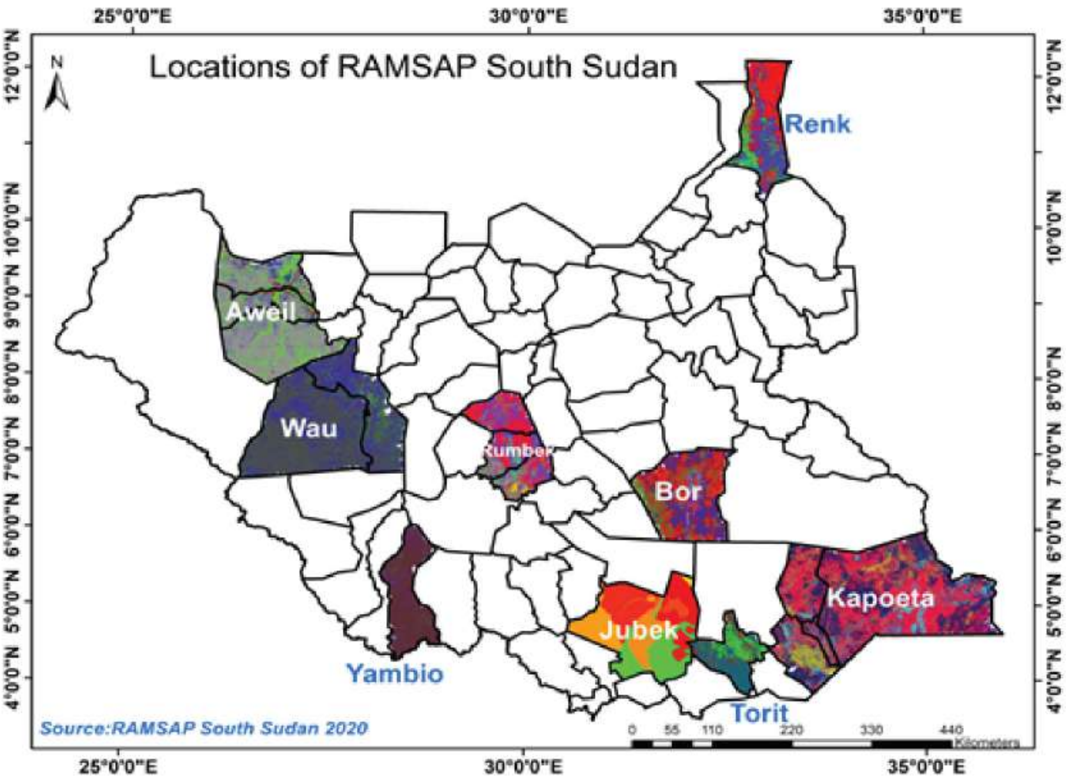


Figure 6. Selected sites for the RAMSAP project in South Sudan.

2.2 Data collection and analysis

Three hundred seventy-five composite auger samples were collected from the nine targeted areas as shown in Figure 6. The samples were marked with the farmer's name and coordinates collected with the help of GPS. The soil samples were collected at three depths, i.e., 0-30, 30-60 and 60-90 cm, and analyzed for PH, EC, Na, Ca, Mg, K, and H. The soil samples were analyzed in Uganda as there was no capacity in South Sudan to tackle this enormous task. Five researchers and field staff were specially trained for the collection of soil and samples. The samples were collected and preserved using standard protocols. The preliminary soil investigations include site observation, variations in Physiography, land use, and visually observable soil features (drainage condition, salt crust at soil surface, soil texture, and others).

The results of soil sample analysis from different locations were used to generate GIS maps. The results show that soil texture at these locations is silt loam (SL), silty clay loam (SCL), and clay loam (Cl). The average profile salinity at all areas (ECe = μS/cm) is shallow at all depths, which shows that these soils are not saline. However, due to the presence of clay, they have workability and permeability problems. The Ca, Mg, and Na values are low, reducing any chances of sodicity in these soils.

The major problem in these soils was low fertility due to the low availability of N, P, K, and organic matter. Lack of access to irrigation water is the most challenging factor for farmers to grow food crops on these soils. Farmers mainly depend on seasonal rain for crop cultivation, which results in severe food shortages during dry seasons. Therefore, establishing alternative water resources such as wells and rainwater harvesting could effectively ensure year-round crop production and arrest food shortages. The lack of healthy and water-efficient crop seeds is another reason for low productivity in these areas. Farmers usually use local seed obtained from the harvesting of their previous crops. These seeds are poorly stored and not disease-free and therefore produce low crop yields. The grown grains are not sufficient for domestic consumption; thus, farmers cannot earn cash to meet other life needs by selling their produce. Consistently lower land productivities in the study areas are causing a reduction in farm incomes, food insecurity, and poverty.

In addition to field measurements, data were also obtained from different sources to perform quantitative and qualitative analyses of soil quality in the selected areas of South Sudan. Data acquired and processing techniques are briefly discussed below:

Land Use and Land Cover (LULC)

The Land Use and Land Cover (LULC) data were obtained from the Climate Change Initiative (CCI) and Land Cover (LC) teams for Africa. It is a high-resolution data at 20 m according to sentinel-2A observations. The data was collected for one year, i.e., December 2015 to December 2016. World Geodetic System 84 (WGS84) reference ellipsoid was the coordinate used. LULC was classified into ten classes (cropland, trees cover areas, grassland, shrubs cover areas, built-up areas, vegetation aquatic or regularly flooded, bare areas, open water, lichen, and mosses/sparse vegetation, and snow and ice) for the study areas. Nine classes were captured except for snow and ice land cover.

Application of Digital Elevation Model (DEM)

The digital elevation model (DEM) was obtained from Shuttle Radar Topography Mission (STRM) which contains elevation data for a given location with high-resolution digital topographical data of 30 m. The model was used to classify slopes to identify appropriate areas of different irrigation systems. STRM provides an improved radar system that coasted onboard the space shuttle endeavor. STRM is managed by National Geospatial-Intelligence Agency (NGA) and NASA at a global level. For data processing, the slope tool in the spatial analyst of ArcGIS 10.7.1 was used to identify the surface slope. Then the study area was categorized based on the resulting ranges of various locations. This helped differentiate the suitable sites from the unsuitable ones within the study area.

Delineation of watersheds

Tt is necessary to delineate the watershed of that area to find the basic properties of hydrological data. Terrain pre-processing was the method applied to delineate the watershed of the targeted sites using DEM with the help of Arc Hydro tools. The output terrain pre-processing was sub-watersheds (representing the optimum collection location), stream network (drainage route from and to each selected area), watershed, and DEM for each watershed.

After identifying the stream network, rainwater collecting points were marked at which a given water flow network is gathered using the ArcGIS tool Editor's construct point. Elevations for each watershed were determined using DEM through using ArcGIS. Elevation differences between sources of each stream and the selected collecting point were calculated for the entire potential areas. Finally, water yield estimation was done with ArcGIS. The total watershed area of each site was multiplied by the average annual precipitation at a given location, which resulted in a total water volume throughout the year.

Analysis of historical precipitation data

Sixty years of precipitation data (1958-2018) of each selected site were processed. The precipitation data was obtained with the help of TEERA high-resolution precipitation maps. It was processed with the use of ArcGIS 10.7.1 through special analysis tools. The TerraClimate is based on the climatically supported interpolation, associating high-spatial-resolution climatological normal driven from the WorldClim dataset with monthly time series coarser resolution data. Data were obtained from the Climate Research Unit

(CRU) and the Japanese 55-year Reanalysis (JRA-55) to generate monthly wind speed values, vapor pressure, precipitation, maximum and minimum temperature, and solar radiation. The spatial-temporal outputs of TerraClimate were validated using data on annual temperature, rain, and estimated reference evapotranspiration from ground stations, in addition to yearly runoff data from flow stream gauges. Their findings revealed that TerraClimate datasets indicated significant improvement in overall temperature and precipitation mean of poor correlations about p= 0.8 and 0.90, respectively. Therefore, the TerraClimate dataset is recommended as inputs for ecological and hydrological research at global levels that need high spatial resolution and time series climate and water balance data.

2.3 Analysis of water samples

Water samples from different sources were collected from several locations in the five target areas. The analysis of water samples shows that the pH and EC values are low in most of the sites (Table 1). This indicates that by improving the farmers' accessibility to water and introducing innovative on-farm water management strategies, agricultural productivity can be significantly enhanced.

Table 1. Results of water samples collected from different locations in five regions.

Region	Locations	pH			EC (µS/cm)		
		Min	Max	Avg.	Min	Max	Avg.
Renk	Awolai stagnant water	6.0	6.1	6.0	10.3	110.7	107.0
	Gozrum stagnant water	6.6	6.8	6.7	99.8	109.9	103.8
	Payuer Tap water	6.8	6.8	6.8	101.2	107.1	103.3
	Payuer stagnant water	7.1	7.7	7.4	100	100.1	100.0
Bor	Panaper borehole 1	8.4	8.5	8.5	192.3	199	195.1
	River Nile	7.6	7.9	7.7	109.9	196.2	167.1
	Tibek borehole	7.1	8.0	7.6	185.0	193.0	190.2
	Panaula 1 borehole	7.3	7.8	7.6	110.1	110.9	110.8
Aweil	B15A	6.7	7.3	7.1	183.5	188.5	186.1
	Rice scheme 1	7.2	7.6	7.4	88.1	99.6	92.5
	Nyalth borehole 1	7.0	7.2	7.1	124.3	127.4	126.1
	Kuom river	7.9	8.2	8.0	110.0	199.9	142.1
Jubek	Kurrola river	7.3	7.5	7.4	103.7	125.5	112.8
	Rajaf East Tokiman borehole	7.3	7.5	7.4	102.0	118.0	110.0
	Rajaf East Mogoro borehole	7.3	7.5	7.4	170.8	181.3	176.1
	Luri river	6.8	6.9	6.8	100.9	109.9	106.9
	Khor William	7.6	7.6	7.6	102.7	110.0	107.5
Kapoeta	Hai Tarawa borehole	7.0	7.3	7.2	183.6	191.4	188.4
	Nalingoro	7.0	7.2	7.1	100.0	110.0	106.3
	Rie North William borehole	7.0	7.5	7.3	103.2	113.5	108.9
	Rie North school borehole	6.9	7.2	7.1	101.1	110.1	105.0
	Palakan Joseph Laguwe borehole	7.1	7.6	7.3	100.1	120.0	109.7
	Morongora borehole	7.1	7.5	7.3	100.0	120.3	107.2
	Napecheke	7.5	7.7	7.6	102.9	110.0	107.6

03 RESULTS OF DATA ANALYSIS

3.1 Aweil filed site

Table 2 shows that trees cover more than 70% of the area, whereas 17.46% is occupied by grassland and 9.39% by shrubs. The area covered by crops is marginal (2.65%). The spatial distribution of vegetation classes is given in Figure 7. Maps related to soil texture, rainwater harvesting, pH, soil salinity, ECP, and surface organic carbon are given from Figures 8-12.

Table 2. Land use and land cover data for Aweil field site.

No.	Vegetation classes	Area (km^2)	Percentage (%)
1	Tree cover areas	14,747	70.30
2	Shrubs cover areas	1969	9.39
3	Grassland	3662	17.46
4	Cropland	555	2.65
5	Vegetation aquatic or regularly flooded	18.0	0.09
6	Lichens Mosses / Sparse vegetation	0.0	0.00
7	Bare and built areas	5.0	0.02
8	Open Water	22.0	0.10
Total Area		**20,978**	**100**

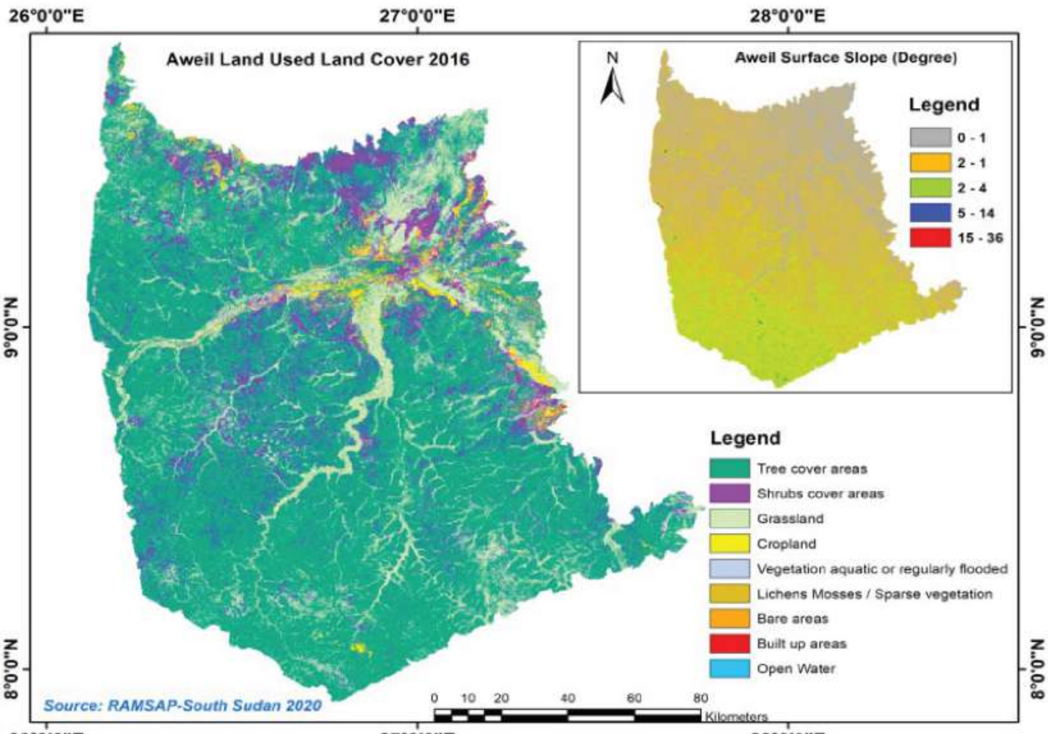


Figure 7. Land use and land cover map for the Aweil field site.

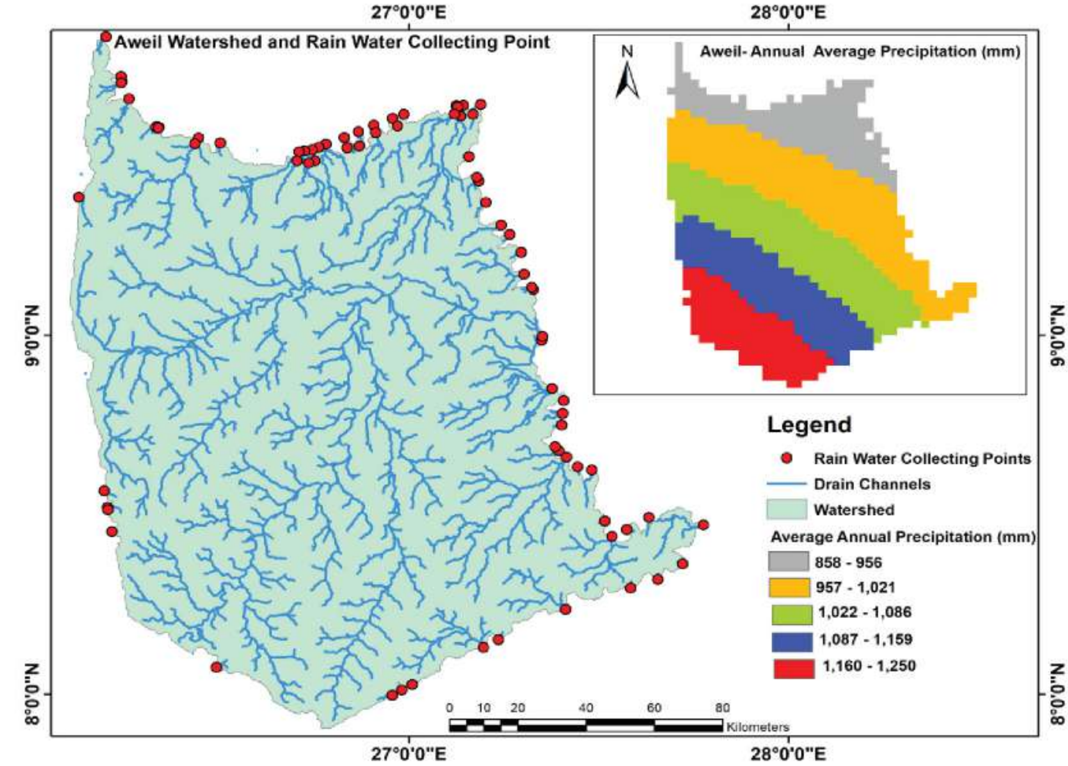


Figure 8. Rainwater harvesting points and surface slopes in Aweil.

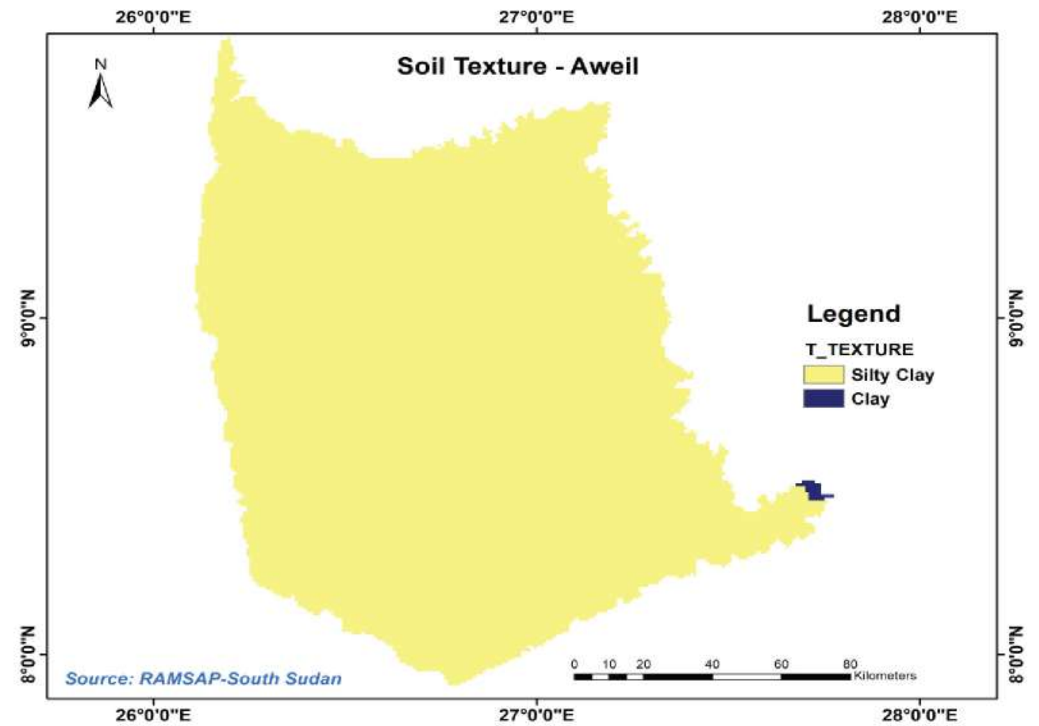


Figure 9. Rainwater harvesting points and surface slopes in Aweil.

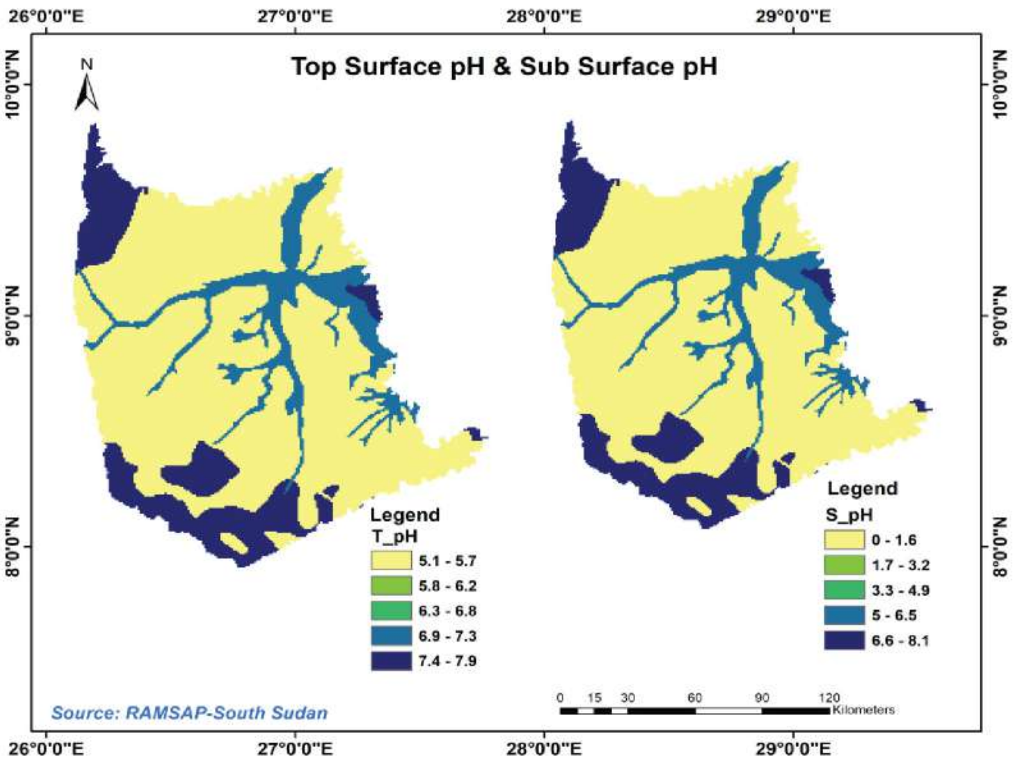


Figure 10. pH of surface and sub surface soil in Aweil field site.

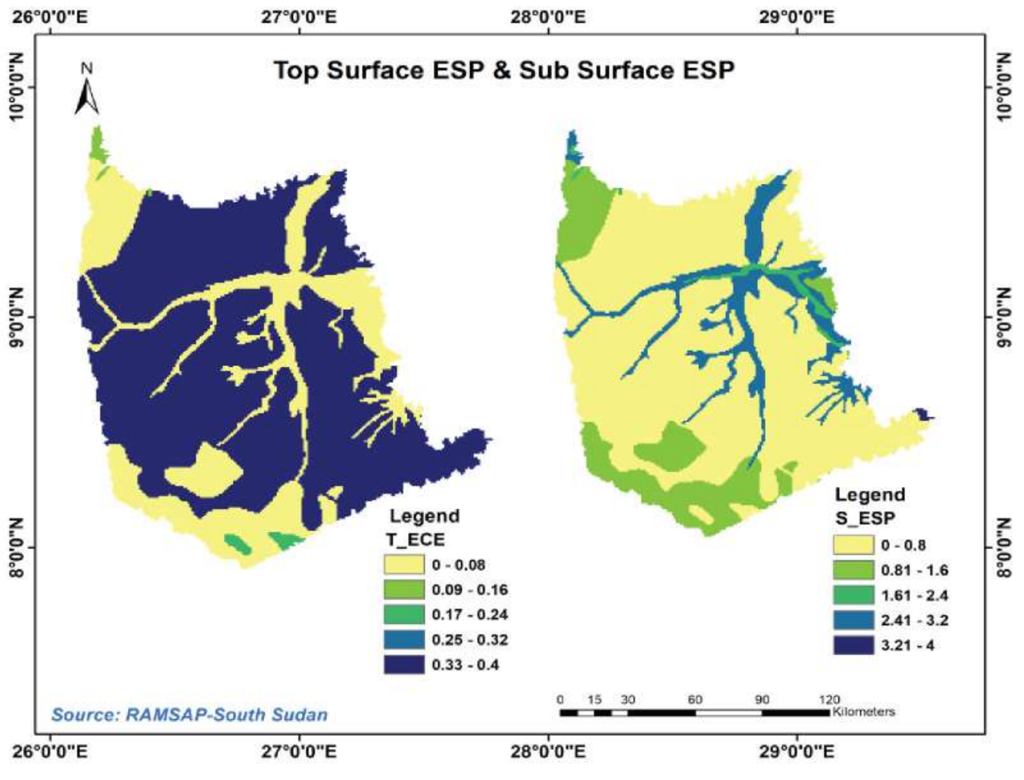


Figure 11. ESP of surface and sub surface soil in Aweil field site.

