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Characterization of Agricultural Soils in Sanbate Irrigation Site at Kachabira Wereda, Kambata Tembaro Zone, Southern Ethiopia

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Abstract

This soil survey has been conducted at the western part of Kachabira woreda covering the right side of the Sanbate River in Gemesha, Wollana kebele, Kachabira woreda, Southern Ethiopia. The objective of the study was to investigate, analyze, and describe the distribution of different soils. Both a rigid and flexible grid system of the survey was adopted. Rhodic Nitisols and Mollic Nitisols are the dominant soil unit of the study area, covering about 188.46ha and 43.71ha of the total study site, respectively. The physical characteristics are mainly marked by the existence of silt clay, clay loam and silt clay loam at the top surface and clay loam and clay soil texture at the subsurface with deep to very deep soil depth, well to moderate drainage class, low to medium rated available water holding capacity, medium level rated infiltration capacity and moderately slow hydraulic conductivity of the soil. As far as the chemical properties are concerned, the soils are characterized by slightly moderately acidic, non-saline and low to moderately exchangeable sodium percentage (ESP) with high to very high cation exchange capacity (CEC), moderate to the high rated level of percent base saturation (PBS) and with medium organic carbon, low to moderate level of soil nitrogen and high rated of available P level. Based on the data collected from representative soil profile and soil physicochemical analytical data; the future development will be constrained unless integrated fertility management is planned and implemented. Concerning world reference base (WRB) soil classification legend, the soils at Sanbate irrigation site were classified as Mollic Nitisols and Rhodic Nitisols. Therefore, the current moderately acidic soil pH rate and the low to medium soil nitrogen and the moderate rate level of ESP soils in the study area will also be a limiting factor in the development of the proposed irrigation project. Hence, Sustainable soil management system, which includes continuous crop cover, mulching, and organic manuring with appropriate inorganic fertilizers should be practiced to maintain and to improve soil fertility and to control soil erosion.

Keywords: ***Chemical; Nitisols; Physical; Soil mapping unit***

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1. Introduction

Soil survey, or soil resource inventory, is the process of determining the soil types and the properties of the soil cover over a landscape and mapping them for others to understand and use. The practical purpose of soil survey is to enable more numerous, more accurate and more useful predictions to be made for specific purposes than could have been made otherwise, i.e., in the absence of location-specific information about soils [1]. Thus, the potency of land resource for agricultural development can be observed through soil survey activity. The tasks of soil survey are description, classification, and mapping of soils. The objective of soil survey is to study about actual and potential land use management strategies [2-3]. The information collected in a soil survey helps in the development of land suitability classification planning and, evaluates and predicts the future soil condition as well as the effects of land use and associated management practices on the environment. Soil is a basic natural resource that determines how irrigation water should be managed. The amount of irrigation water the soil can hold for plant use is determined by its physical and chemical properties. This amount determines the length of time that a plant can be sustained adequately between irrigation or rainfall events, the frequency of irrigation, and the amount and rate to be applied. Along with plant evapotranspiration (ET), it also determines the irrigation system capacity system needed for desired crop yield and product quality. Thus, the soil survey study of the current project is one of the key sectors of study in implementing the successful irrigation project in Southern Ethiopia.

The soils of the project command area had not undergone previous surveys, nor had they been described for morphological, physical, chemical and mineralogical characteristics. Hence, a soil survey study was found to be a crucial case to realize the development of the proposed irrigation project. The surveyed area is specifically situated at the western part of Kachabira woreda Shinshecho city covering the right side of the Sanbate River in Gemesha and Wollana kebele, Kachabira woreda, Kambata and Tembaro Zone, Southern Nation Nationalities People Regional States, covering a total of 232.2ha. Therefore, the aim this study to characterize, classify soils of the irrigation site, and to assess the soil fertility status of the proposed site.