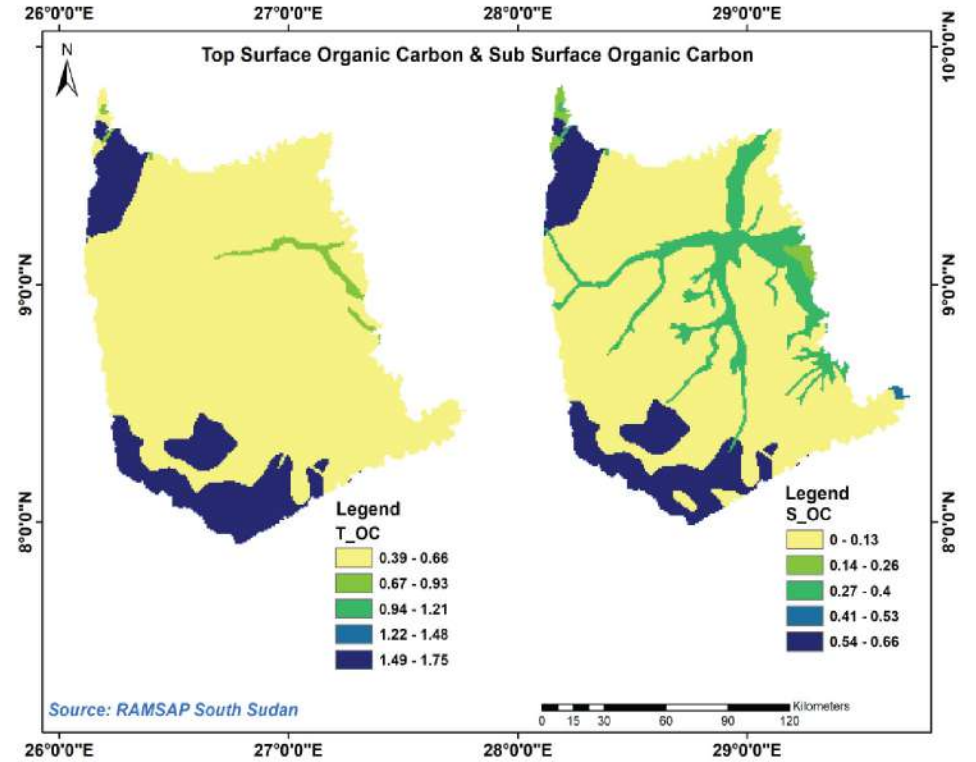


Figure 12. Organic contents in surface and sub surface soil in Aweil field site.

3.2 Bor field site

Table 3 shows that 44.29% area is under grass while 31.78% and 19.48% are covered by shrubs and trees, respectively. The area covered by crops is marginal (3.89%). The spatial distribution of vegetation classes is given in Figure 13. Maps related to soil texture, rainwater harvesting, pH, soil salinity, ECP, and surface organic carbon are given from Figures 14-19.

Table 3. Land use and land cover data for Bor field site.

No.	Vegetation classes	Area (km^2)	Percentage (%)
1	Tree cover areas	2431	19.48
2	Shrubs cover areas	3966	31.78
3	Grassland	5527	44.29
4	Cropland	485	3.89
5	Vegetation aquatic or regularly flooded	10	0.08
6	Lichens Mosses / Sparse vegetation	0	0.00
7	Bare and built areas	9	0.07
8	Open Water	51	0.41
Total Area		**12,478**	**100**

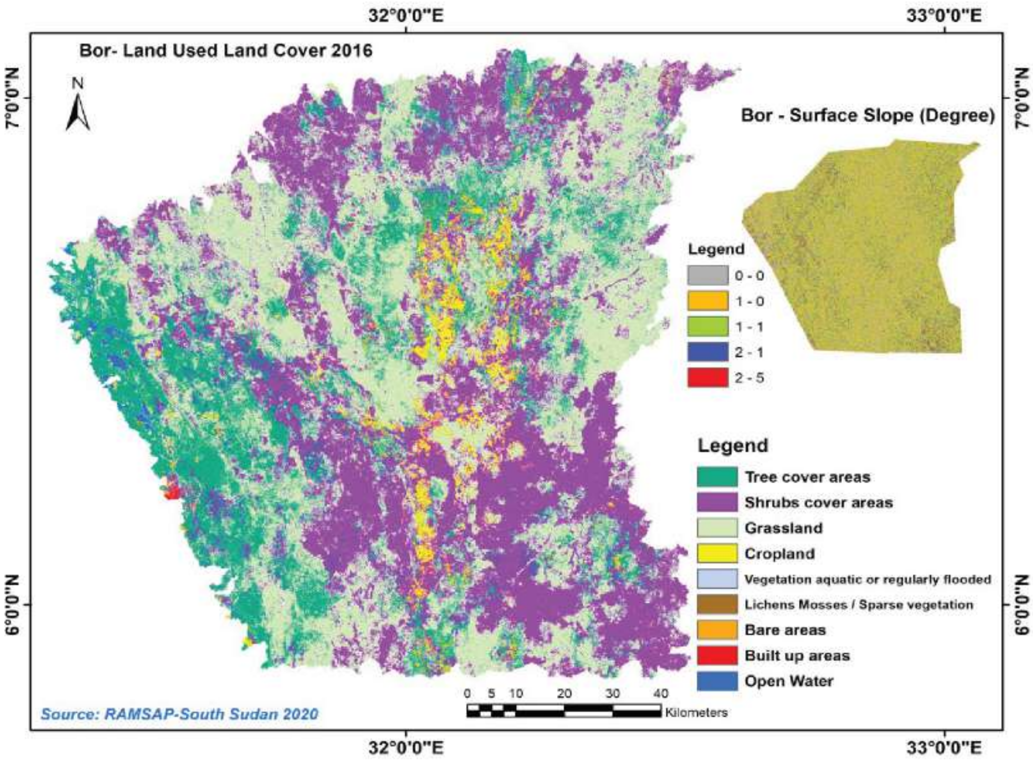


Figure 13. Land use and land cover map for the Bor field site.

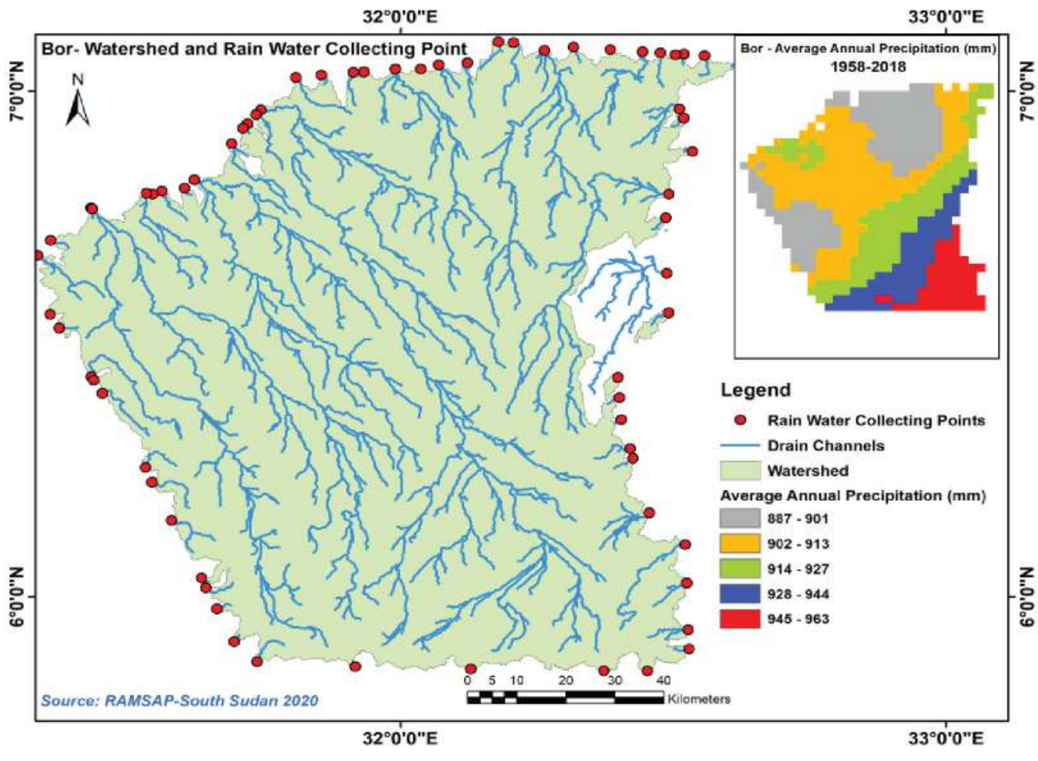


Figure 14. Rainwater harvesting points and surface slopes at Bor field site.

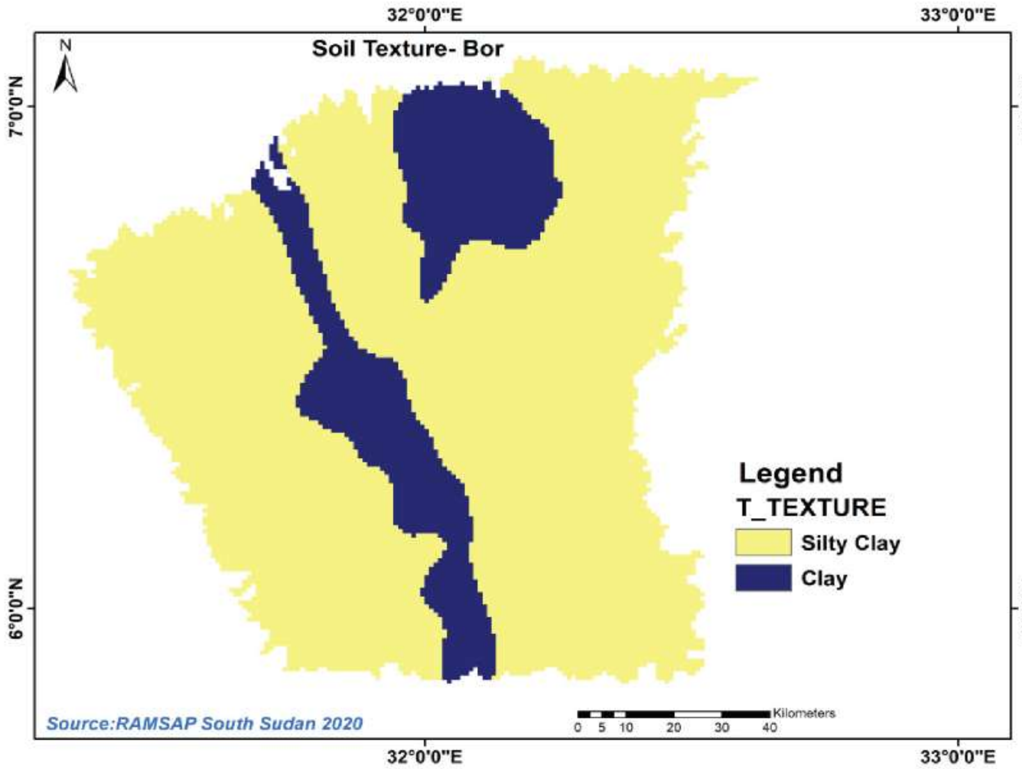


Figure 15. Soil texture at Bor field site.

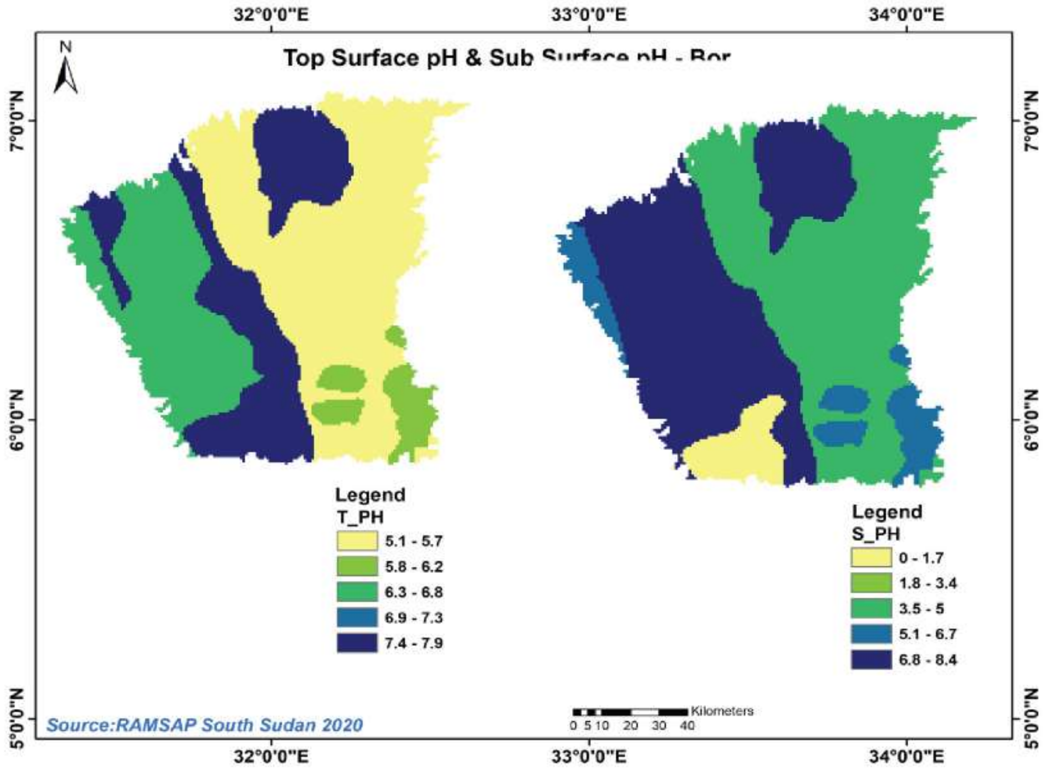


Figure 16. pH of surface and sub surface soils at Bor field site.

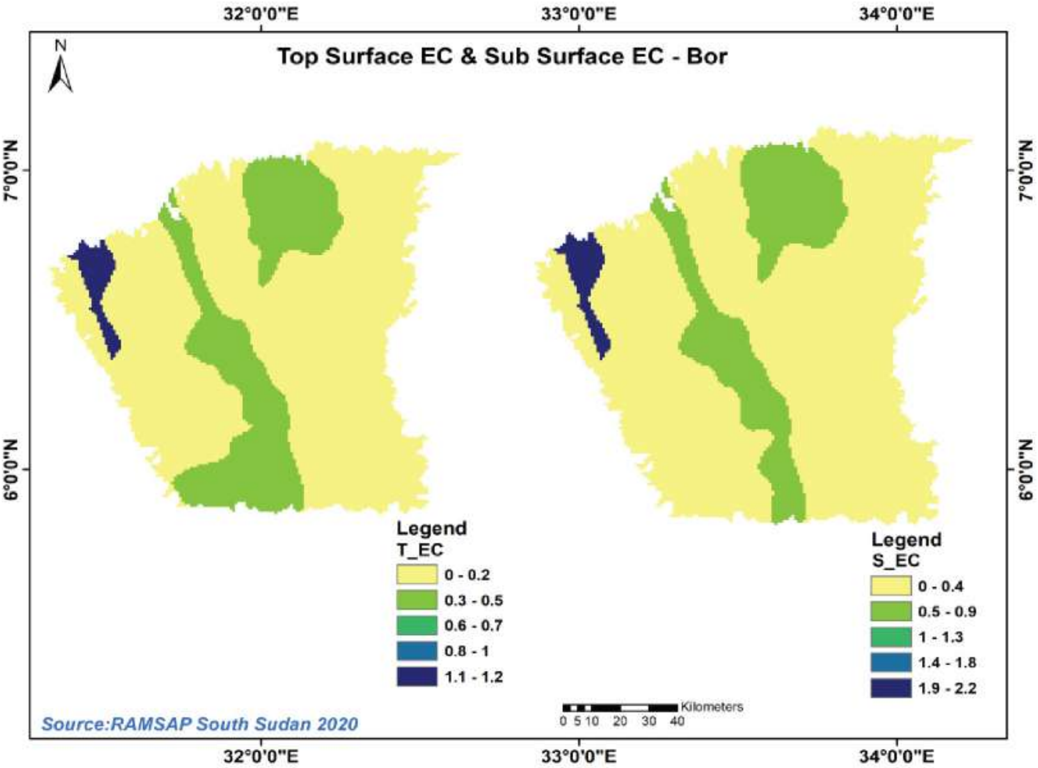


Figure 17. ECe of surface and subsurface soils at Bor field site.

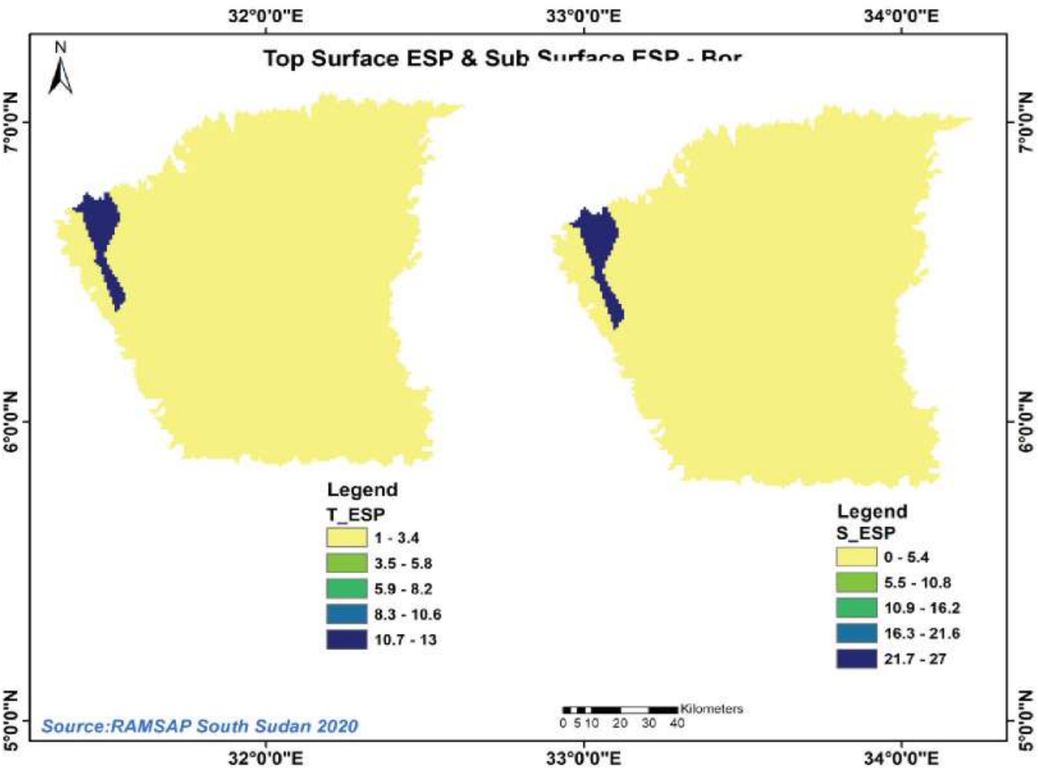


Figure 18. ESP of surface and sub surface soils at Bor field site.

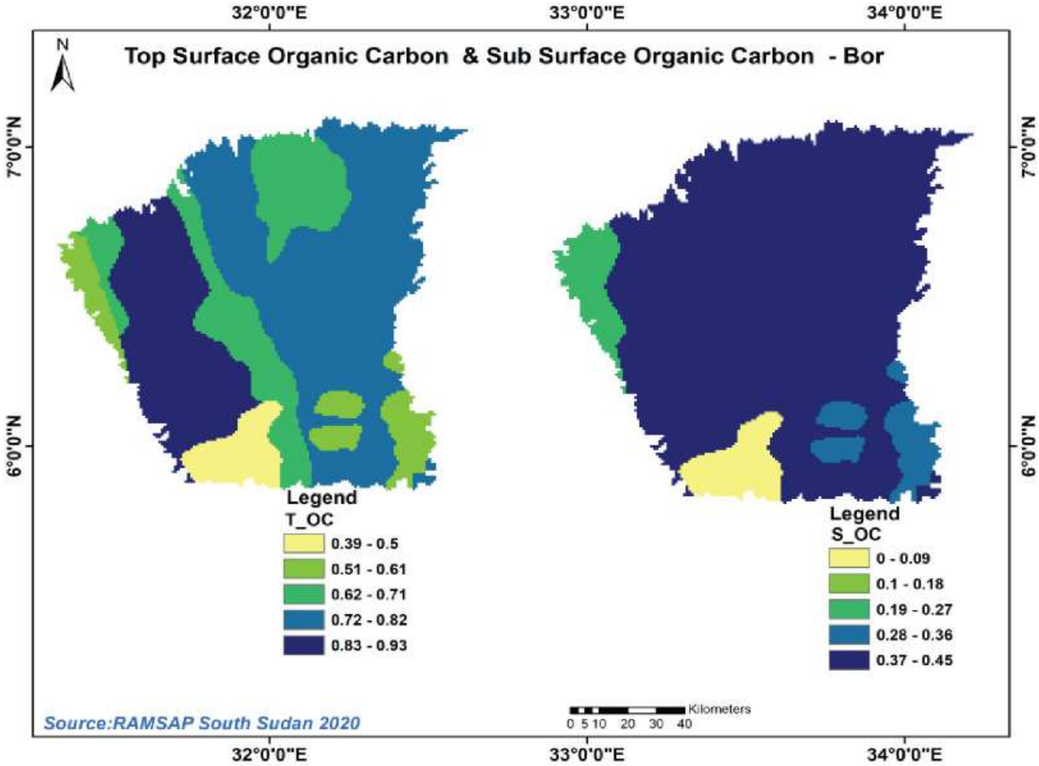


Figure 19. Organic content in surface and sub surface soils at Bor field site.

3.3 Kapoeta field site

Table 4 shows that 50.70% area is under grassland while 29.58% and 11.56% are covered by shrubs and trees, respectively. The area covered by crops is 7.86%). The spatial distribution of vegetation classes is given in Figure 20. Maps related to soil texture, rainwater harvesting, pH, soil salinity, ECP, and surface organic carbon are given from Figures 21-26.

Table 4. Land use and land cover data for Kapoeta field site.