2. Materials and Methods

2.1 Description of the study area

Sanbate irrigation project is located in Gemesha and Walena kebele, Kachabira woreda, in the Kembata and Tembaro Zone of SNNP Regional State. It covers a total command area of 232.2 ha, which is 21 km west of Durame town, 155 km North West from Hawassa and 3.5 km south west to Shinshecho Town. The command area is specifically located at 37º 43’22” to 37º 45’ 26” Longitude 70 12’ 15” to 7º 11’08” Latitude (FIG. 1).

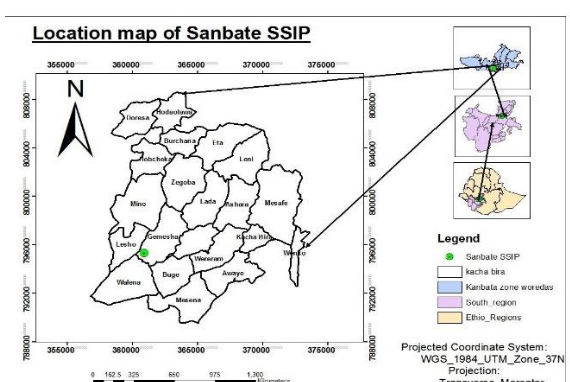

FIG. 1. **Location map of Sanbate SSIP command area.**

2.2 Climate

Meteorological data indicates that the study area has a mean annual rainfall of 970 mm. According to the Metrological data the maximum rainfall is recorded on July, August with 131mm and 128 mm, respectively (TABLE 1). The average mean annual maximum and minimum temperature of the study area is 26.4ºC and 11.5ºC respectively.

As a result, the mean annual temperature of the area is about 18.95ºC. The lowest minimum temperature of the area is about 7.2ºC and it is recorded in December. The relatively high temperature was recorded on particularly in the months of December, January, February, and March. In general, the hottest season is from November to May with temperature ranges of 27.6 to 28.1ºC. The coldest season is from October to December with the temperature ranges of 7.9ºC to 10.5ºC (TABLE 1).

TABLE 1. **Metrological data Adopted for the proposed irrigation project.**

Month	**Min Temp °C**	**Max Temp °C**	**Humidity %**	**Wind km/day**	**Sun hours**	**Rad MJ/m²/day**	**ETo mm/day**	**Rain-mm**	**Eff rain-mm**
January	10.8	27.6	57	78	8.1	19.8	3.8	32	30.4
February	12.1	28.1	54	78	8.2	21.1	4.17	89	76.3
March	*12.3*	*27.7*	*59*	*78*	*8.5*	*22.6*	*4.43*	*98*	*82.6*
April	12.9	27	63	78	8.1	21.9	4.31	124	99.4
May	12	26.9	74	78	7.6	20.6	4	107	88.7
June	12.3	25.3	75	95	6.5	18.5	3.62	64	57.4
July	12.8	23.5	78	52	5.3	16.9	3.18	131	103.5
August	12.6	23.8	77	35	5.4	17.5	3.23	128	101.8
September	12.5	25.1	77	69	5.2	17.4	3.37	112	91.9
October	10.5	26.6	71	69	8.2	21.2	3.96	48	44.3
November	9.2	27.1	58	86	8.8	21	4.01	32	30.4
December	7.9	27.8	53	86	8.3	19.7	3.82	5	5
Average	11.5	26.4	66	73	7.3	19.8	3.83	970	811.7

2.3 Land use and land cover

The prevailing land-use practiced in the project command area is rain fed arable cropping depends on the plough. The principle crops are maize, teff, taro, haricot bean. At small size farmers have been growing perennial crops like coffee, banana and Eucalyptus while the livestock grazing is carried out on the degraded, exposed areas with patches of grass land and communal grazing lands along the banks of Sanbate River. In term of land cover type, the irrigable area is dominated by intensively cultivated land for cereal crops (maize, teff, beans and taro) and perennial crops (such as banana and coffee). Eucalyptus trees are common around homes and at the farm boundaries and in some parcel lands and found in patches which were used as immediate income source for smallholders.

2.4 Topography

According to the (FAO, 2006) slope class of the study area is categorized, described and presented below. About 148.3 ha of the gross command area varies with slope class rated as flat to gently sloping (0%-5%), sloping class. While 41.27 ha and 42.67 ha of the command area are classified as undulating or sloping and strongly sloping to steep slope class, respectively (TABLE 2; FIG. 2).

TABLE 2. **Slope class and area coverage of the proposed irrigation command area.**

Slope description	Slope class (%)	Area (ha)	Area (%)
Flat	0-2	63.68	27.42
gently undulating gently sloping	2-5	84.62	36.44
undulating or sloping	5-8	41.27	17.77
rolling or strongly sloping	8-15	27.03	11.64
moderately steep	15-30	11.8	5.08
Steep	>30	3.84	1.65
Total Gross command area		232.2	100.00

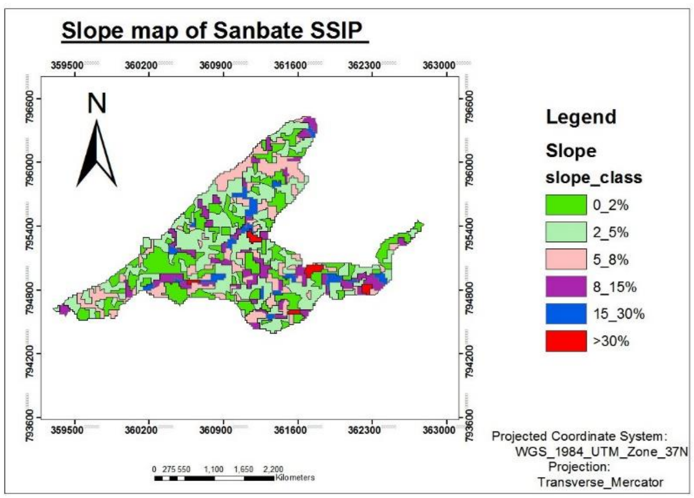

FIG. 2. **Slope map of Sanbate irrigation command area.**

2.5 Auger and pit observation tests

In the present survey area, combinations of both fixed and flexible grid survey method were adopted to conduct the field soil survey investigation. Parallel transects were spaced at 200 m interval and auger observations were made every 200 m-250 m along each transect, deepening on the homogeneity and heterogeneity (texture, color, drainage, slope) of the area. As a result the auger observation intensity was done at 1per 4 ha to 5 ha while the overall intensity of soil observations is done at 1per 0.28 ha depending on command area conditions (variability of soils in different mapping units) of the current study area.

A total of eight profile pits have been opened, however only 3 profile pits from which every identifiable horizon was sampled. Each profile pit measured 1 m × 2 m and up to 2 m in depth. The samples were taken to the laboratory for physicochemical analysis. The observations and recorded characteristics on the field and the chemical characteristics were used to produce a soil map (TABLE 3). The horizon characteristics were also described, using the Munsell color chart where necessary, e.g., for color. The thickness, texture, structure, consistence (moist and wet), presence of roots, soil faunal activities, accumulations, concretions, ferruginous hardenings, drainage characteristics, mottling, soil moisture state and horizon boundary were all noted. These observations and notes were made according to the soil survey guidelines for soil profile description [4]. Field provisional classifications were made, and these were modified and adopted or changed, as the case may be, after laboratory analysis.

2.6 Deep boring and core ring sample test

Deep borings have been carried out at representative sites up to 2.0 m to 4 m below the bottom of the profile pits to check the drainage characteristics of sub-surface and substrata layers, with particular reference to salinity and to locate any impermeable layers. From the deep borings, samples were collected for determination of salinity. Core Samples from significant natural horizons of the representative profiles were taken to for laboratory test of soil field capacity (FC), permanent wilting point (PWP) and soil bulk density.