No.	Vegetation classes	Area (km^2)	Percentage (%)
1	Tree cover areas	4520	11.56
2	Shrubs cover areas	11566	29.58
3	Grassland	19822	50.70
4	Cropland	3071	7.86
5	Vegetation aquatic or regularly flooded	11	0.03
6	Lichens Mosses / Sparse vegetation	74	0.19
7	Bare and built areas	36	0.09
8	Open Water	0	0.00
	Total Area	**39,099**	**100**

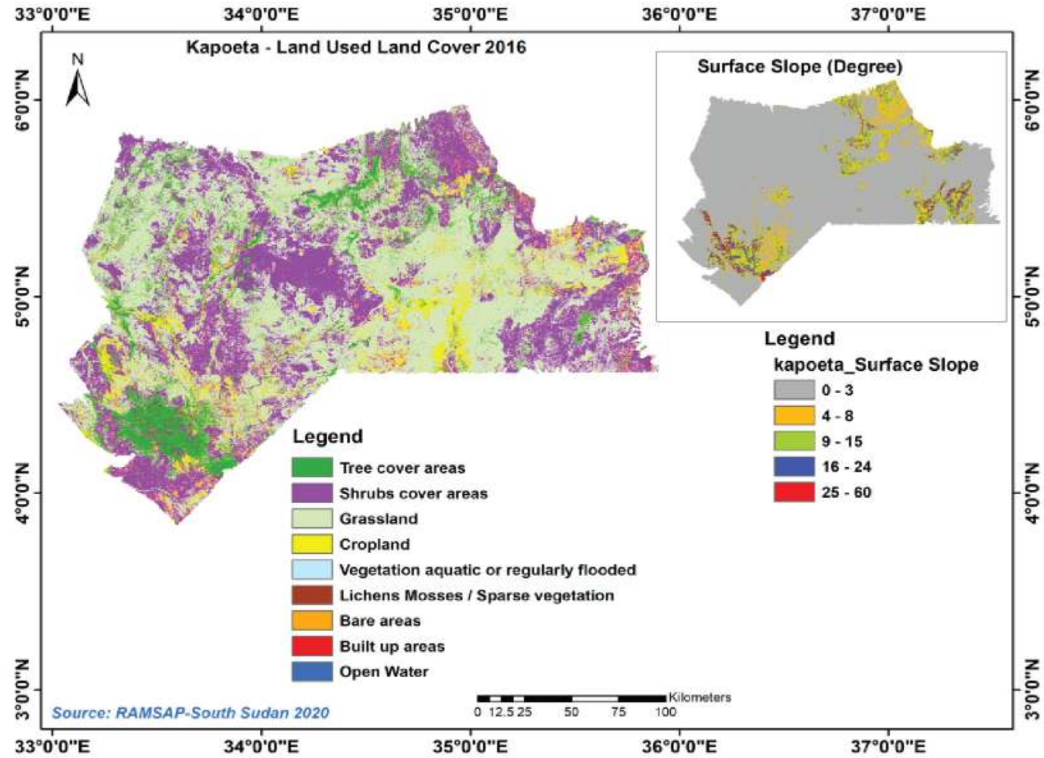


Figure 20. Land use and land cover at the Kapoeta field site.

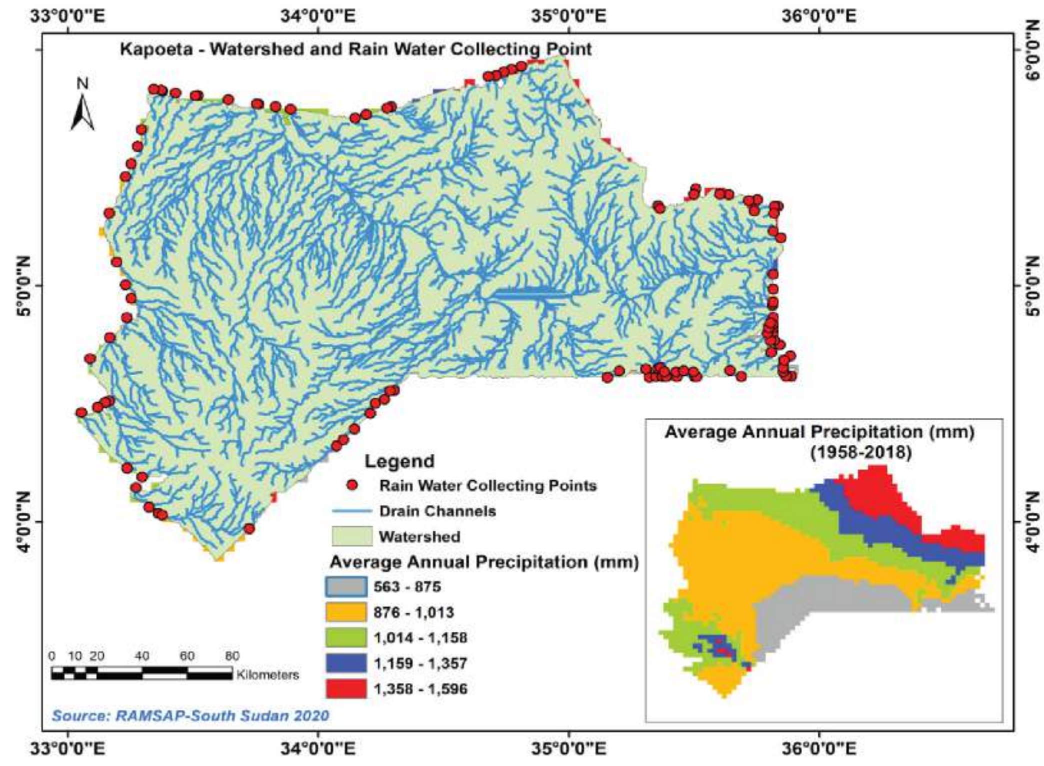


Figure 21. Rainwater harvesting points and surface slopes at Kapoeta field site.

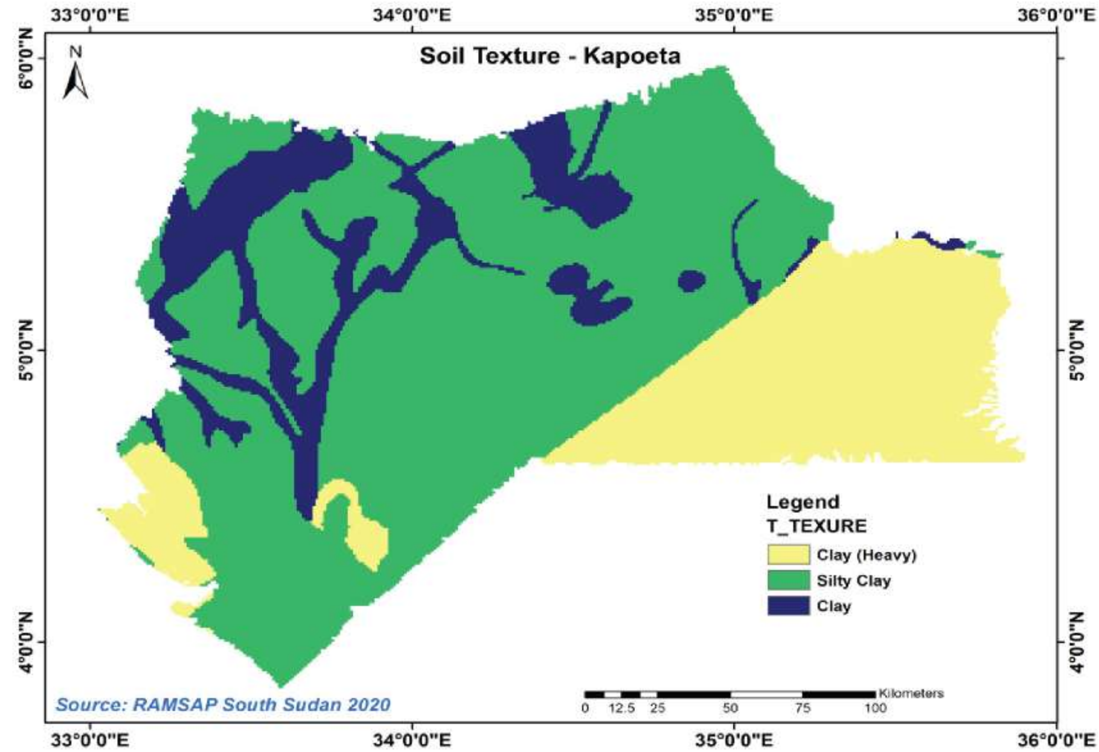


Figure 22. Soil texture at Kapoeta field site.

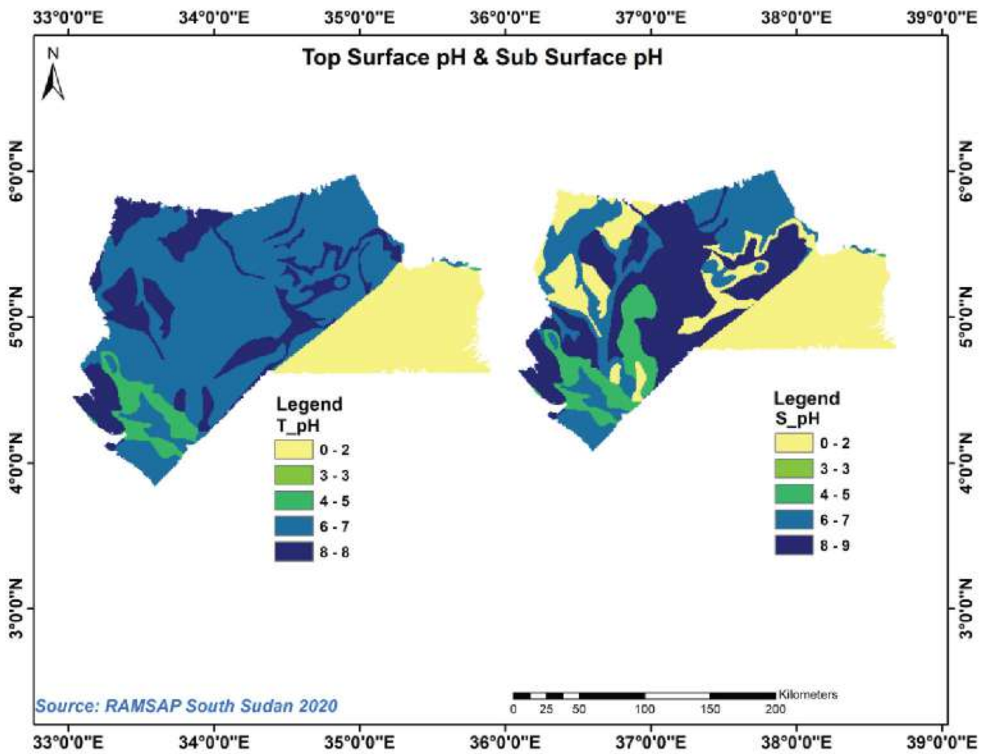


Figure 23. pH of surface and sub surface soils at Kapoeta field site.

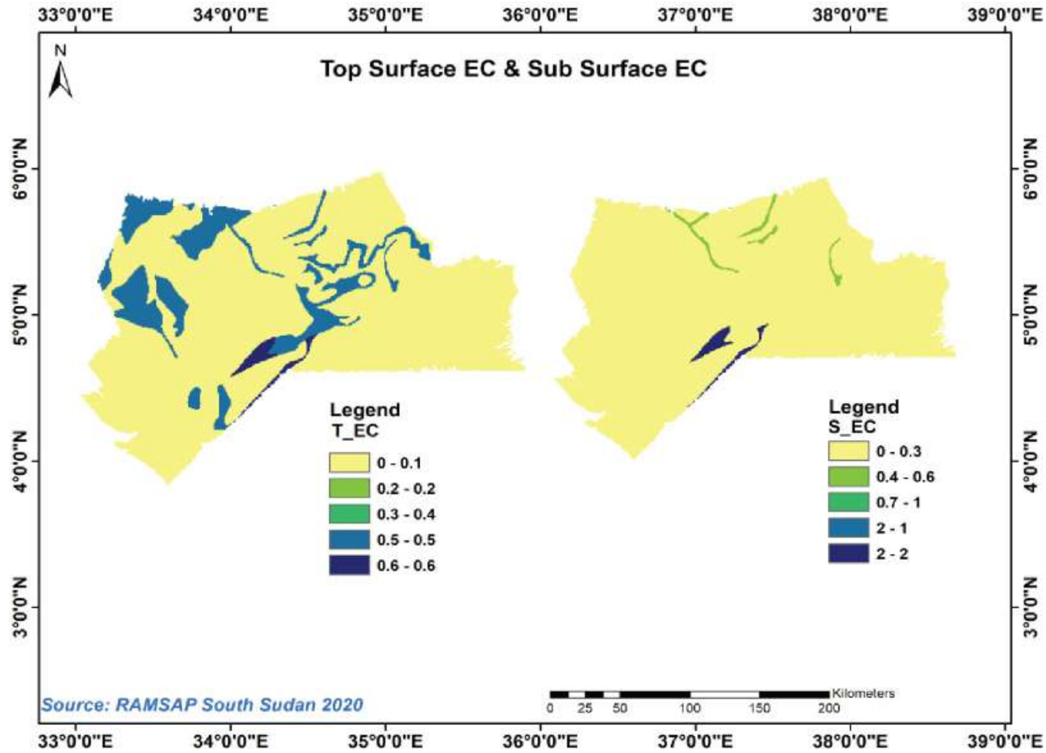


Figure 24. ECe of surface and sub surface soils at Kapoeta field site.

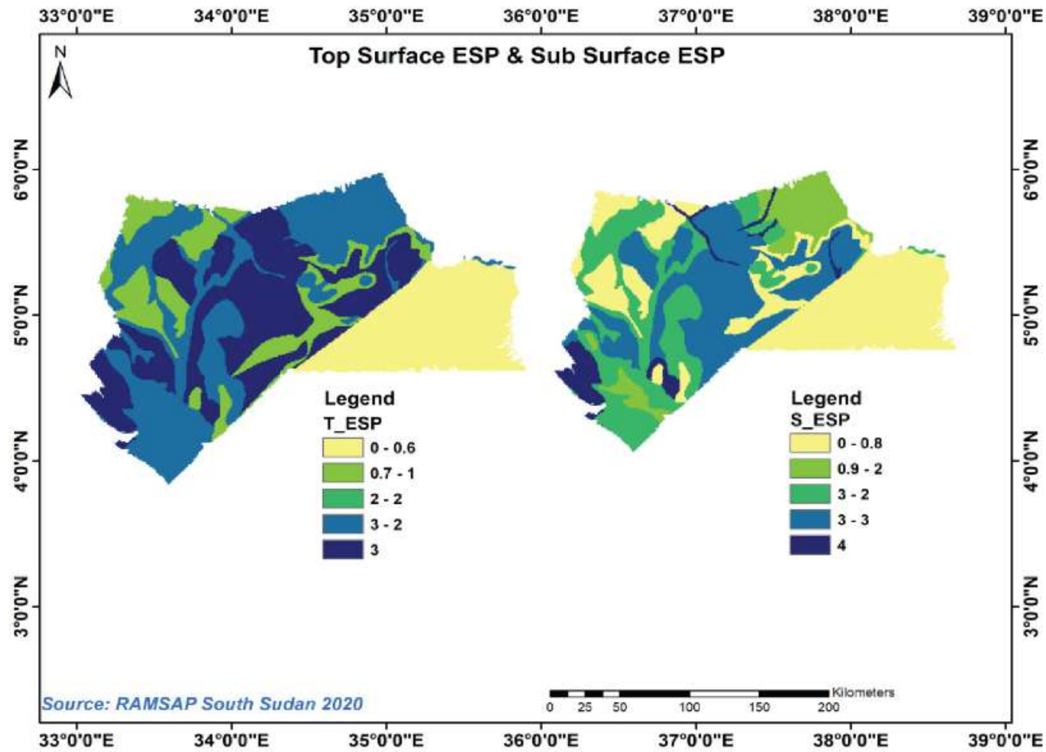


Figure 25. ESP of surface and sub surface soils at Kapoeta field site.

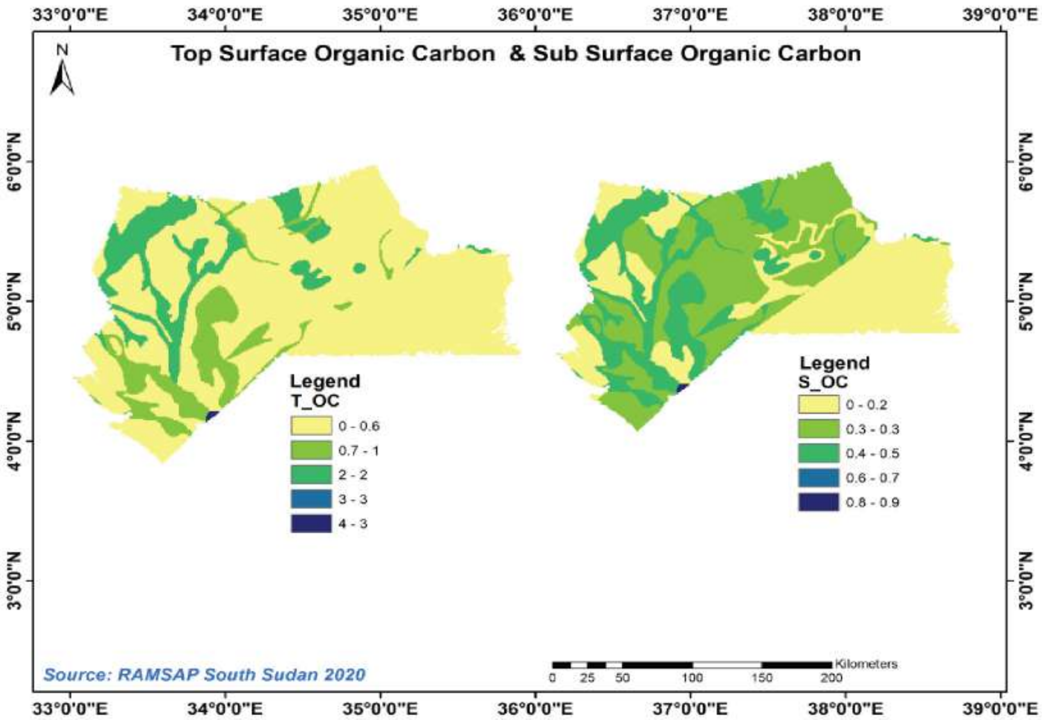


Figure 26. Organic content in surface and sub-surface soils at Kapoeta field site.

3.3 Renk field sites

Table 5 shows that 25.66% area is under grassland while 17.65% and 13.60% are covered by shrubs and trees, respectively. The area covered by crops is 42.90%. The spatial distribution of vegetation classes is given in Figure 27. Maps related to soil texture, rainwater harvesting, pH, soil salinity, ECP, and surface organic carbon are given from Figures 28-33.

Table 5. Land use and land cover data for Renk field site.

No.	Vegetation classes	Area (km²)	Percentage (%)
1	Tree cover areas	1239	13.60
2	Shrubs cover areas	1608	17.65
3	Grassland	2338	25.66
4	Cropland	3907	42.90
5	Vegetation aquatic or regularly flooded	11	0.12
6	Lichens Mosses / Sparse vegetation	0	0.00
7	Bare areas	4	0.05
8	Built up areas	2	0.02
9	Open Water	0	0.00
Total Area		**9108**	**100**

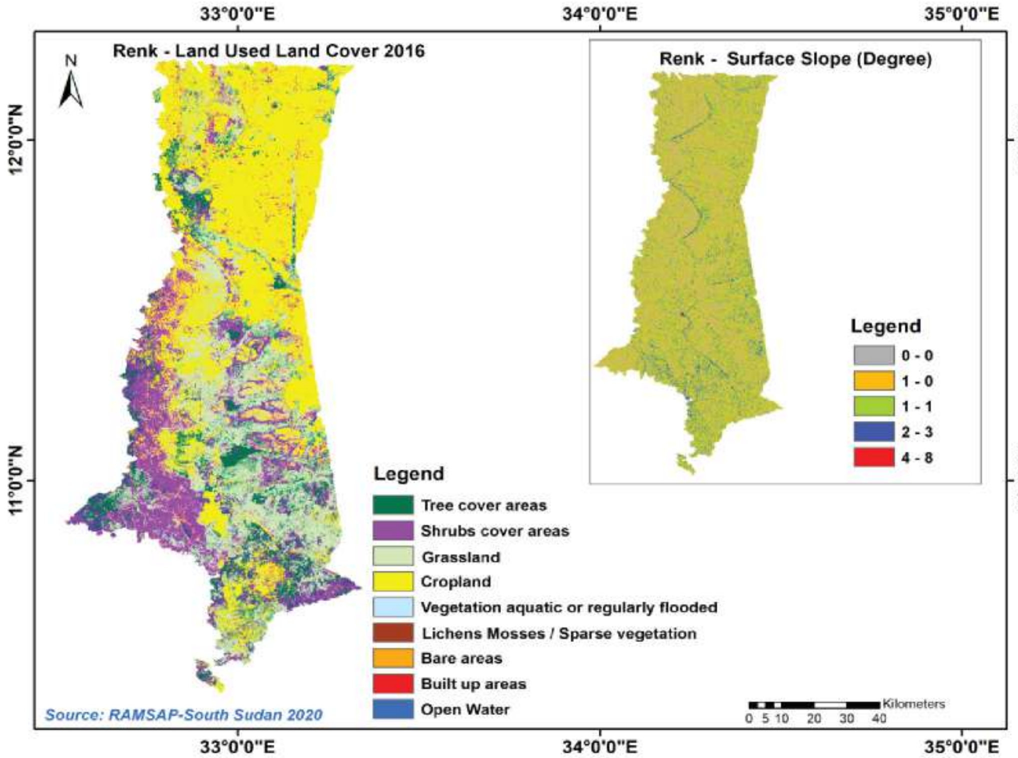


Figure 27. Land use and land cover at Renk field site.

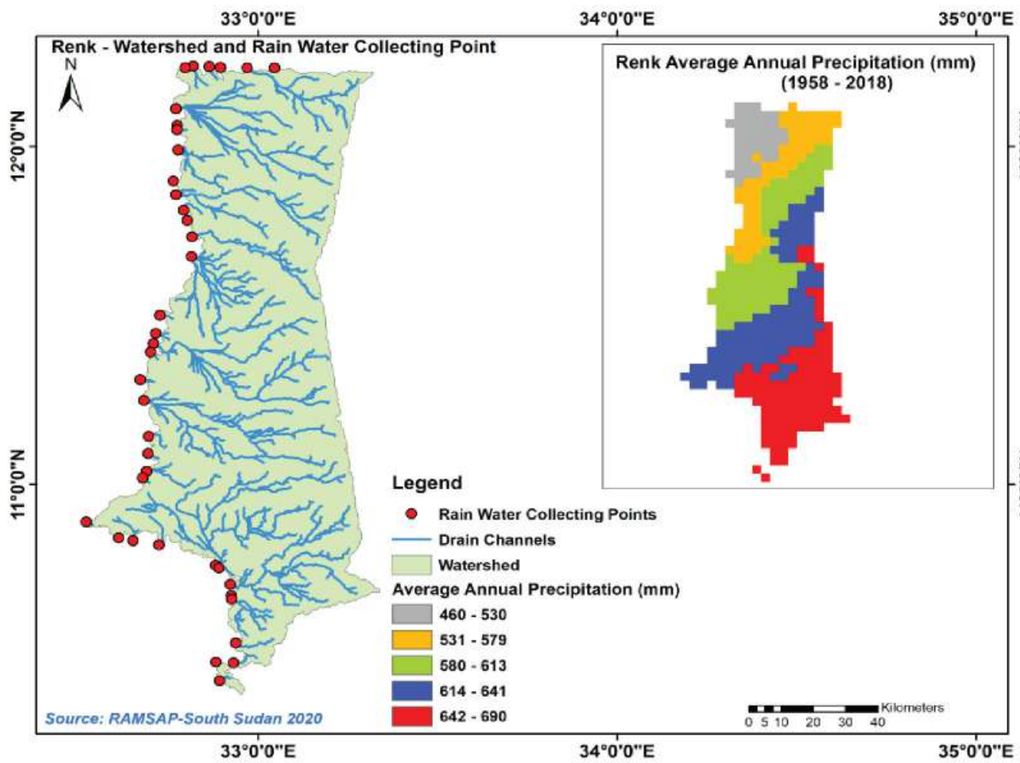


Figure 28. Rainwater harvesting point and surface slopes at Renk field site.