2.7 Soil Permeability/Infiltration

Infiltration of representative soil samples was measured in the field using the double ring infiltrometer method. This method involves the use of two concentric rings (inner- 25 cm diameter ring and outer 55 cm diameter ring) with the outer annular spacing serving as a buffer or guard to ensure the desired vertical in the inner annular space. Both rings were driven into the soil, extending 8 cm below and 22 cm above the soil surface. Water was applied by ponding under a constant head of 10 cm. Infiltration was continued at each site until equilibrium was attained, usually after 2-5 hrs. In-situ soil hydraulic conductivity measurements were carried out using Inverse Auger Hole Method respectively. The overall field work includes description of soil profile pits (5 sampled and 3 non sampled pits) and 56 soil auger observation points, 2 *In-situ* infiltrations and hydraulic conductivity testing and 2 deep boring (TABLE 3). Out of described profile pits a total of 16 soil samples collected from natural horizons of four representative profile pits were analyzed for routine physical and chemical tests and besides 2 core ring samples were collected and analyzed for bulk density and moisture characteristics (FC and PWP) All the field observations were recorded on the soil description sheets prepared for augers, pits, infiltration, and permeability tests separately based on the procedures set [5].

TABLE 3. **Summary of soil survey Observation conducted.**

Code	Status	Number of Observations sites	Remark
PS	Soil profile pits sampled	3	
PW	Soil profile pits without sampling	5	
AW	Auger holes without sampling	56	
IR	Infiltration test	2	
HY	Hydraulic conductivity test	2	
DB	Deep boring	2	
CS	Core sample	2	

2.8 Laboratory analysis

Texture was determined by hydrometer method [6]. The soil pH was potentio-metrically measured in the supernatant suspension of a 1:2.5 while the electrical conductivity was measured in Conductivity Cell Potentiometric EC (mS/cm) (1:2.5). Organic carbon was determined using Walkley-Black oxidation method [7]. Total nitrogen was determined by the micro- Kjeldahl digestion, distillation and titration method, and available P was determined using the standard Olsen extraction method [8]. Total exchangeable bases were determined after leaching the soils with ammonium acetate [9]. Amounts of K^+, Na^+, $Ca^{2+}$and Mg^{2+} in the leachate were analyzed by AAS. Cation exchange capacity was determined at soil pH level of 7 after displacement by using 1N ammonium acetate method in which it was, thereafter, estimated titrimetrically by distillation of ammonium that was displaced by sodium [10]. Field Capacity (%) at 0.33 bar and Permanent Wilting Point (%) at 15 bar determined using Pressure Membrane Extractor, and the bulk Density (g/cm^3) was measured using core method.

2.9 Soil types and soil mapping units

The soil types and soil mapping units of the project command area are delineated, classified, characterized, and mapped as per [11-12] WRB. Each soil mapping unit was discussed with respect to slope, physiographic position, and surface feature, and soil depth, soil physical and chemical characteristics.

3. Results and Discussion

3.1 Morphological characteristics of soil

3.1.1 Effective soil depth

Soil depth refers to the thickness of the soil materials which provide structural support, nutrients, and water for plants. Accordingly, Most of the command area lies under very deep (>150 cm) categories.

3.1.2 Soil color

Soil color is the most obvious features of the soils that can be easily identified by any person. It is related to specific chemical, physical and biological properties of the soils. Accordingly, the major dominant soil of the project command area is dark brown. the soil color at the surface soils of the representative pedon (GSP-01, GSP-02 and GSP-06 ranges from dark reddish brown ((2.5YR ¾) to Dark reddish (2.5YR 3/6) and the soil color for the pedons GSP-03,GSP-08 and GSP-07 have dusk red(2.5YR 3/2) while the soil color at the sub surface of all the representative ranges from dark red to dark reddish brown (TABLE 4). Generally, the soil color at the surface soil layer was a darker color than their subsurface counterparts. Perhaps this could be due to the relatively higher organic matter contents in the surface horizons. this result agrees with the result of several authors reported that the surface horizons have a darker color than the corresponding subsurface horizons as a result of relatively higher soil OM contents [13-15]. Similarly, the finding of [16] indicated that soil color could be related to organic matter, waterlogging, carbonate accumulations and redoximorphic features.

3.1.3 Soil structure

According to FAO [5] the soil structure based on their grade, size and shape of the soil structure of the representative pedon where evaluated. The structure of the soils in the surface layers of the pedons varied from weak fine to medium, sub-angular blocky to weak, fine to medium with angular blocky, whereas in the subsurface horizons it ranged from strong to moderate, medium to coarse, Angular blocky (TABLE 4). The better developed structure of the subsurface layers could be due to the relatively higher clay content of the subsurface horizons than that of the surface horizons [17].

3.1.4 Consistence

the consistency of the representative pedon at surface soil horizon where characterized as very friable to firm(wet), very sticky/very plastic to sticky/ plastic (moist) while at the sub surface soils of GSP-01, GSP-02 and GSP-07 pedons owing firm to friable (wet), sticky and plastic (moist) and for GSP-6, GSP-08 and GSP-03 characterized as slightly hard to hard (dry),firm to friable (wet), stick and plastic (moist) for GSP-06, GSP-03 and GSP-08 (TABLE4). The observed differences in soil consistence at the top surface and sub-surface horizons could probably be explained by the differences in particle size distribution, particularly clay content, OM and nature of the clay particles. The findings of this study are in agreement with the results reported by [18] who indicated that soil consistence varied with soil texture. Mulugeta and Sheleme [14] has pointed out that the friable consistence observed in the surface soils of the pedons could be attributed to the higher soil OM content.

TABLE 4. **Selected morphological characteristics of soils of the proposed project.**

Profile code	**Depth**	**Soil color**	**Structure**			**Consistency**		
		wet	Grade	Size	Shape	dry	moist	wet
GSP-01	0-30	DR(2.5YR 3/6)	W	C	SAB		VFR	VST/VPL
	30-60	DRB(2.5YR ¾)	S	M	AB	SH	FI	ST/PL
	60-110	DRB (2.5YR ¾)	S	M	AB		FI-FR	ST/PL
	110-200	DRB (2.5YR ¾)	S	M	AB		FI-FR	ST/PL
GSP-02	0 - 30	DRB (2.5YR ¾)	W	F-M	AB		VFR	VST/VPL
	30-78	DR (2.5YR 3/6)	Mo	M	AB		SFI-FR	ST/PL
	78-120	DR (2.5YR 3/6)	Mo	M-C	AB		FI	ST/PL
	120-200	DR(2.5YR 3/6)	S	M	AB		FI	ST/PL
GSP-03	0 - 30	DRB(2.5YR ¾)	W	F-M	AB		VFR	ST/PL
	30-70	DR(2.5YR 3/6)	Mo	F-M	AB	SH	FI-FR	ST/PL
	70-110	DuR(2.5YR 3/2)	Mo	M-C	AB	H	FI-FR	ST/PL

	110-200	DB(2.5YR 3/6)	Mo	M	AB	H	FI-FR	ST/PL
GSP-04	0-25	DuR (2.5YR 3/2)	W	F	AB		FI	ST/PL
	25-60	DR(2.5YR 3/6)	W	F	AB		FI	ST/PL
	60-130	DR(2.5YR 3/6)	Mo	F-M	AB	SH	FI-FR	ST/PL
	130-200	DR(2.5YR 3/6)	Mo	F-M	AB	SH	FI-FR	ST/PL
GSP-05	0-25	DuR(2.5YR 3/2)	W	F	AB		VFR	VST/VPL
	25-60	DR(2.5YR 3/6)	W	F-M	AB		FI	ST/PL
	60-130	DRB(2.5YR 3/4)	S	M-C	AB	SH	FI-FR	ST/PL
	130-200	DRB(2.5YR 3/4)	Mo	M	AB	SH	FI-FR	ST/PL
GSP-06	0-30	DuR(2.5YR 3/2)	W	F-M	AB	SH	FI-FR	ST/PL
	30-80	DRB (2.5YR 3/4	W	M	AB		FI	ST/PL
	80-130	DRB (2.5YR 3/3)	Mo	M-C	AB		VFR	ST/PL
	130-200	DRB (2.5YR 3/3)	Mo	M-C	AB		FI	ST/PL