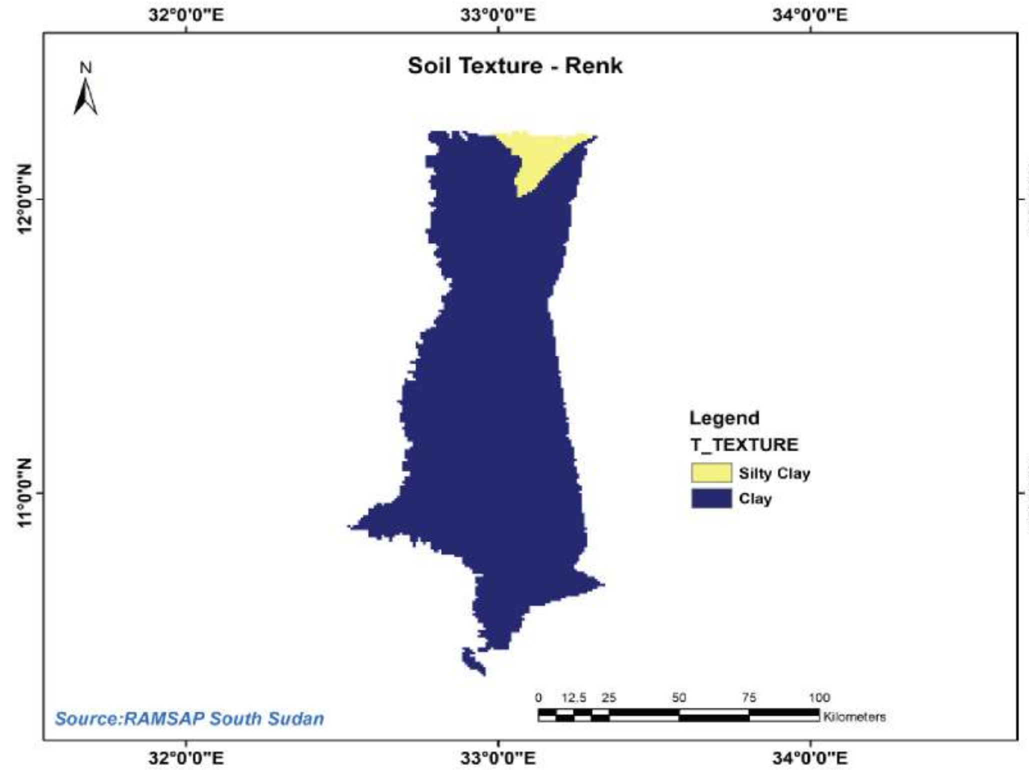


Figure 29. Soil texture at Renk field site.

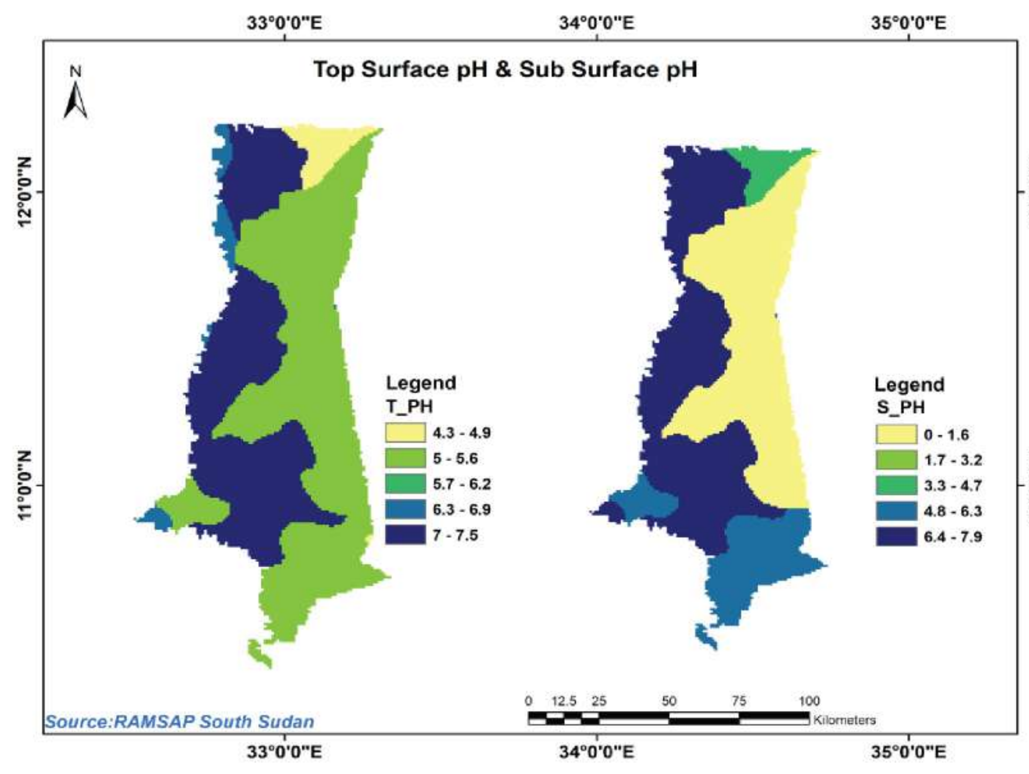


Figure 30. pH in surface and sub surface soils at Renk field site.

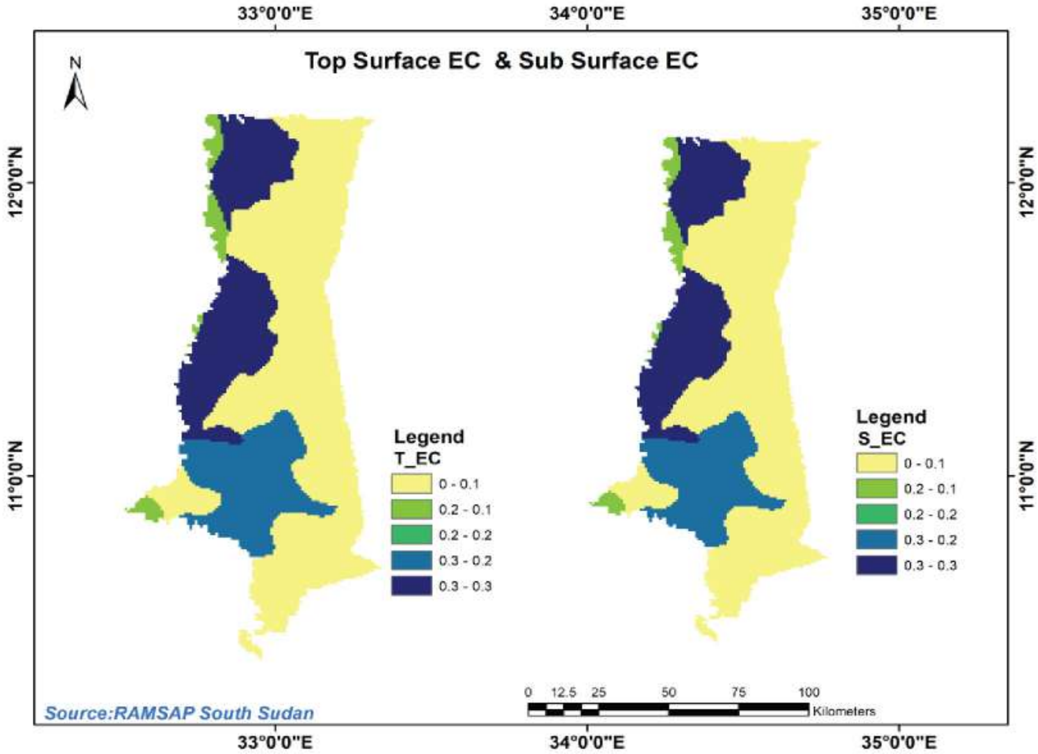


Figure 31. ECe in surface and sub surface soils at Renk field site.

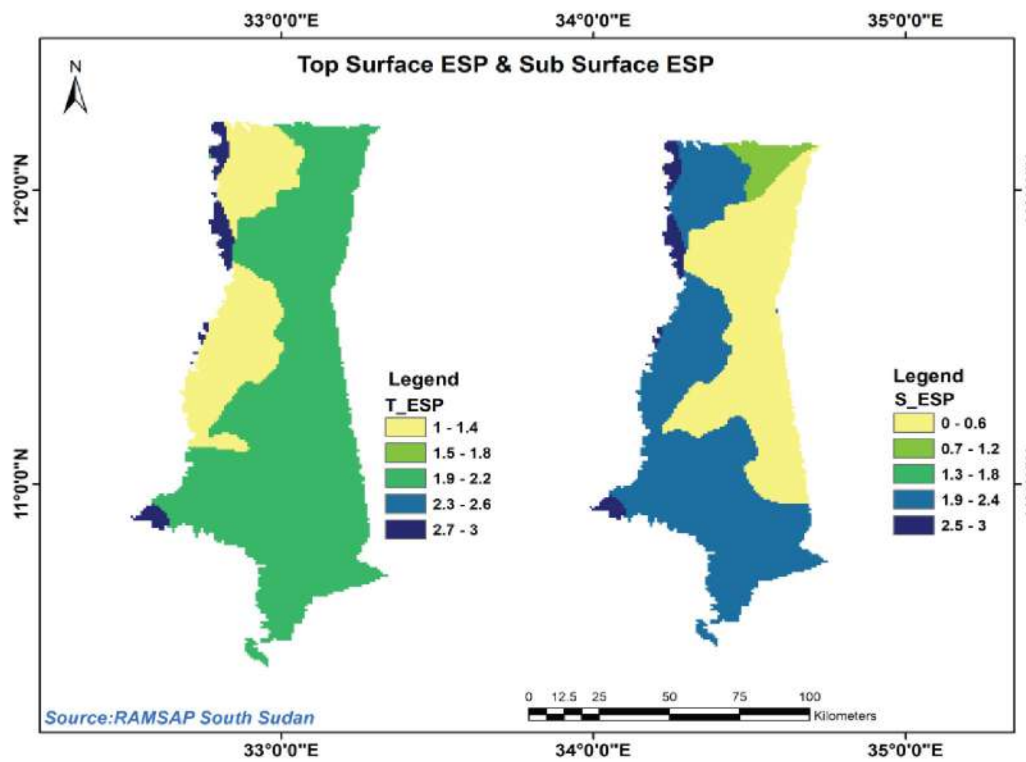


Figure 32. ESP in surface and sub surface soils at Renk field site.

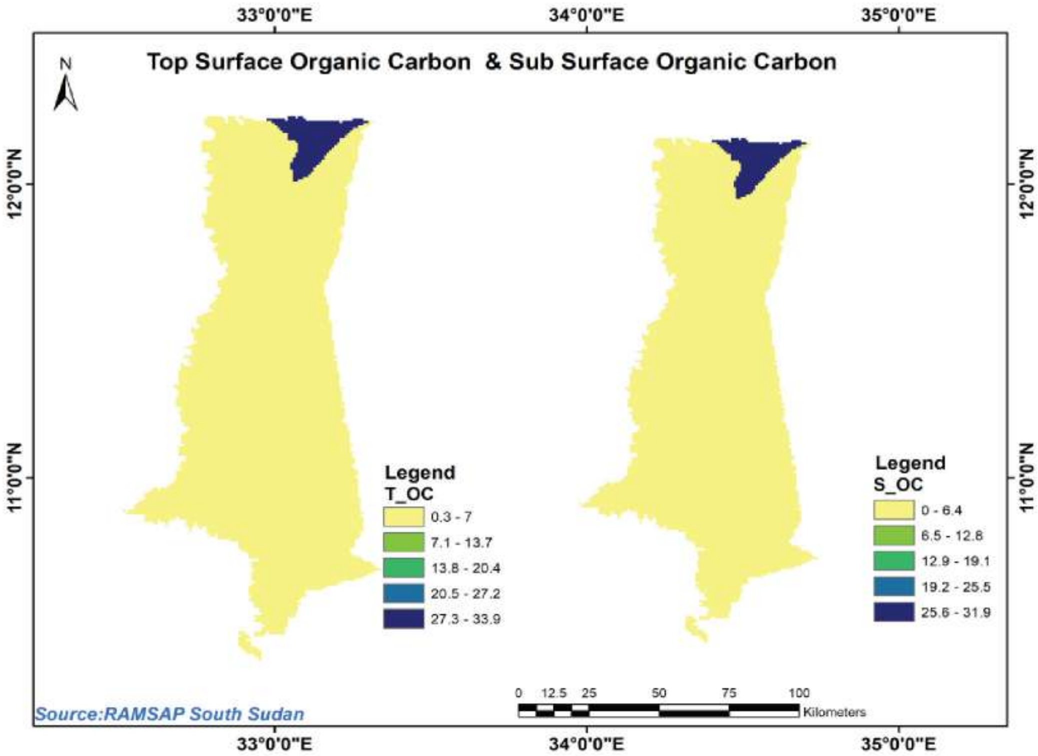


Figure 33. Organic content in surface and sub-surface soils at Renk field site.

3.3 Renk field sites

Table 6 shows that 13.77% area is under grassland while 24.66% and 58.44% are covered by shrubs and trees, respectively. The area covered by crops is marginal (3.05%). The spatial distribution of vegetation classes is given in Figure 34. Maps related to soil texture, rainwater harvesting, pH, soil salinity, ECP, and surface organic carbon are given from Figures 35-40.

Table 6. Land use and land cover data for Torit field site.

No.	Vegetation classes	Area (km^2)	Percentage (%)
1	Tree cover areas	3034	58.44
2	Shrubs cover areas	1281	24.66
3	Grassland	715	13.77
4	Cropland	159	3.05
5	Vegetation aquatic or regularly flooded	0	0.00
6	Lichens Mosses / Sparse vegetation	0	0.00
7	Bare and built areas	4	0.08
8	Open Water	0	0.01
Total Area		**5192**	**100**

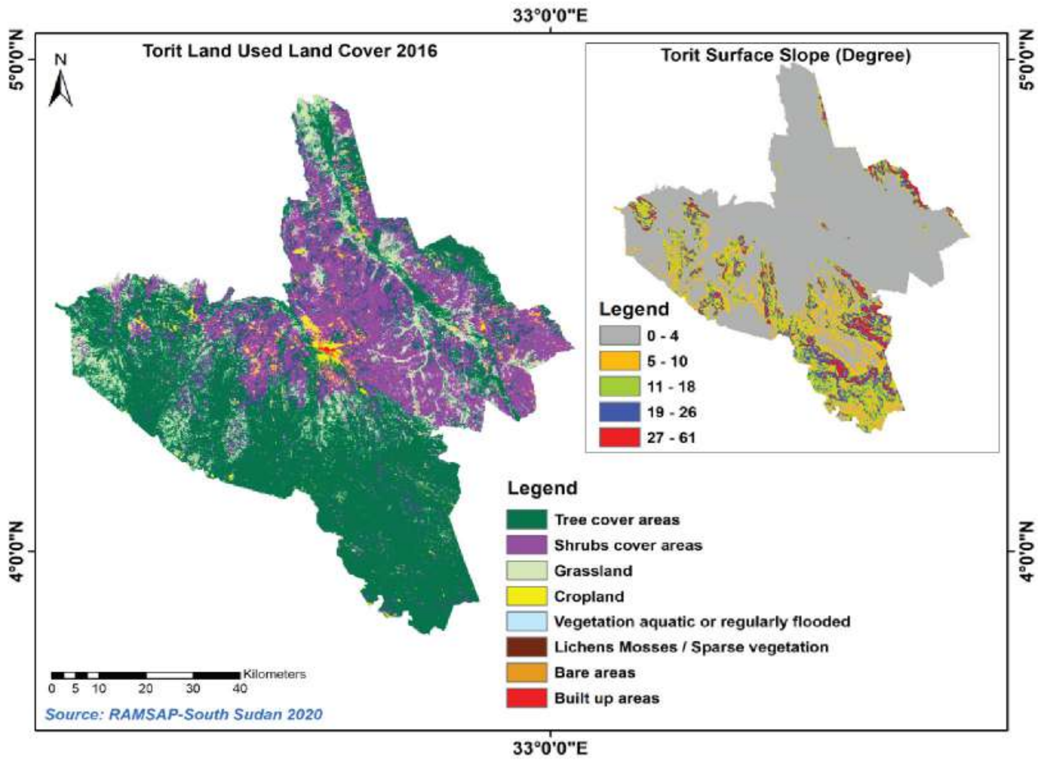


Figure 34. Land use and land cover at Torit field site.

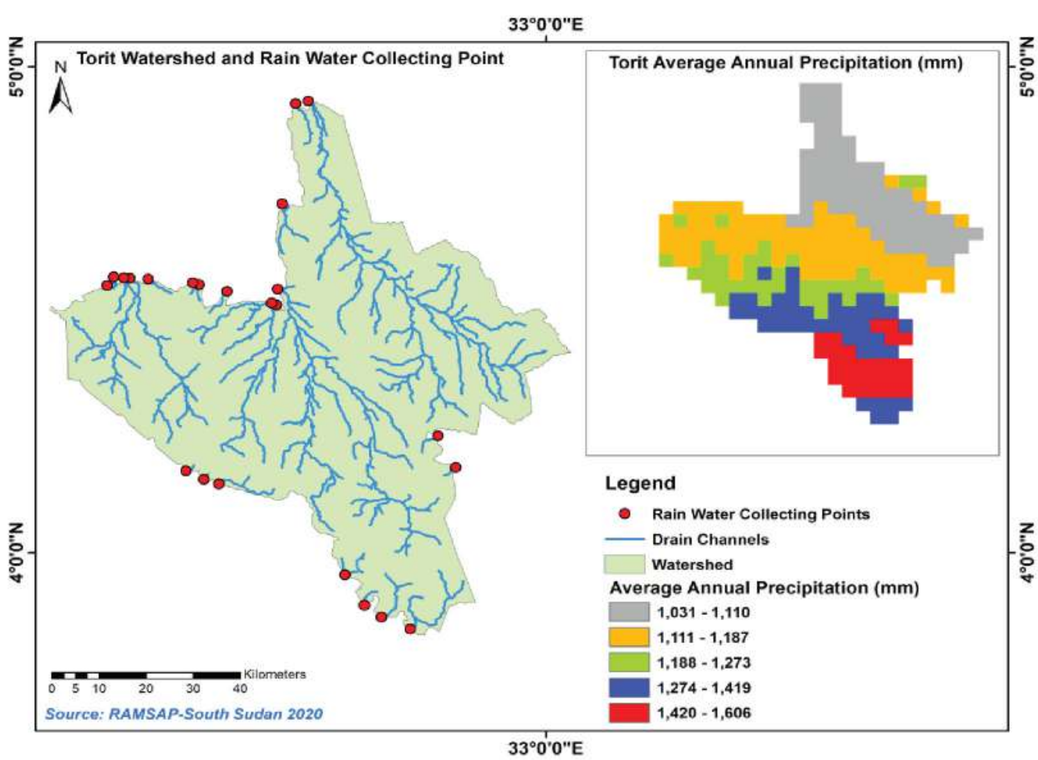


Figure 35. Rainwater harvesting points and surface slopes at Torit field site.

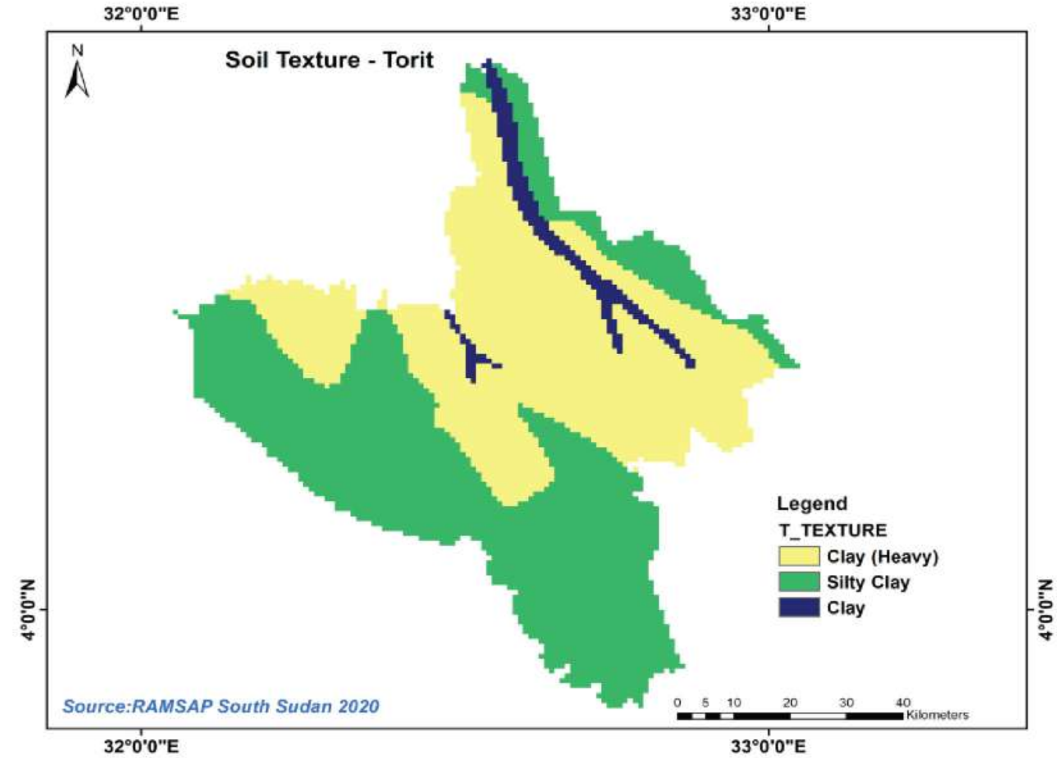


Figure 36. Soil texture at Torit field site.

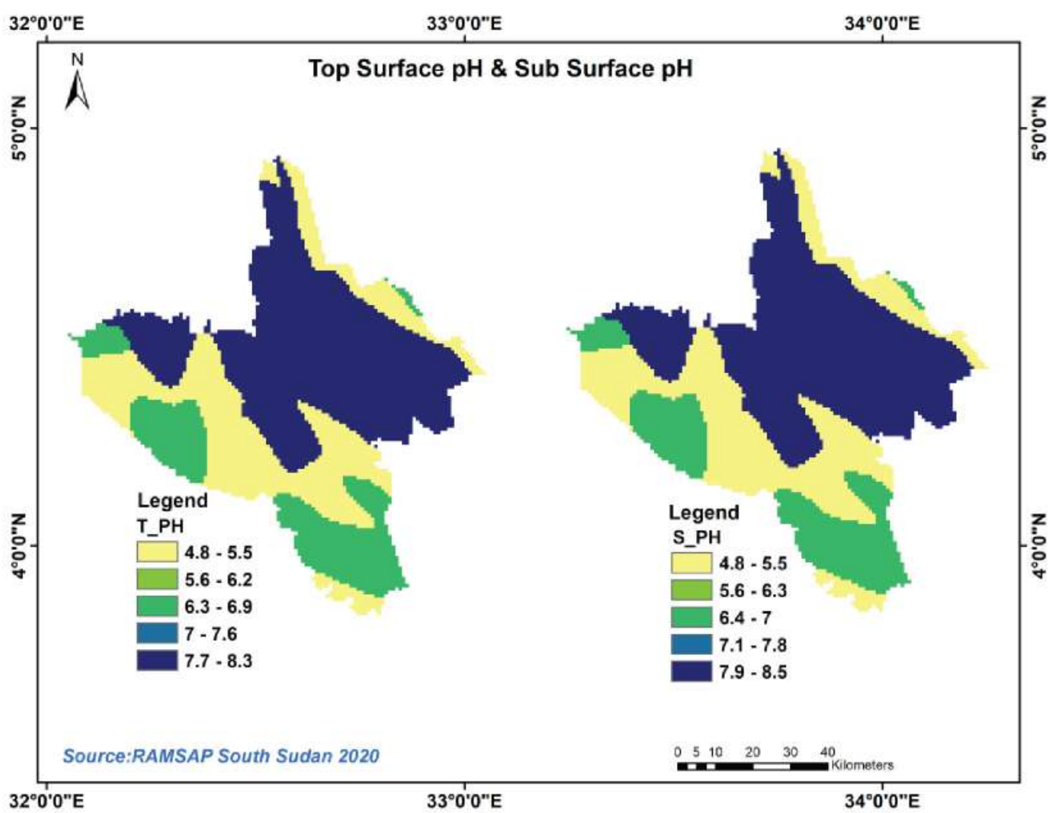


Figure 37. pH in surface and sub surface soil at Torit field site.