NB:DRB=dark reddish brown, DuR= dusk red, DR=dark red, DB= dark brown, Mo=moderately= weak, S= strong, C= coarse, M=medium, M-C= medium to coarse, F-M= fine to medium, F=fine, AB= angular blocky, SAB=sub-angular blocky, SH= slightly hard, H= hard, FI= firm, VFR= very friable, FI-FR firm to friable, SFI-FR= slightly firm to friable, VST/VPL= very sticky and very plastic, ST/PL= sticky and plastic

3.2 Physical characteristics of the Soils

3.2.1 Soil texture

The results of the particle size analysis indicated that the soils within the study area silt clay to clay loam and silt clay loam textural class at the top surface horizons and clay loam, silty clay and clay textural class at the sub soil horizons. The proportion of clays in these textural classes ranges from 28.92 to 82.62% while sand and silt varies 1.98 to 45.73 and 10.12% to 51.68%, respectively (TABLE 5). However, the clay contents down the horizons were observed with an increasing proportion in all the representative pedons.

TABLE 5. **Soil textural class and percentile composition of the project command area.**

Profile No.	Depth (cm)	Total Sand (%)	Silt (%)	Clay (%)	Texture class
GSP-01	0-30	1.98	41.84	56.18	Silt clay
	30-60	44.38	26.65	28.92	clay loam
	60-110	20.92	10.12	68.91	Clay
	110-200	45.73	12.44	41.83	sandy clay
GSP-02	0-25	30.56	37.97	31.46	Clay loam
	25-50	4.83	42.94	52.23	silt clay
	50-100	9.06	10.77	80.17	Clay
	100-200	6.6	10.78	82.62	Clay
GSP-06	0-30	15.01	51.68	33.31	Silt clay loam
	30-70	13.84	21.54	64.62	Clay
	70-110	8.15	12.95	78.79	Clay
	110-200	5.33	12.7	81.93	Clay

3.2.2 Soil permeability test

A soil's permeability is a measure of the ability of air and water to move through it. Permeability is influenced by the size, shape, and continuity of the pore spaces, which in turn are dependent on the soil bulk density, structure and texture. In most cases, soils with a slow, very slow, rapid or very rapid permeability classification are considered poor for irrigation. The average result of the measurement was ranging from 0.56 to 1.24m/day (TABLE 6). Hence the hydraulic conductivity of the soils of the command area classified as moderately slow class [19].

3.2.3 Soil infiltration test

Infiltration rate is important parameters in design of irrigation system and soil conservation. The results are also used for determining the most efficient methods of applying irrigation and making runoff calculations. Coarse textured soils such as sands and gravel usually have high infiltration rates. The infiltration rates of medium and fine textured soils such as loams, silts, and clays are lower than those of coarse textured soils and more dependent on the stability of the soil aggregates. Water and plant nutrient losses may be greater on coarse textured soils, so the timing and quantity of chemical and water applications is particularly critical on these soils. The overall results of the measurements of infiltration rate are between 1.9-2.2 cm/hr (TABLE 6). According to Miller and Donahue [20] the surface infiltration rate of the soils rated as medium which is indicating that the soils are optimum for surface irrigation system [21].

TABLE 6. **The Infiltration and Hydraulic conductivity test.**

Profile code	**Replication**	**Infiltration test**		**Hydraulic connectivity rate m/day**	
GSP-03		Value in cm/hrs.	Rating	Value in m/day	Rating
	R-1	2.3	medium	0.42	moderately slow
	R-2	2.1		0.73	

	R-3	2.1		0.53	
	Average	2.2		0.56	
GSP-06	R-1	2.0	medium	1.4	moderately slow
	R-2	1.8		0.91	
	R-3	1.8		1.4	
	Average	1.9		1.24	

3.3 Soil moisture characteristics

The soil water content retained at field capacity (33kPa) ranged from 40.06% to 39.99% whereas at permanent wilting point (1500 kPa), it was between 366.7 to 314.6 mm/m (TABLE 7). This FC and PWP value of the command area soil lies within the range recommended by [22]. The high-water retention values for both suctions are indication for the presence of waterlogging problem at the study site, which could be related with amount of clay content and organic matter. In accordance with the findings of [23] clay offers a higher resistance to movement of water because of its high proportion of micro-pores that hygroscopically or in film store water. The available water holding capacity (AWHC) of the soil varied from 133.9 to 85.36 mm/m on horizon basis and could be rated as moderate to very low in accordance with [22,24]. The main factor which contributes becoming low available water holding capacity, particularly at the depth 50 cm - 100 cm is the fine texture which contributed to compaction of the soil and as a result the high bulk density of the soils and justification for the low AWC at the depth 50 cm - 100 cm.

TABLE 7. **Summary of soil moisture characteristics FC, PW and AWC.**

Profile Code	**Depth (cm)**	**FC (mm/m)**	**PWP (mm/m)**	**AWHC (mm/m)**
GSP-03	0-50	400.6	366.7	133.9
	50-100	399.9	314.6	85.3

3.4 Chemical characteristics of the soils

3.4.1 Soil pH, electrical conductivity and calcium carbonate content

The pH-H_2O values varied from 5.83 to 6.11 in the surface layers and 5.56 to 6.15 in the subsurface horizons with an increasing trend with depth in all pedon (TABLE 8). Similarly, the pH-KCl values ranged from 4.19 to 4.76 and 4.11 to 4.96 in the surface and subsurface soils, respectively. According to Jones [25] categorization, it has been rated as moderately to slightly acidic, which is preferred range for most crops with some management. The soils are very good for most arable, staple crops of the host community. Plant nutrients would be available to crops at these pH values. Thus, the detrimental effects of soil acidity are not envisaged in the near future in these soils. The soils of all pedons showed very low electrical conductivity values that ranged from 0.01 to 0.06mS/cm with an average of 0.03mS/ cm, indicated that the soils are non-saline [26].

TABLE 8. **Soil pH, and EC of the proposed project irrigation project.**

Profile No.	Depth-cm	pH-H20	pH-KCL	EC(1:2.5) ms/cm
GSP-06	0-30	5.83	4.47	0.01
	30-70	5.87	4.48	0.01
	70-110	5.93	4.13	0.05
	110-200	5.73	4.16	0.02
GSP-03	0-25	6.11	4.19	0.03
	25-50	6.15	4.11	0.03
	50-100	6.04	4.23	0.02
	100-200	6.06	4.31	0.01
GSP-01	0-30	6.03	4.76	0.06
	30-60	6.12	4.96	0.02
	60-110	5.56	4.37	0.02
	110-200	5.97	4.54	0.02

3.4.2 Organic carbon, total nitrogen, and available phosphorus

The organic carbon (OC) content ranges from 1.78% to 2.08% and all pedons and OC content rated as medium level throughout their profile depth but generally decreased with soil depth in all pedons (TABLE 9). According to the ratings suggested by [27], the OC contents of the soils in the study area can be categorized as moderate level contents of organic carbon. The current moderate level of organic content of the soils of the study could probably due to the rich experience of the farmers in the study area cultivation with application of external organic inputs which is a common practice in the area. The total N content of the soils ranged from 0.09% to 0.18% (TABLE 9) and could be rated as low to moderate in accordance with the rating of [28]. The distribution pattern of total N with soil depth was observed that at the surface soil horizons range from 0.13% to 0.18% rated as moderate while the Total N at the sub surface ranges from 0.09 to 0.13 rated as low to very low. The content of available phosphorus on surface soil of the project area ranges from 19.83 to 34.16 mg/kg with an average value of 27.49 mg/kg, while the available P under surface soil varies from 19.42 to 27.33 mg/kg with an average value of 22.84 mg/kg and these values are ranged from high to very high as per the rating suggested by [8,29]. Generally, the available phosphorus content of the soils is higher level at the surface than the sub surface showing a slight decreasing with profile depth in all pedons, which could be attributed to the relatively higher OC contents in the surface layers, and application of phosphorous containing fertilizer, which is commonly named as DAP and compost by farmers on cultivated lands.