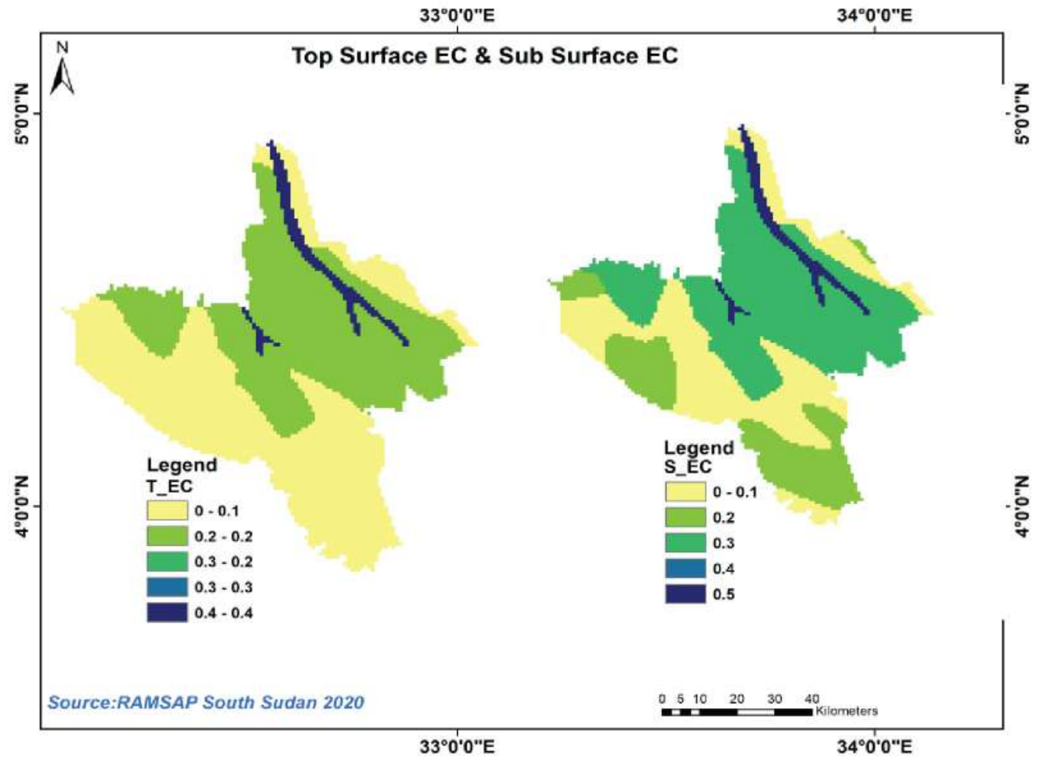


Figure 38. EC in surface and sub surface soil at Torit field site.

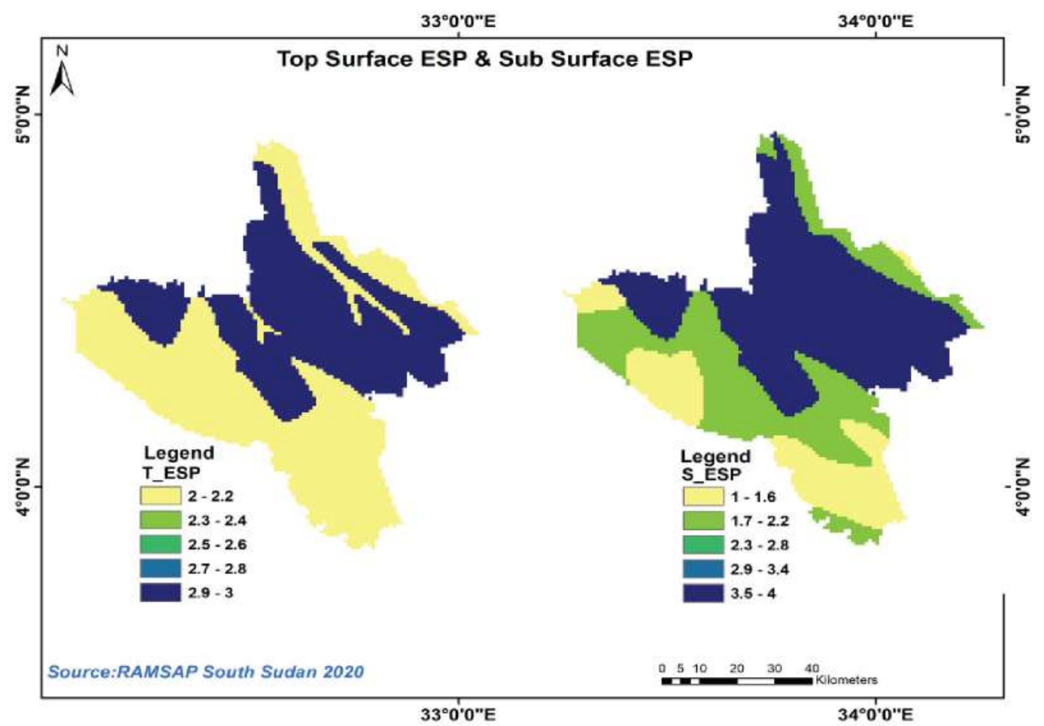


Figure 39. ESP in surface and sub-surface soil at Torit field site.

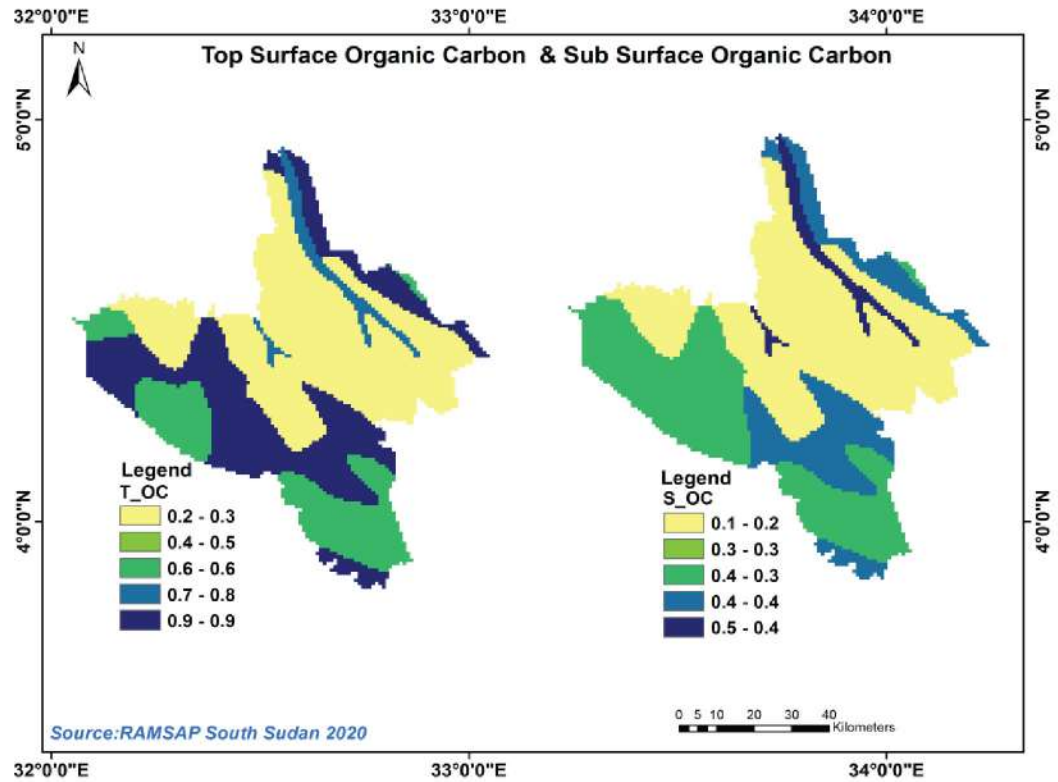


Figure 40. Organic content surface and sub-surface soil at Torit field site.

3.6 Wau field site

Table 7 shows that 19.50% area is under grassland while 4.47% and 75.12% are covered by shrubs and trees, respectively. The area covered by crops is almost nil (0.76%). The spatial distribution of vegetation classes is given in Figure 41. Maps related to soil texture, rainwater harvesting, pH, soil salinity, ECP, and surface organic carbon are given from Figures 42-47.

Table 7. Land use and land cover data for Wau field site.

No.	Vegetation classes	Area (km^2)	Percentage (%)
1	Tree cover areas	20,578	75.12
2	Shrubs cover areas	1224	4.47
3	Grassland	5342	19.50
4	Cropland	209	0.76
5	Vegetation aquatic or regularly flooded	12	0.04
6	Lichens Mosses / Sparse vegetation	0	0.00
7	Bare and built areas	28	0.10
8	Open Water	0	0.00
	Total Area	**27,393**	**100**

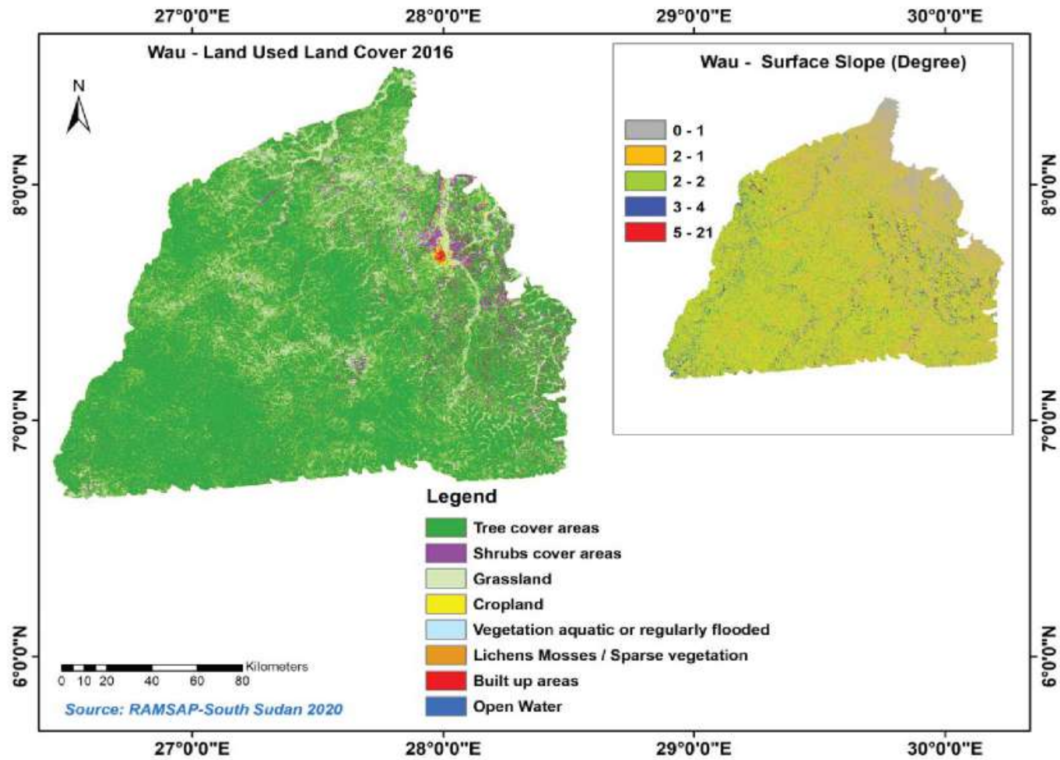


Figure 41. Land use and land cover at Wau field site.

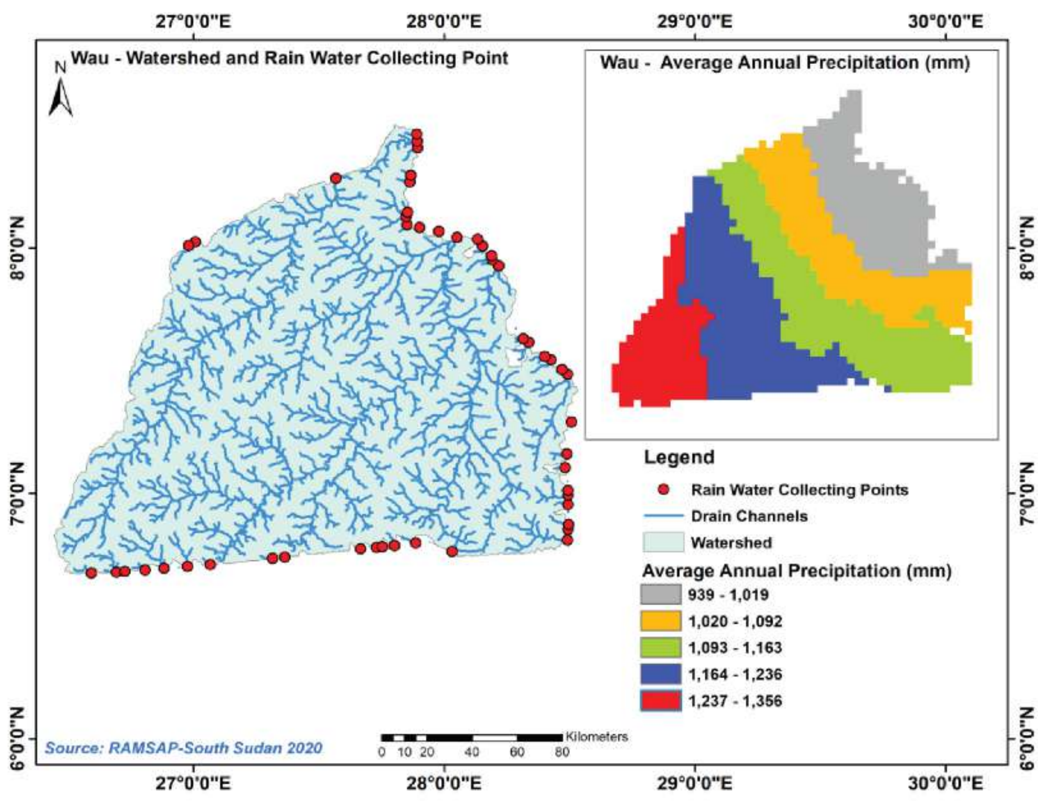


Figure 42. Rainwater harvesting points and surface slopes at Wau field site.

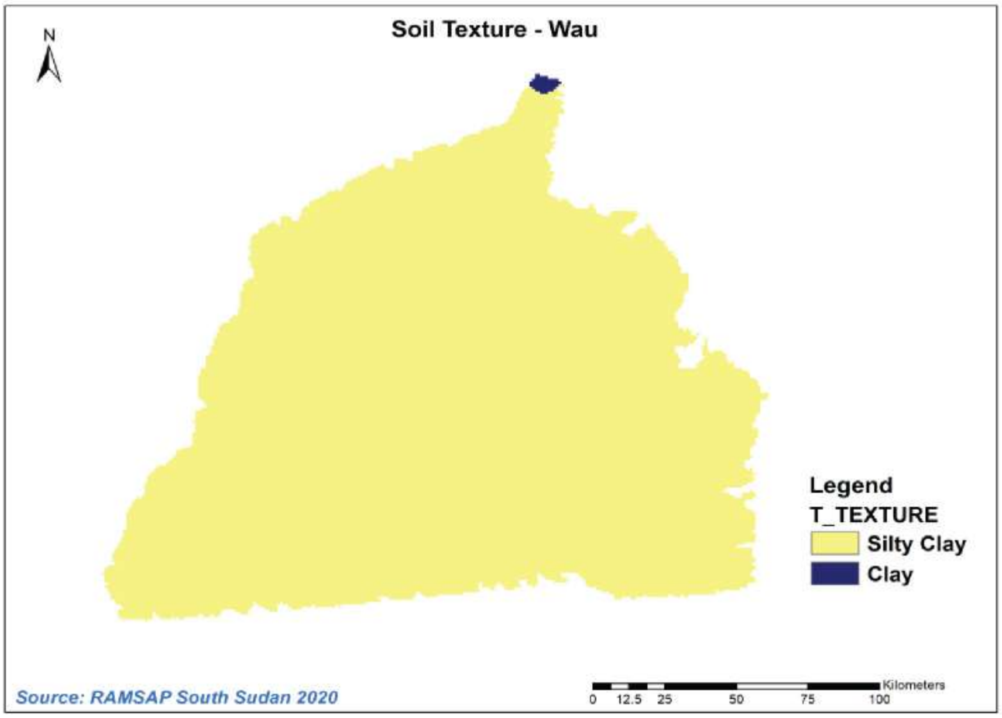


Figure 43. Soil texture at Wau field site.

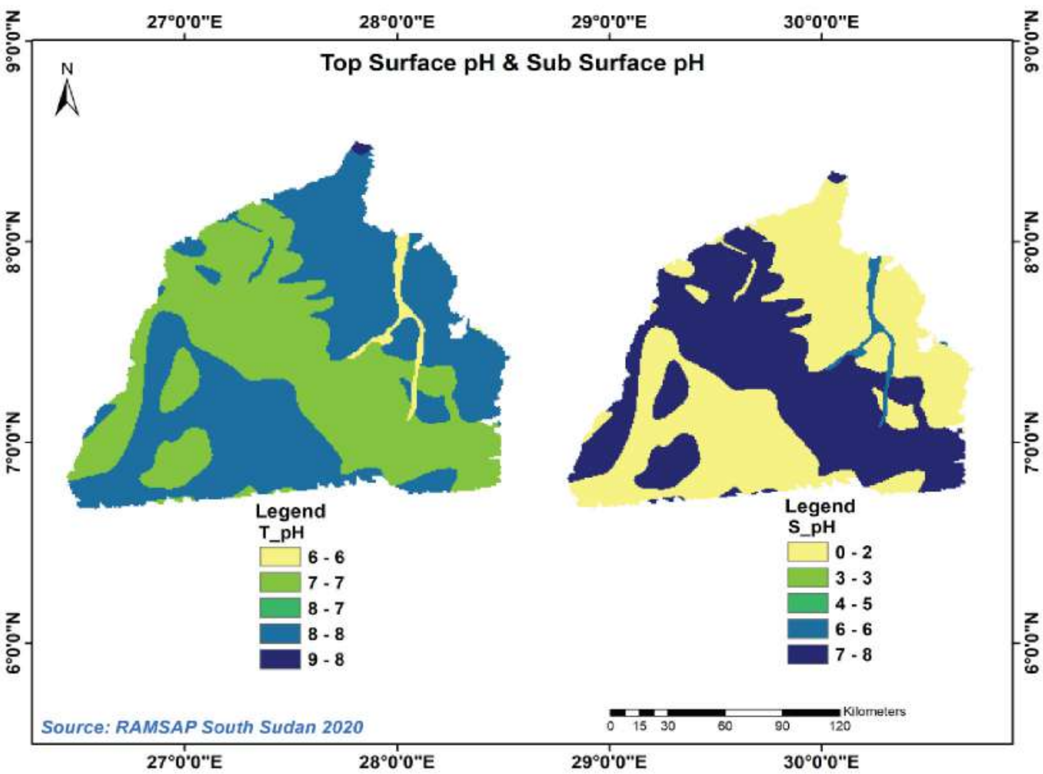


Figure 44. pH of surface and sub-surface soil at Wau field site.

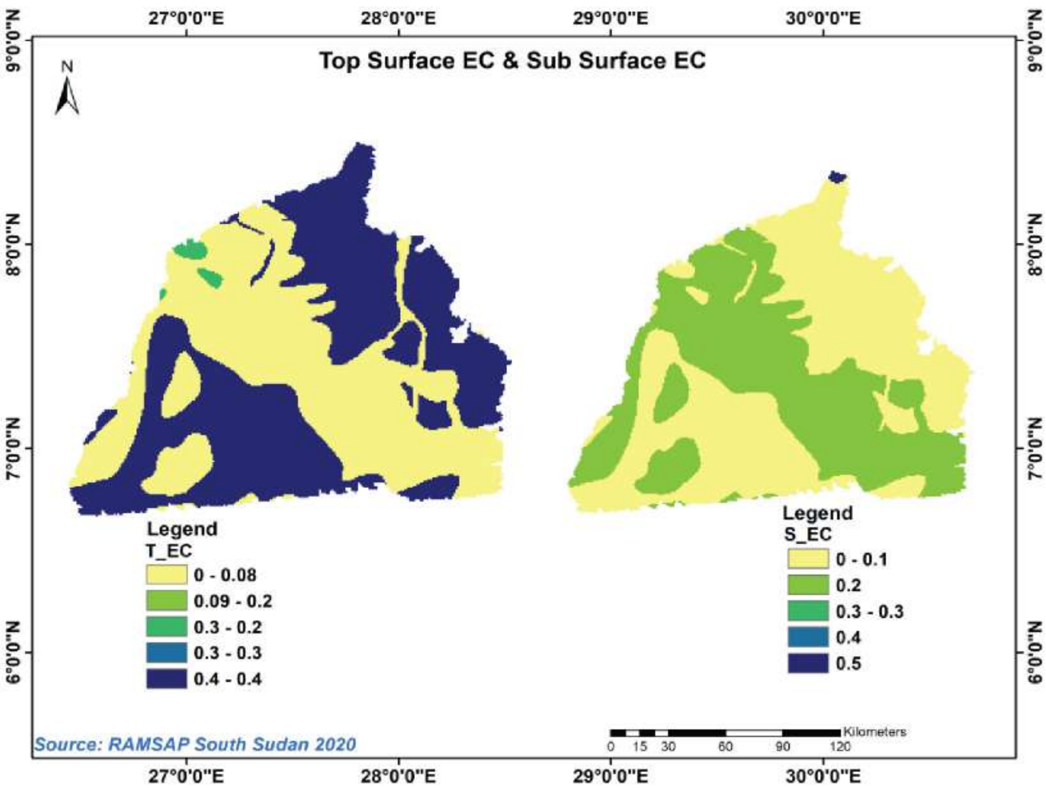


Figure 45. ECe of surface and sub-surface soil at Wau field site.

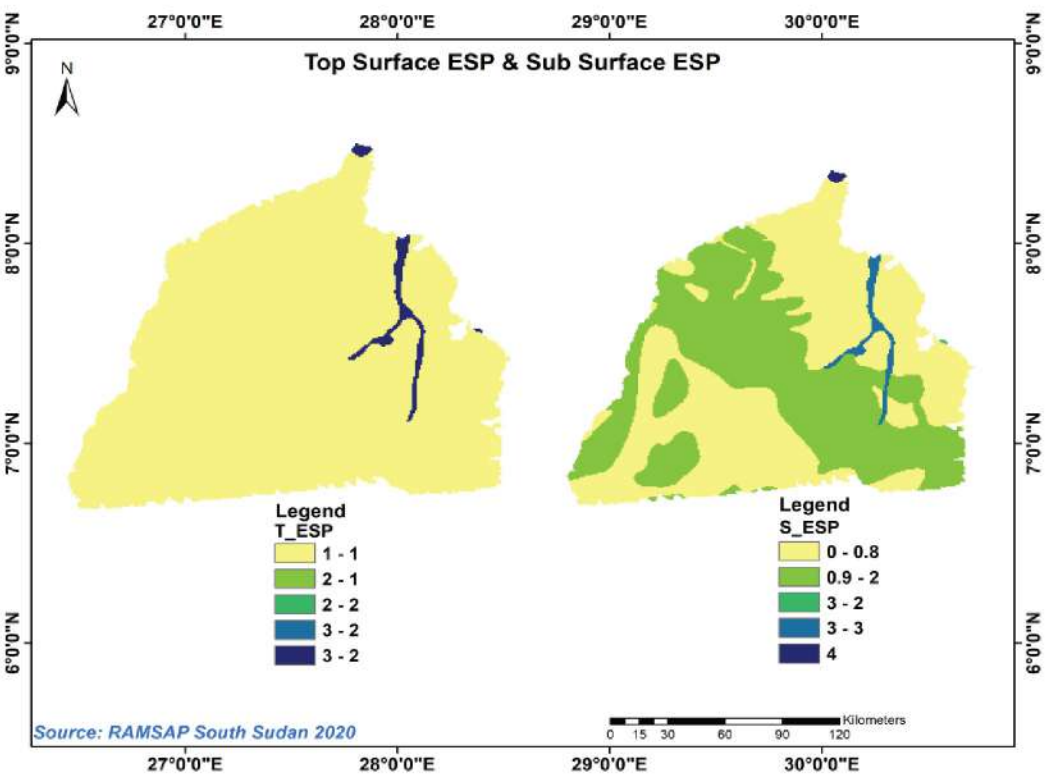


Figure 46. ESP of surface and sub-surface soil at Wau field site.

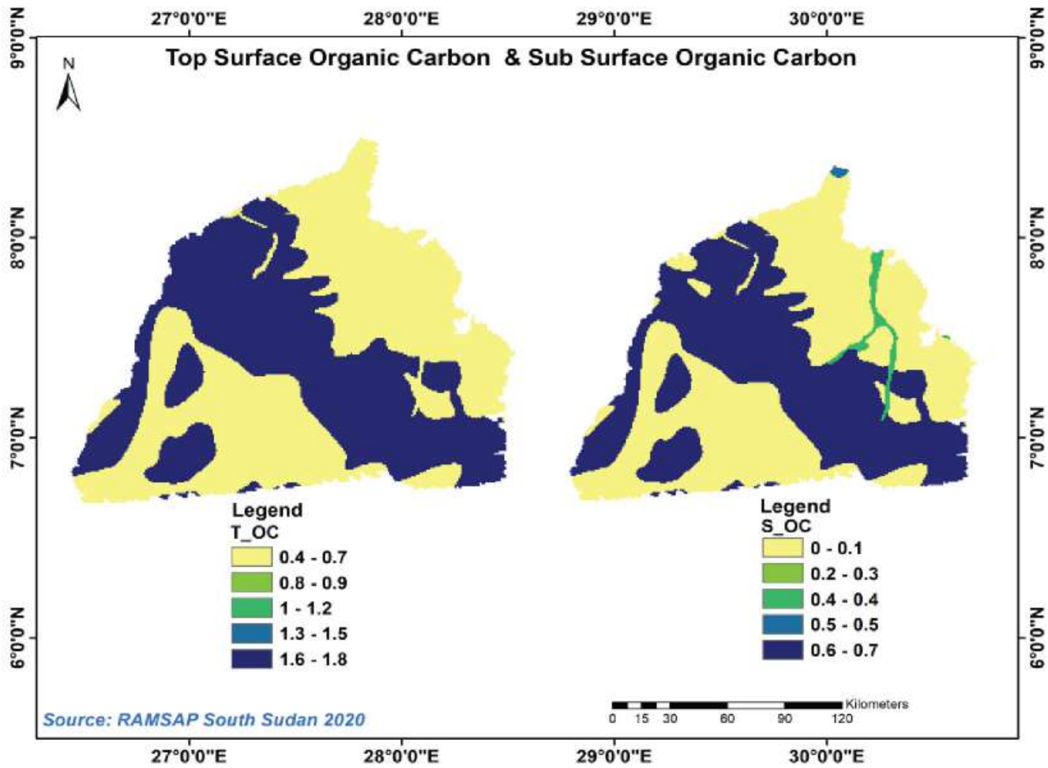


Figure 47. Organic contents in surface and sub-surface soil at Wau field site.

3.7 Yambio field site

Table 8 shows that 5.56% area is under grassland while 2.25% and 91.97% are covered by shrubs and trees, respectively. The area covered by crops is almost nil (0.76%). The spatial distribution of vegetation classes is given in Figure 45. Maps related to soil texture, rainwater harvesting, pH, soil salinity, ECP, and surface organic carbon are given from Figures 46-51.

Table 8. Land use and land cover data for Yambio field site.

No.	Vegetation classes	Area (km^2)	Percentage (%)
1	Tree cover areas	7,239	91.97
2	Shrubs cover areas	177	2.25
3	Grassland	437	5.56
4	Cropland	13	0.16
5	Vegetation aquatic or regularly flooded	0	0.00
6	Lichens Mosses / Sparse vegetation	0	0.00
7	Bare areas	5	0.07
8	Open Water	0	0.00
	Total Area	**7,871**	**100**

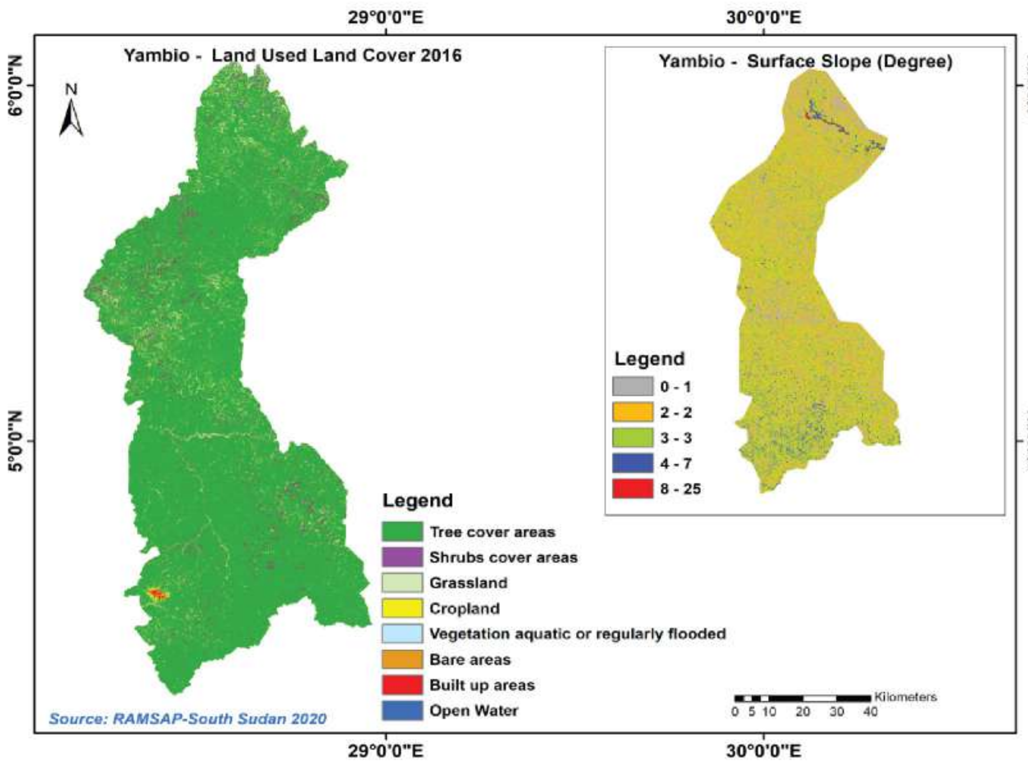


Figure 48. Land use and land cover at Yambio field site.

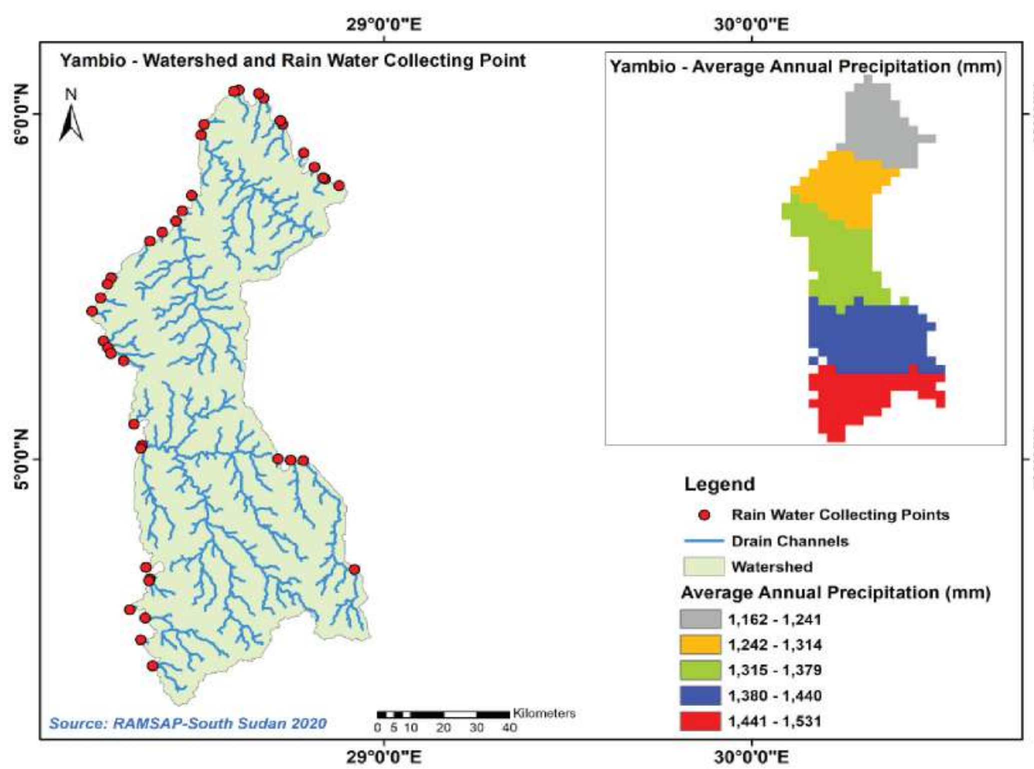


Figure 49. Rainwater harvesting points and surface slopes at Yambio field site.

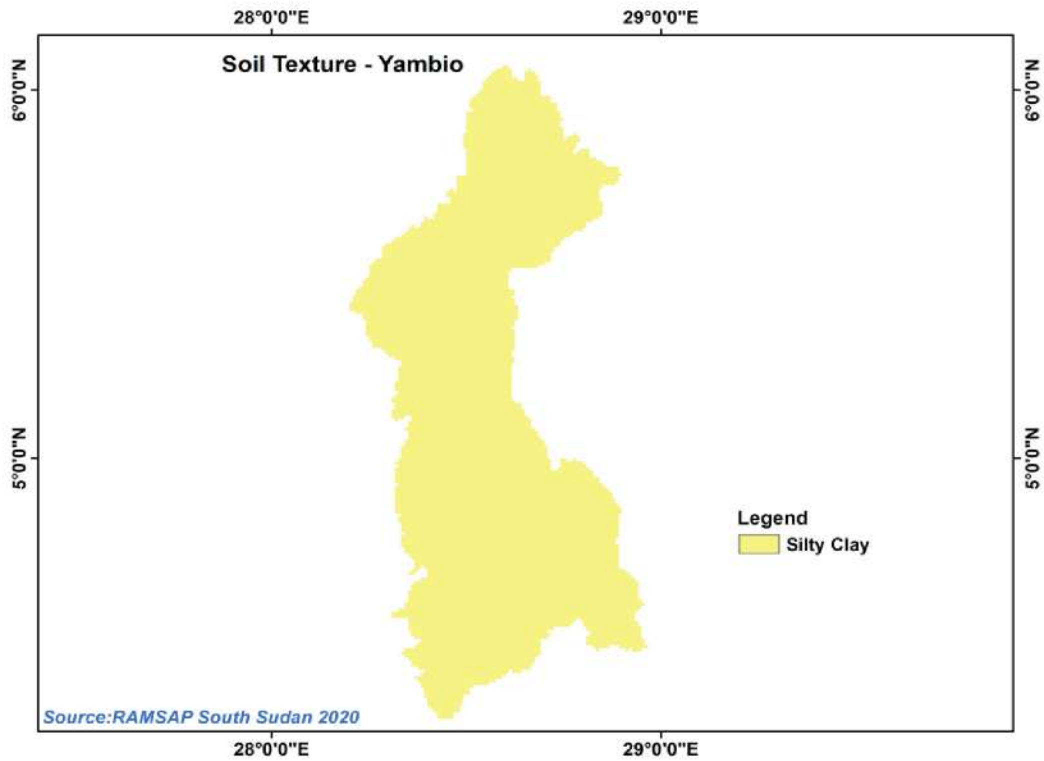


Figure 50. Soil texture at Yambio field site.

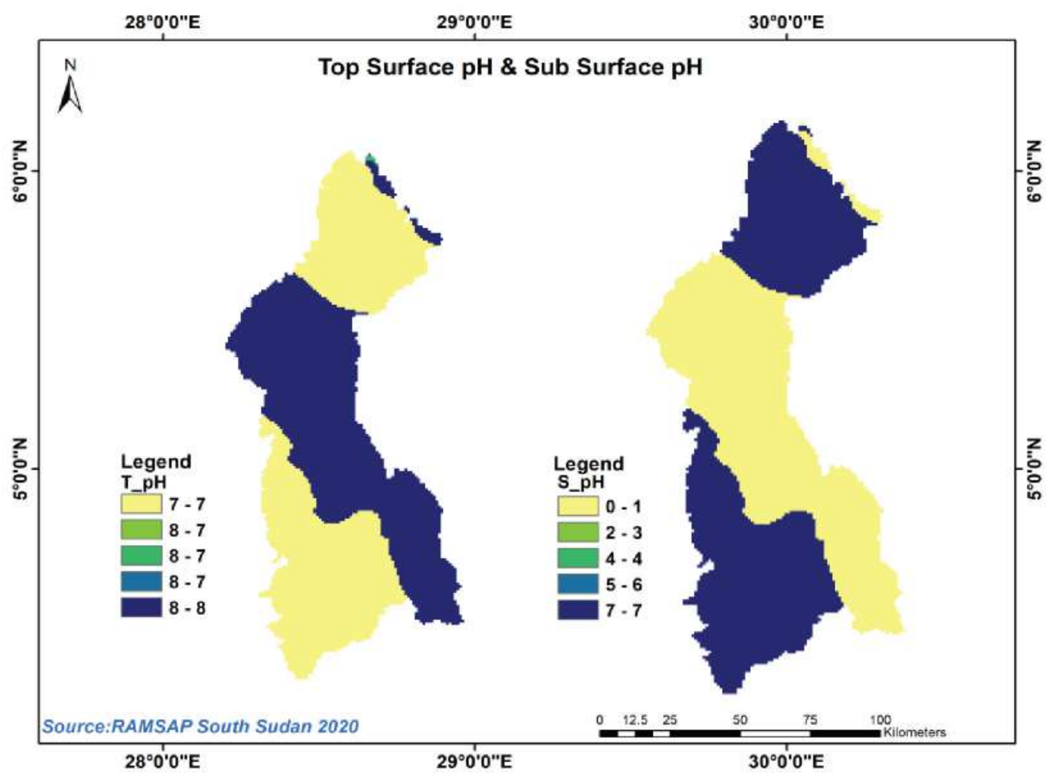


Figure 51. pH of surface and sub-surface soil at Yambio field site.

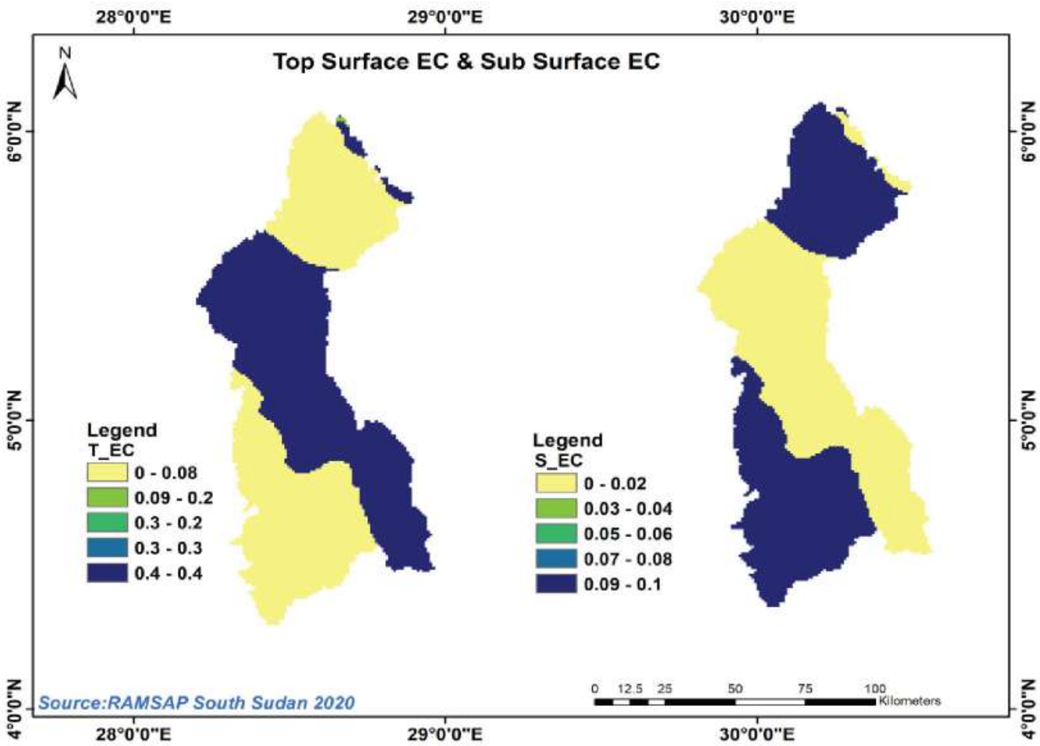


Figure 52. EC of surface and sub-surface soil at Yambio field site.

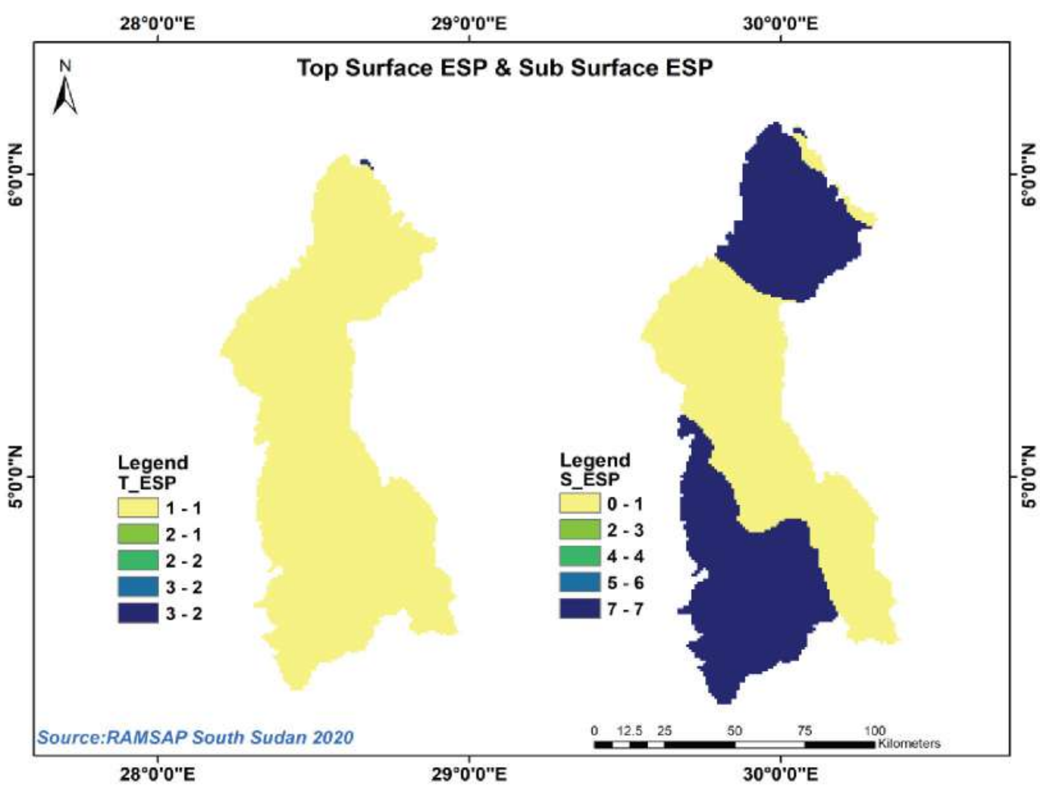


Figure 53. ESP of surface and sub-surface soil at Yambio field site.

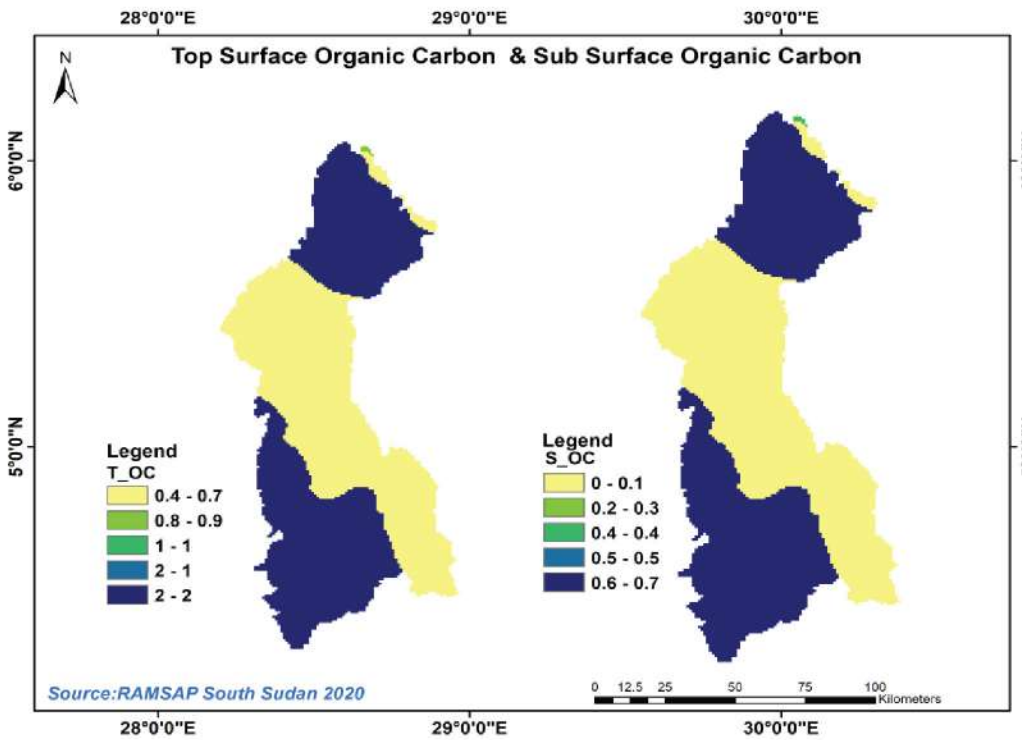


Figure 54. Organic contents in surface and sub-surface soil at Wau field site.

3.8 Rumbek field site

Table 9 shows that 5.56% area is under grassland while 2.25% and 91.97% are covered by shrubs and trees, respectively. The area covered by crops is almost nil (0.76%). The spatial distribution of vegetation classes is given in Figure 52. Maps related to soil texture, rainwater harvesting, pH, soil salinity, ECP, and surface organic carbon are given from Figures 53-58.

Table 9. Land use and land cover data for Rumbek field site.

No.	Vegetation classes	Area (km^2)	Percentage (%)
1	Tree cover areas	2654	25.33
2	Shrubs cover areas	2918	27.85
3	Grassland	4534	43.27
4	Cropland	318	3.03
5	Vegetation aquatic or regularly flooded	40	0.38
6	Lichens Mosses / Sparse vegetation	2.4	0.03
7	Built up areas	5.2	0.05
8	Open Water	4.4	0.42
	Total Area	**10,476**	**100**

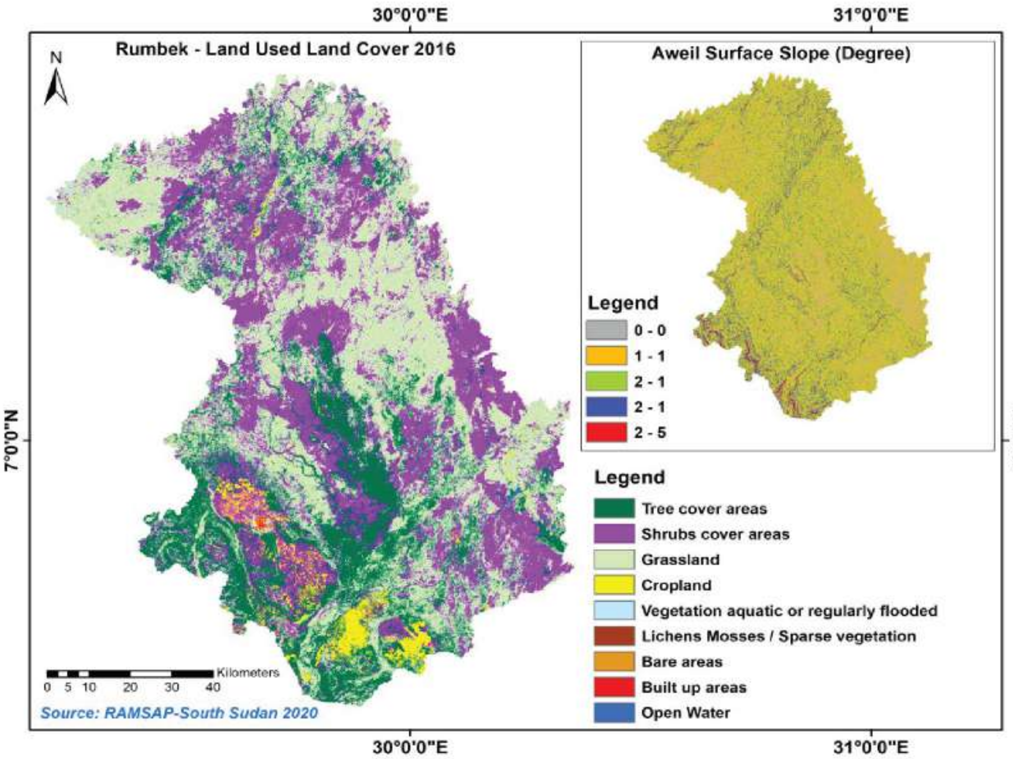


Figure 55. Land use and land cover at Rumbek field site.

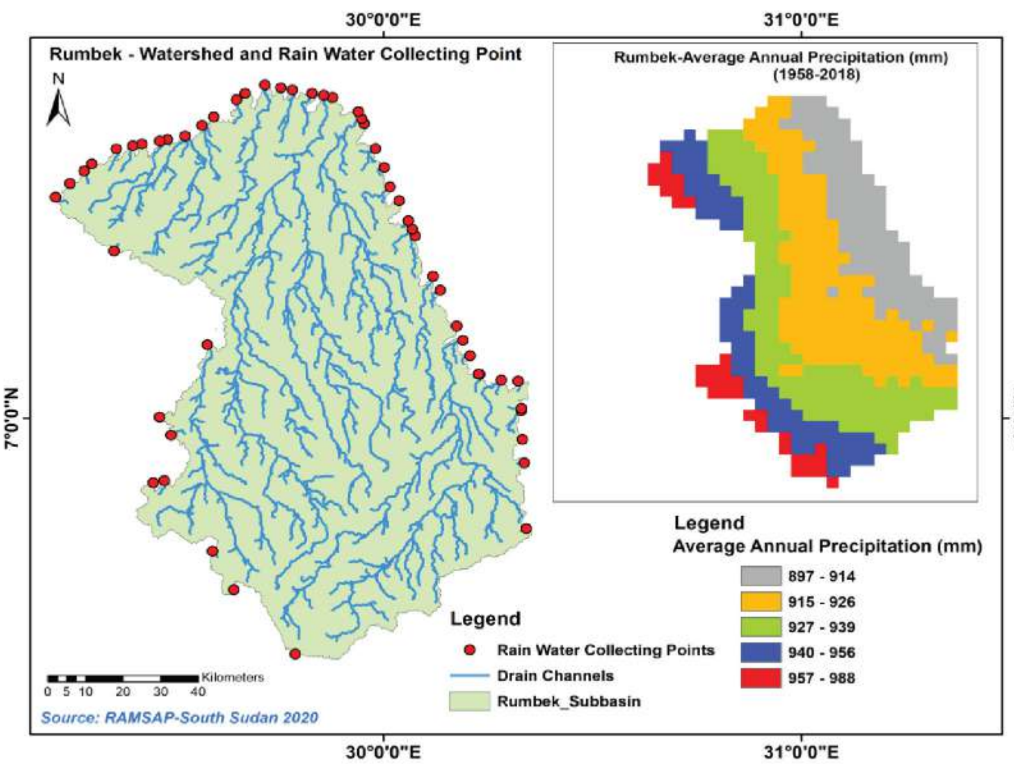


Figure 56. Rainwater harvesting points and surface slopes at Rumbek field site.

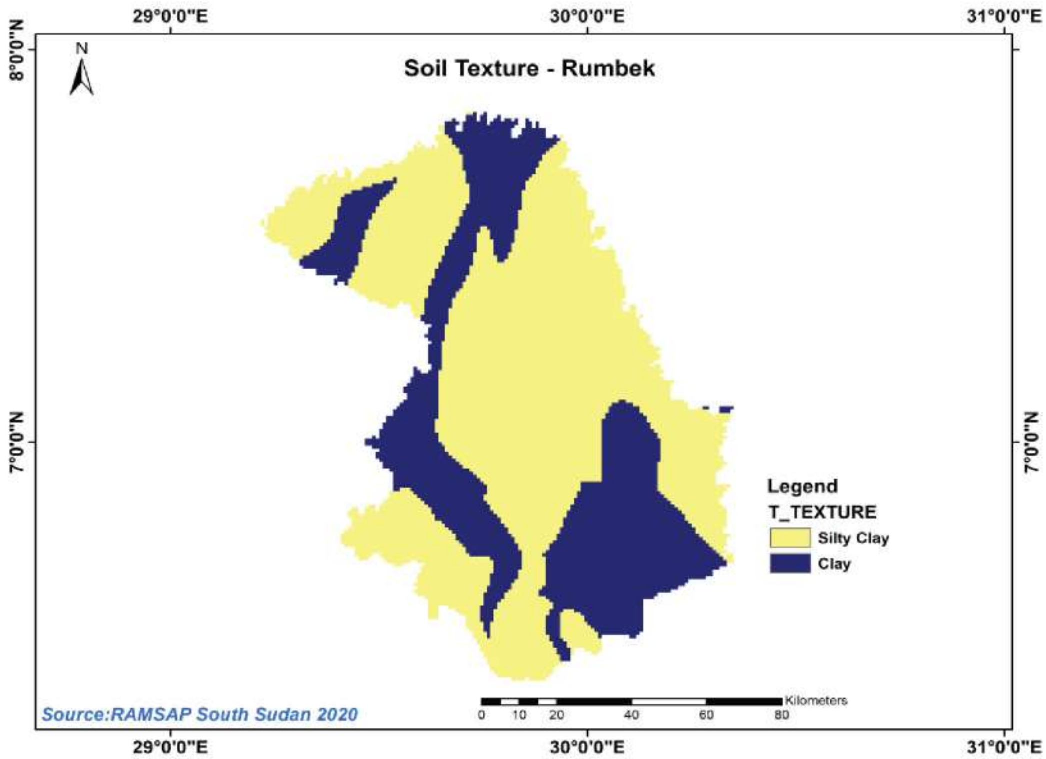


Figure 57. Soil texture at Rumbek field site.

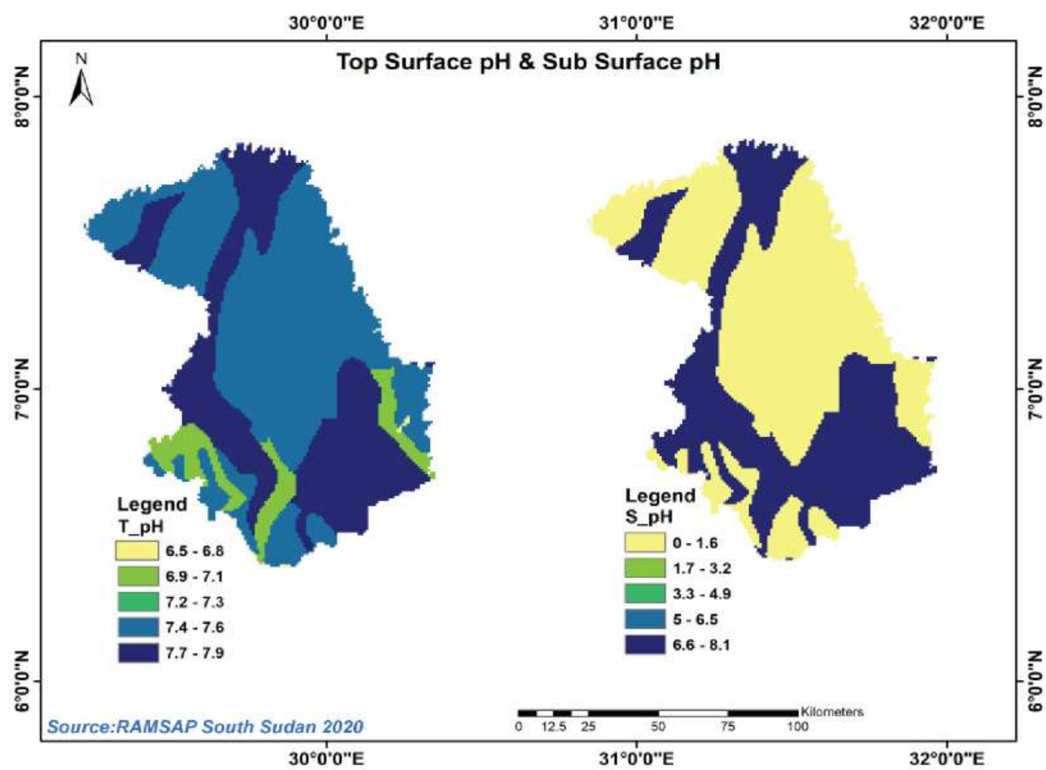


Figure 58. pH of surface and sub-surface soil at Rumbek field site.

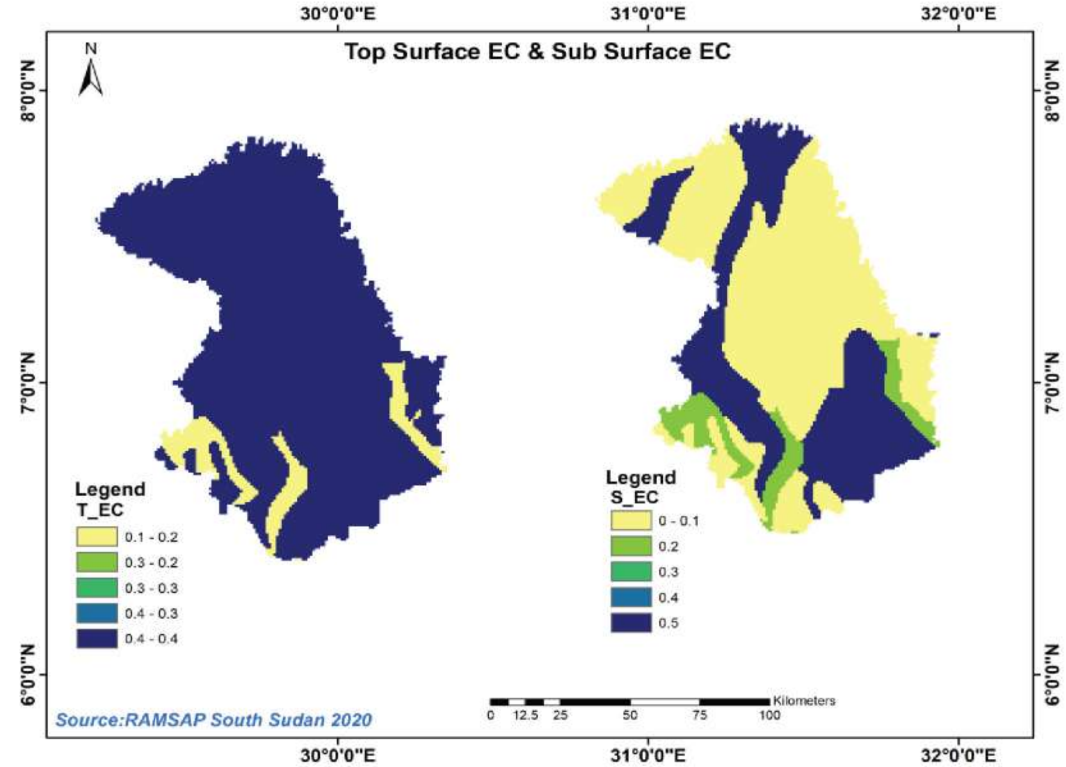


Figure 59. EC of surface and sub-surface soil at Rumbek field site.

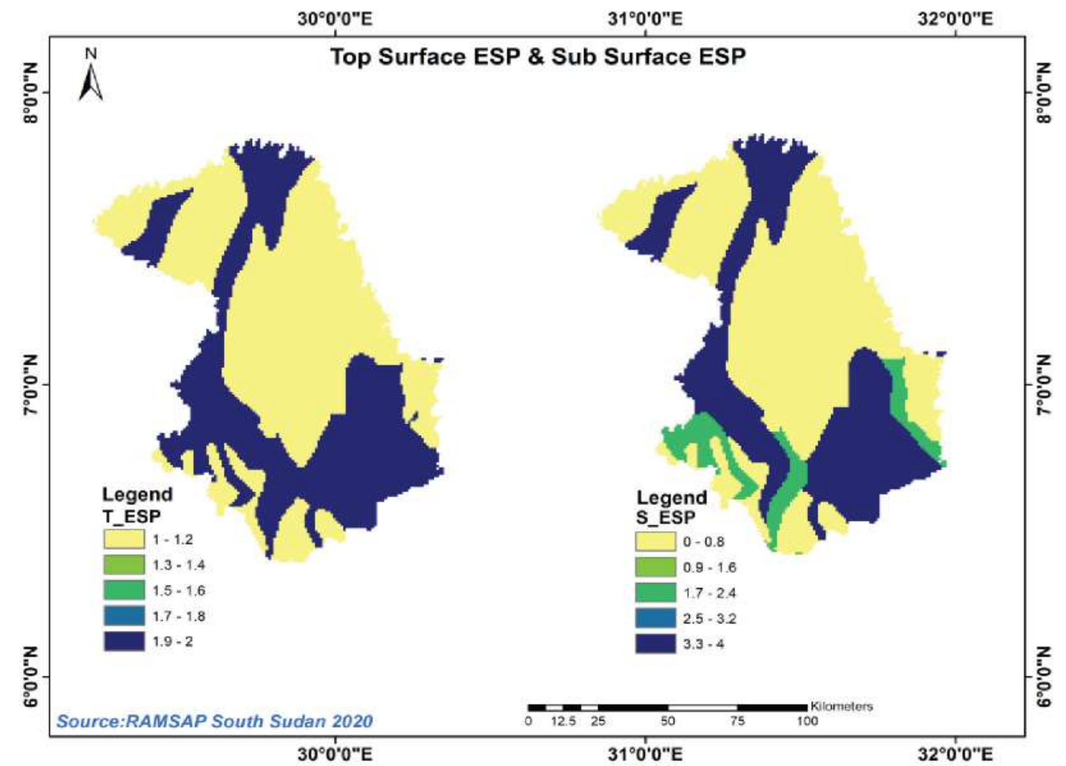


Figure 60. ECP of surface and sub-surface soil at Rumbek field site.

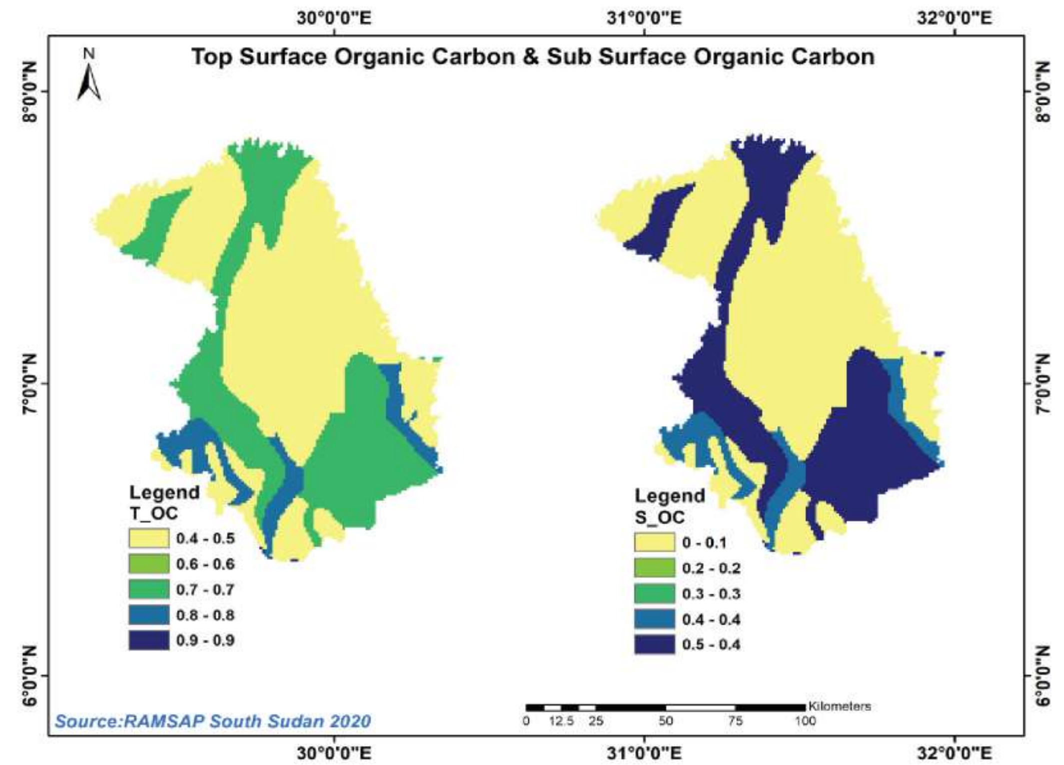


Figure 61. Organic content of surface and sub-surface soil at Rumbek field site.

3.9 Jubek field site

Table 10 shows that 5.56% area is under grassland while 2.25% and 91.97% are covered by shrubs and trees, respectively. The area covered by crops is almost nil (0.76%). The spatial distribution of vegetation classes is given in Figure 59. Maps related to soil texture, rainwater harvesting, pH, soil salinity, ECP, and surface organic carbon are given from Figures 60-65.

Table 10. Land use and land cover data for Jubek field site.

No.	Vegetation classes	Area (km²)	Percentage (%)
1	Tree cover areas	5629	32.32
2	Shrubs cover areas	2688	15.43
3	Grassland	8657	49.71
4	Cropland	352	2.02
5	Vegetation aquatic or regularly flooded	5.3	0.03
6	Lichens Mosses / Sparse vegetation	0.0	0.0
7	Built up areas	42	2.41
8	Open Water	41	2.40
	Total Area	**17,413**	**100**

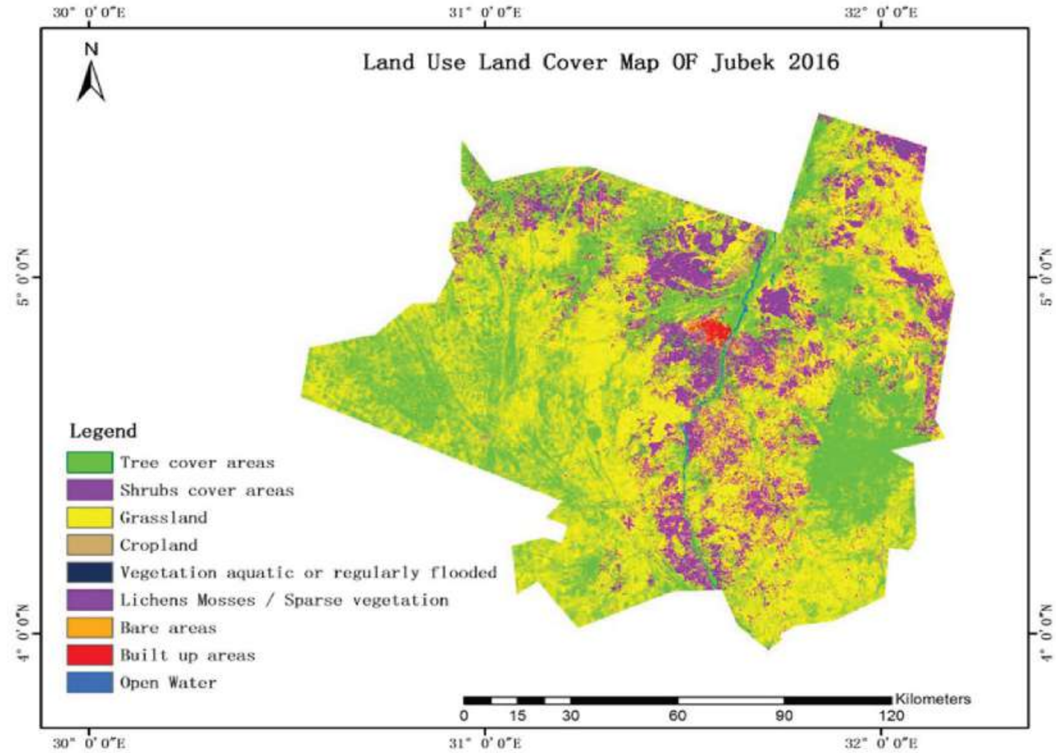


Figure 62. Land use and land cover at Jubek field site.

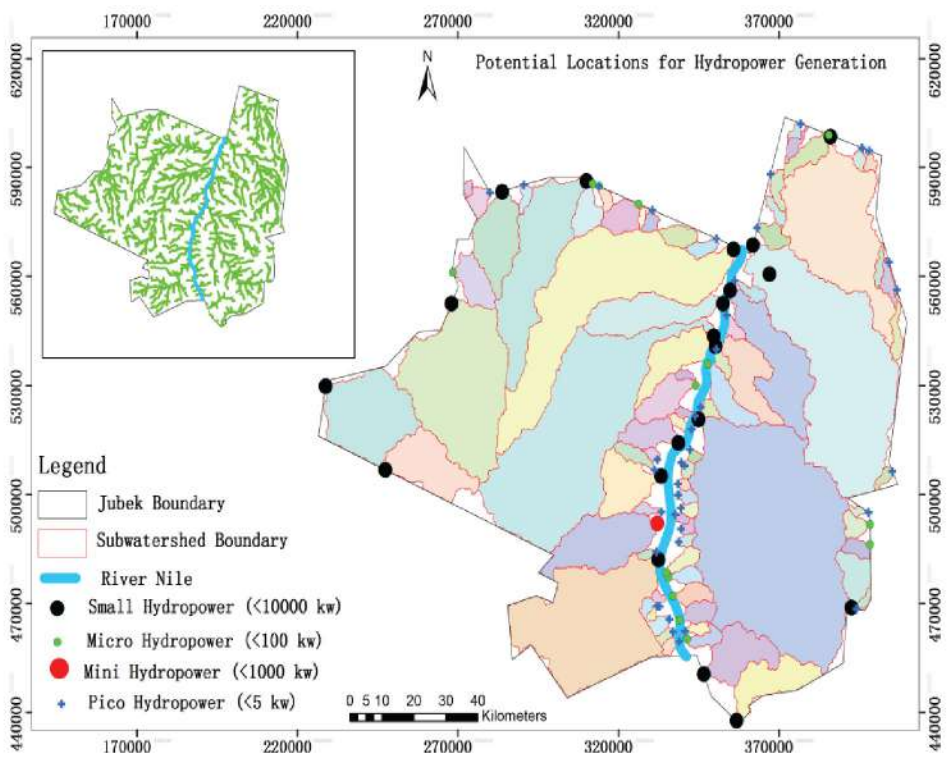


Figure 63. Rainwater harvesting points and surface slopes at Jubek field site.

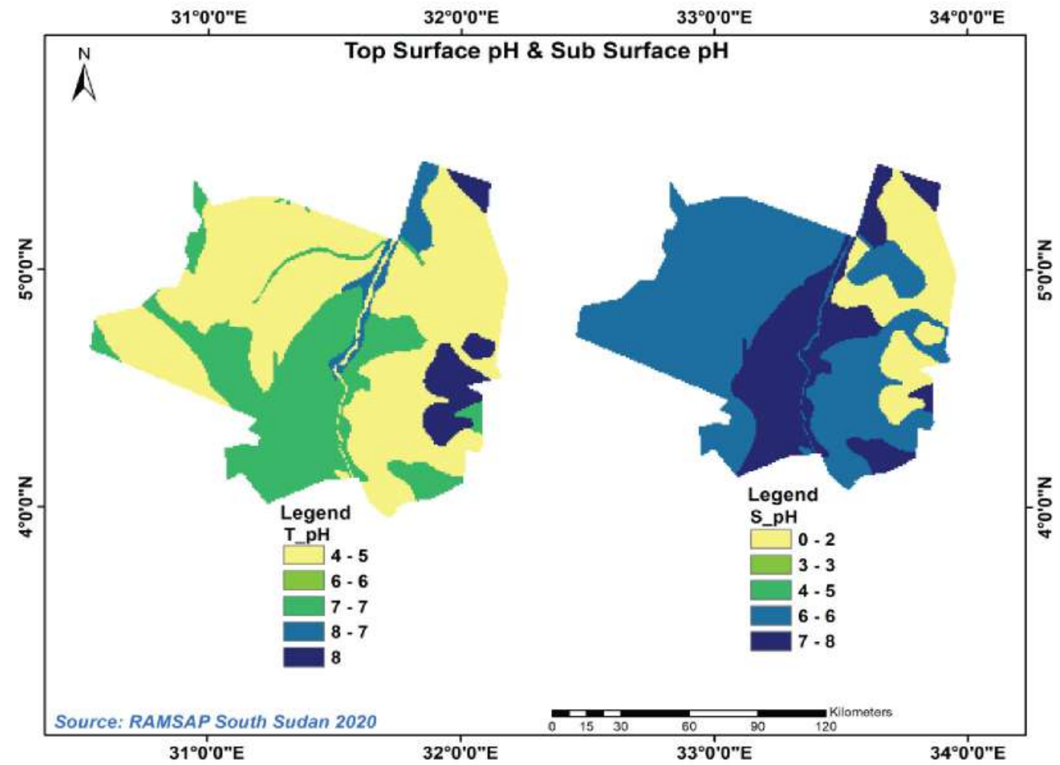


Figure 64. pH of surface and sub-surface soil at Jubek field site.

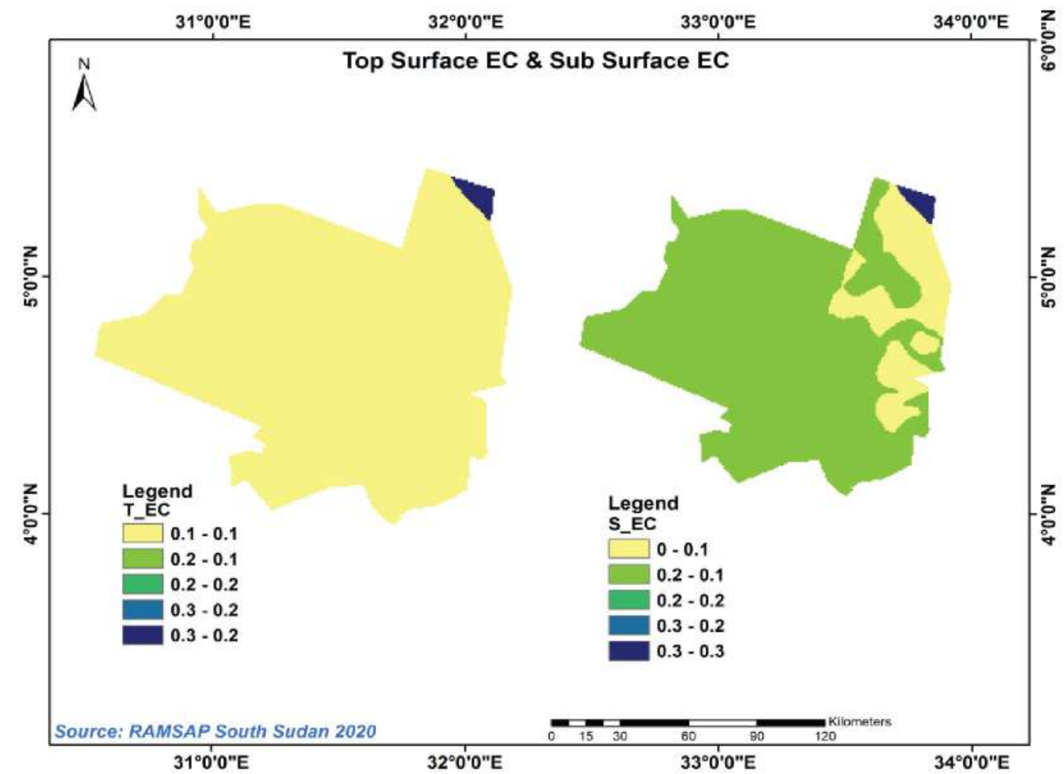


Figure 65. EC of surface and sub-surface soil at Jubek field site.

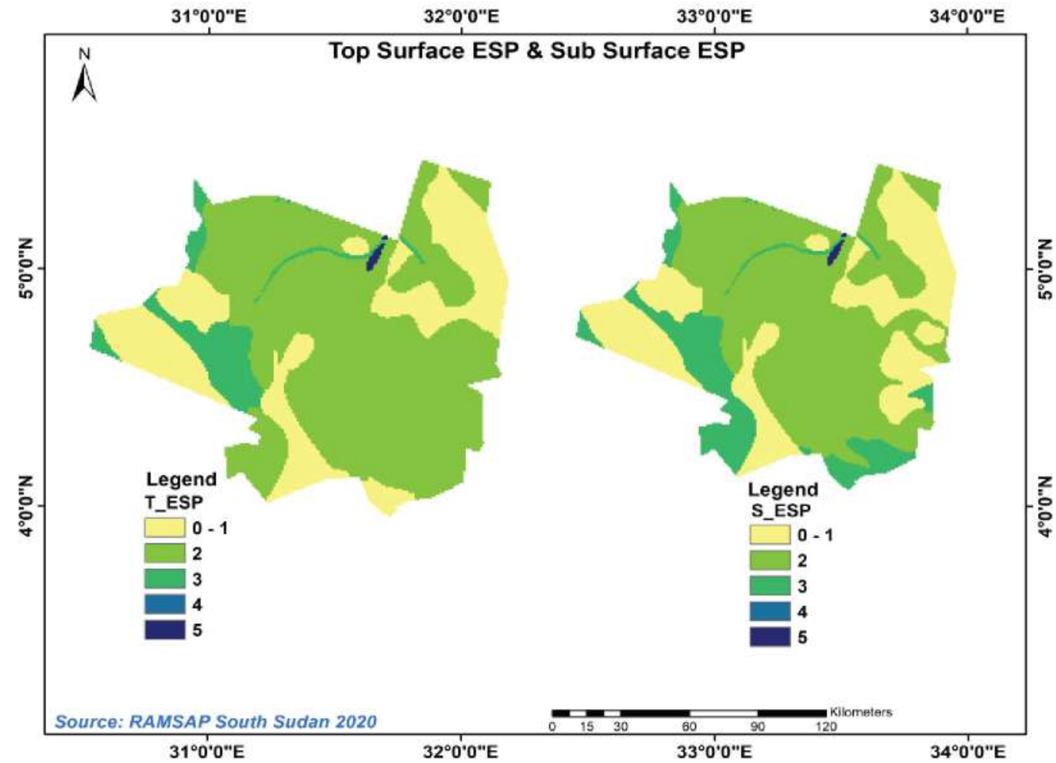


Figure 66. ECP of surface and sub-surface soil at Jubek field site.

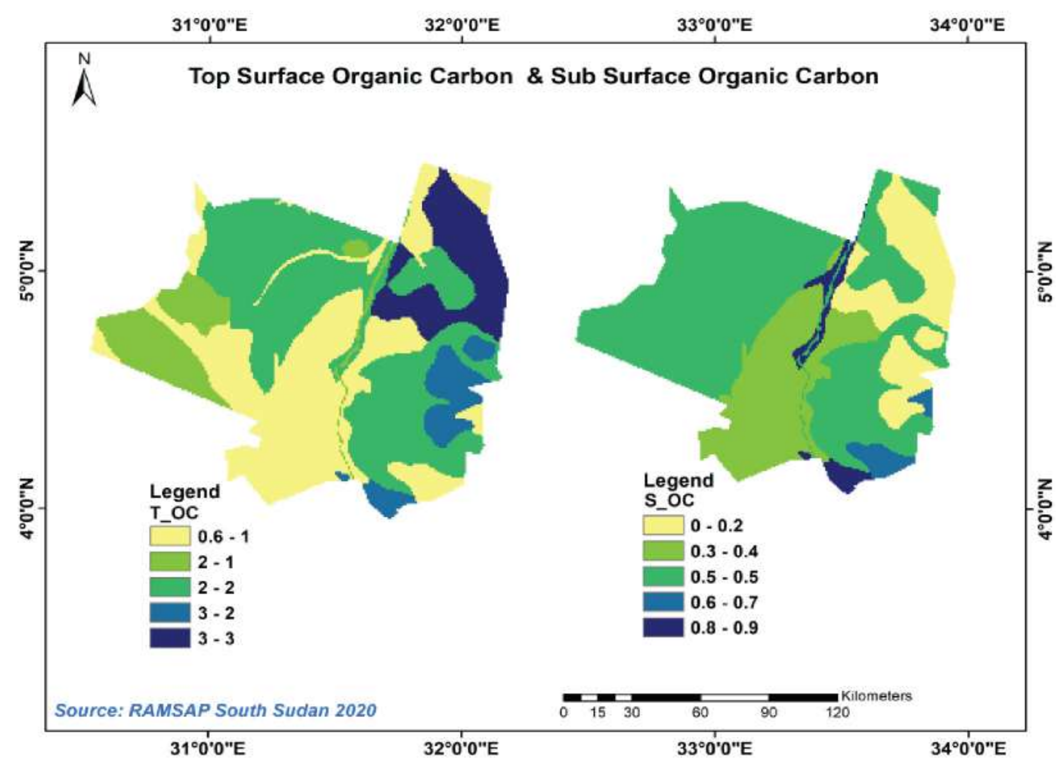


Figure 67. Organic content of surface and sub-surface soil at Jubek field site.

04

CONCLUSIONS

The increasing population in South Sudan after the Comprehensive Peace Agreement (CPA) in 2005 results in high demand for food. Despite having fertile lands and sufficient water resources, only 5% of the area is cultivated. In addition to other factors, the lack of accurate data and information about the potential cultivated areas that can be used to grow food and feed crops are challenging issues that need immediate attention. Recent famine reported by some international agencies and later confirmed by the government of South Sudan is evidence that such information is required urgently for timely decision-making to reduce or eliminate such threats in the future. It is estimated that about 46.7% of the population in South Sudan is severely food insecure. Field data collection on land use, identification of suitable locations for different types of irrigation, the establishment of stream networks, and potential areas for rainwater harvesting is an expensive, time-consuming, and laborious task. Therefore, modern tools such as remote sensing and GIS can develop datasets and information that policymakers can use to make timely policy decisions.

This study used remote sensing and GIS approaches to collect and process the soil quality data to develop spatial distribution maps of the target areas. The RAMSAP project field team did field measurements to validate the results achieved using remote sensing data for the nine target areas, i.e., Aweil, Bor, Renk, Torit, Kapoeta, Wau, Yambio, Rumbek, and Jubek. The collected data and information were used to develop detailed GIS maps of land use land cover, digital elevation model, watershed, precipitation, rainwater collecting points, soil salinity, sodicity, soil pH, and organic carbon content. The results of this study were compared with the FAO soil data. It was found that there is a close relationship between the FAO soil data and the RAMSAP soil work (R2 = 76.6).

The land use and land cover map of South Sudan show that the biggest cropland is in Renk (42.9%), followed by Kapoeta (7.9%), Bor (3.9%), Torit (3.1%), Aweil (2.6%), Wau (0.8%) and Yambio (0.2%). Apart from Renk, the other parts of the targeted areas show small portions of land under cultivation. However, there is a high potential to transform shrub and grasslands into farmlands if land transformation policy is implemented correctly. The results of DEM model revealed that most of the surface land of the study areas has a slope angle between 00 – 40, which means that the sites are appropriate for most agricultural practices using different irrigation methods. This requires expansion of irrigation network and training of farmers on improved on-farm water management strategies. Similar studies should be conducted in other parts of the country to develop a strategic policy framework to enhance agricultural productivity, increase food security, and reduce poverty.

BRIEF ABOUT THE RAMSAP PROJECT

Background

Increasing salinity remains a challenge to the sustainability of irrigated agriculture in Ethiopia and South Sudan as it reduces natural biodiversity and farm and livestock productivity. The agricultural sector in Ethiopia supports 85% of the workforce. About 85% of the population living in rural areas is directly dependent on agriculture for their livelihood. Seven million smallholder farmers produce more than 95% of the total agricultural outputs, including food crops, cereals, oilseeds, and pulses. Cotton and sugar are grown in state-owned large-scale enterprises. Ethiopia also has enormous livestock resources, including cattle, sheep, goats, and camels. Despite this high biodiversity and distinctive ecosystems, Ethiopia is one of the world's poorest countries and known as a country of famine. Food shortages are widespread, and since 1970 there have been severe famines almost once per decade.

Land degradation is considered one of the major causes of low and, in many places, declining agricultural productivity and continuing food insecurity, and rural poverty in Ethiopia. Today, Ethiopia stands first in Africa in salt-affected soils due to human-induced and natural causes. Currently, about 11 million ha (Mha) land in Ethiopia is exposed to salinity and sodicity, out of which 8 Mha have combined salinity and alkalinity problems. In contrast, the rest 3 Mha have alkalinity problems. About 9% of the population lives in salt-affected areas. The saline areas in Ethiopia are in the Tigray region and Awash River basin, and the situation is expected to exacerbate in the future due to climate change-induced factors. There is an urgent need for salt-affected soils to be restored to their production potential to produce enough food for the rising population.

In South Sudan, agriculture accounts for 36% of the non-oil GDP, with 80% of the population living in rural areas largely dependent on subsistence farming and 75% of the households consuming cereals as a prominent part of their daily diet. Despite abundant water supplies, only 5% of the total 30 million ha arable land is cultivated. Crop yields are low, which negatively affects the incomes and livelihood of poor farmers. Significant barriers are lack of agricultural inputs such as seed and fertilizer, poor advisory services, and inefficient irrigation management. Although South Sudan has the highest livestock per capita globally, with 23 million head of cattle, sheep, and goats, there is little use of improved varieties of seed or breeds of livestock. For increased livestock productivity, there is a need to introduce improved forage varieties resistant to common diseases. The salt-affected lands in South Sudan are in the White Nile irrigation schemes. These areas have hardly been utilized for agricultural production despite having great potential due to freshwater availability from the Nile. Therefore, bringing these degraded lands to acceptable production levels is essential to ensure food security and social stability.

With a 3% average population growth in these countries, future food security and the livelihood source for a considerable portion of the population remains a challenge to the governments. Increasing the productivity of existing salt-affected lands and protecting newly developed areas from the spread of salinity is therefore of paramount importance. The smallholder farmers in both countries can increase their agricultural productivity and farm incomes if their technical and financial capacity is enhanced. They need guidance on the improved irrigation and salinity management strategies and access to modified salinity-tolerant seeds for crops and forages. Therefore, for millions of farm families in these countries, access to improved knowledge and inputs will be a dividing line between poverty and well-being.

The areas of low to moderate salinity levels can be restored by improving irrigation and crop management practices. However, in areas where increased salinity levels have restricted the growth of normal field crops, use of Biosaline Approach could be a potential solution. This approach is based on adaptable technology packages of salt-tolerant fodders and halophytes integrated with livestock and appropriate management systems. These integrated crop and forage-livestock feeding systems can increase resilience of small-scale crop-livestock farms, particularly in Ethiopia and South Sudan where livelihood of smallholder farmers is largely dependent on the development of the livestock sector.

This project will devise a strategy to improve the productivity of saline soils to an economically feasible level and minimize future salinity development in these areas. The project will draw on past work's successful experiences to identify the most productive alternative crop and forage production systems, and devise a strategy for scaling up these production packages to improve livelihood of rural communities, especially women in the target areas of both countries. Through enhanced crop yields and reduced loss of land to degradation, the project will improve farmers' resilience, thereby reducing migration to cities and health problems due to stress on families suffering from the impact of salinity on their livelihoods.

Project Goals and Objectives

The project's overall goal is to attain higher agricultural productivity, food security and income for smallholder farmers, agropastoral/pastoral communities through rehabilitation and sustainable management of irrigated salt-affected farming areas of Ethiopia and South Sudan. The main objective of this project is to introduce, test, and promote appropriate technologies and practices for rehabilitation and sustainable management of irrigated salt-affected farming systems and in Ethiopia and South Sudan and draw lessons for scaling up.

The Target Group

The project will directly target 5,000 smallholder farmers in selected areas in Ethiopia and South Sudan who face high food insecurity due to their high dependency on marginal water and land resources. The indirect beneficiaries will be about 50,000 farmers (40,000 farmers in Ethiopia and 10,000 farmers in South Sudan) dependent on forage production in both countries with an estimated total area of about 200,000 ha (150,000 ha in Ethiopia and 50,000 in South Sudan). These targets will be achieved by producing and distributing tested crop and forage seeds, disseminating improved soil and water management practices, and training farmers and extension workers in the target areas.

The rehabilitation of degraded lands will improve the livelihood of 9% of the population of Ethiopia which lives in salt-affected areas. In South Sudan, where only 7% of 30 million ha of land is being cultivated,

The Biosaline approach was developed by ICBA, in partnership with NARS of at least eight African countries and support of international donors including IFAD, OFID and IDB.

rehabilitation and management strategies developed under this project will open a window of opportunity for thousands of rural farmers to improve the productivity of their degraded lands and increase their farm incomes. The outcomes of this project will significantly benefit women as they will have better access to food and health facilities. The transformation of degraded lands into productive lands will also create direct and indirect job opportunities for the large young population. This will help in reducing the migration trends of unemployed youth from rural areas to urban areas.

The project will target Ethiopian highlands (Tigray, Amhara, and Afar) and lowlands (Omara and Somali), which produce 87% of Ethiopia's cattle and 5% of its sheep and goats; however, land degradation has reduced farm and livestock productivity of these areas resulting in rural poverty. The developed crop-livestock value chain system will benefit Ethiopia because this is the largest livestock producer in Africa.

The project will target the White Nile irrigation schemes (50,000 ha area) in South Sudan. These soils have an immense potential due to the availability of fresh water from the White Nile River and its tributaries which run through 7 out of 10 states, providing ready access to an abundant water supply and river transport access for agriculture producers. However, these soils are not being cultivated for decades due to low soil fertility and the non-availability of good quality seeds for crops and forages. Currently, 18% of the land is not cultivated because of seed shortage, and 9% is due to low soil fertility. Increasing the productivity of these lands will be crucial to ensure food security for the smallholder farmers of the area.

Strategy, Approach and Methodology

This project will adopt an integrated soil and water management approach to tackle the salinity problems in irrigated areas of both countries. The project strategy would be first to diagnose the issues and then develop long-term mitigation, management, and rehabilitation strategies at the farm and regional level relevant to the problem using proven and high-level international salinity science and management. Since the rehabilitation of saline soils through engineering (drainage systems) or chemical amendments is an expensive and time-consuming process, this project will work on adaptive and mitigation approaches for rehabilitating salt-affected soils.

This project will adopt a participatory approach to conduct field trials in different parts of both countries to test the suitability of local and imported crop and forage species to rehabilitate salt-affected soils. Adaptation trials will be conducted at the Farmers Training Centers (FTCs) and volunteer farmers' plots in collaboration with the national partners. These trials will also be used for demonstration purposes before scaling up. The project team will jointly implement the best management practices for salinity control at the farm level. Smallholder farmers (especially women and young farmers) will be trained to establish seed/gene banks at the community level. ICBA has successfully applied this approach in SSA.

The project will generate and disseminate sustainable integrated crop-livestock technology packages to diversify farmers' incomes through the sale of animal products and forages to local markets, thus making the production systems economically sustainable. However, salt-tolerant forage plants are variable in biomass production and nutritional value. The available salt-tolerant forages have not been selected or managed for improved livestock production. For this reason, they need to be tested locally for their (a) edible biomass production (kg/ha/year); (b) nutritional value (i.e., the response in animal production per unit of voluntary feeding intake), and (c) the use of micronutrients and nutraceutical properties.

The project will address gender equality and social issues as cross-cutting themes in each area. The project will include the most vulnerable groups of the society to ensure that the interventions benefit poor men and women farmers and households. Since rural women play a crucial role in undertaking agricultural and livestock activities, enhancing their knowledge and capacity will be one of the main targets of this project.

Project Outcomes and Impacts

The immediate outcome will be the full implementation of new salt-affected management strategies within the pilot sites with related benefits to farming communities and land management organizations. The long-term effect will be new thinking and awareness about the new salinity management approaches and implementation of overall system reform. This, in turn, will lead to out-scaling of alternative production packages beyond the project area through project partners, including key government organizations. The successful implementation of the above activities will increase the productivity of salt-affected lands, which will positively contribute to the country's economy and reduce rural poverty. The overall impact of the project will be revitalized agriculture in Ethiopia and South Sudan.

Scaling up Pathways

The critical element of this project is to pilot innovative test strategies and approaches for the rehabilitation and management of salt-affected soils and then "scale up' recommended technologies to reach up to a more significant number of rural poor. As discussed before, all activities of this project will be carried out with the involvement of local rural communities. Once convinced, these communities will act as the champions of change and critical drivers in the process of scaling up. For successful scaling up, policy support and institutional infrastructure is very crucial. Opportunities and constraints that may affect the scaling up process will be critically evaluated during the pilot stage. For long-term sustainability, the overall impact of the alternative production systems on the lives of the rural poor, natural resources and environment will also be reviewed.

Socio-Economic and Environmental Impacts

The project will develop modified approaches to improve water management for salinity control and demonstrate best soil management practices for different salt-tolerant crops and forages. Adopting alternative crop and forage production systems will reduce the area lost to salinity degradation, bring income to farmers, and improve the livelihood of poor rural communities, especially women. The transformation of salt-affected lands into productive lands will also contribute directly to poverty reduction by increasing fuelwood, construction materials, wild foods, and medicinal plants.

The International Center for Biosaline Agriculture (ICBA) is implementing a 4-year project on the "Rehabilitation and management of salt-affected soils to improve agricultural productivity (RAMSAP)" in Ethiopia and South Sudan. The project is funded by the International Fund for Agricultural Development (IFAD) and is being implemented with the technical support of the Ministry of Agriculture (MoA), Ehiopia and the Directorate of Research and Training (DRT), South Sudan. The project is of great importance for both countries as it directly targets resource-poor smallholder farmers, especially women and children, who face high food insecurity due to their dependence on marginal soils. The project is introducing innovative soil and water management practices and salt-tolerant genotypes of food and forage crops that have the potential to grow in marginal areas. In addition, scientists, extension workers and farmers are being trained to improve their capacity for the management of marginal resources. Through improved crop yields and reduction of loss of land to degradation, the project empowers farmers by increasing their resilience against the impact of salinity on their livelihoods.

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