The cation exchange capacity of the soils ranged from 39.77 to 50.41 meq/100g of soil (TABLE 9) which is high to very high according to the rating of [30]. This could be associated with soil OC and relatively high clay contents. The high CEC results showed that the soil of the study area has good nutrient retention and buffering capacity. The high CEC of these soils indicate their richness of weathering and /or the less intensity of leaching and serves as a storehouse of nutrient for plant use [31]. The percent base saturation of the soil of the study area varied from 49.81% to 73.66% with a slightly increasing trend with depth, which might be due to leaching of bases from the overlying layers and subsequent accumulation in the subsurface horizons. The percent base saturation in the soils of the area was also in the moderate to high ranges and they are with moderately inherent fertility status [28].

TABLE 9. OC, TN, available P, CEC and PBS of the proposed irrigation project.

Profile No.	**Depth (cm)**	**OC (%)**	***TN (%)***	**C/N**	**Available P(mg/kg)**	**CEC meq/100g**	**PBS (%)**
GSP-06	0-30	1.97	0.16	12.31	34.16	45.17	52.03
	30-70	1.95	0.13	15	26.33	40.83	50.31
	70-110	1.91	0.1	19.1	26.33	41.03	54.11
	110-200	1.88	0.1	18.8	24.31	42.39	52.21
GSP-03	0-25	1.81	0.18	10.06	19.83	40.32	51.93
	25-50	1.81	0.1	18.1	19.8	42.07	56.52
	50-100	1.79	0.09	19.89	19.75	45.05	49.81
	100-200	1.78	0.09	19.78	19.42	44.57	50.57
GSP-01	0-30	2.08	0.13	16	28.47	40.47	52.41
	30-60	2.02	0.13	15.54	27.33	44.49	53.38
	60-110	1.89	0.12	15.75	22.13	50.41	73.66
	110-200	1.89	0.12	15.75	20.17	39.77	58.31

3.4.3 Exchangeable sodium percentage and exchangeable bases

The level of the exchangeable cations in soil indicated the existing nutrient status and can be used to assess balance among the cations. Many effects on soil structure and nutrient uptake by crops are influenced by the relative concentration of cations as well as by their absolute levels. All Exchangeable cations except K are found to be rated as high to very high, while the exchangeable K is rated as medium to high [5]. Ca was the dominant cation on the exchange sites followed by Mg, Na and K across the pedons (TABLE 10), showing appropriate basic cation distribution in accordance with [5]. The contents of exchangeable Ca and Mg varied from 11.81 to 23.55 and 4.10 to 9.10 meq/100g of soil, respectively, whereas exchangeable K and Na varied from 0.39 to 2.39 and 1.18 to 2.27 meq/100g of soil, respectively. Generally, the contents of exchangeable bases increased with increasing soil depth, showing that their level at the surface horizons is lower than its sub surface horizons, this could perhaps due to leaching.

Soils with ESP <15% is generally non-sodic whereas soils with ESP >15% is sodic and require amendment. The maximal value of ESP on top the soil depth between 0 and 100 cm is ranging from 5.87% to 9.53% with an average value of 7.19%. Similarly, the ESP at the subsurface varies from 5.24 to 11.05 with an average value of 7.63 which is rated as low to moderate level. Accordingly, the soils of the project command area has low to moderate sodicity problems.

TABLE 10. **Average value of Exchangeable cation composition of Sanbate irrigation project.**

Profile No.	**Depth, cm**	**Exc Cations(meq/100g of soil)**				**ESP (%)**
		Ca	Mg	K	Na	
GSP-06	0-30	13.91	6.96	0.39	2.24	9.53
	30-70	11.81	5.9	0.56	2.27	11.05
	70-110	13.16	6.08	0.74	2.22	10

	110-200	12.97	5.99	1.2	1.97	8.9
GSP-03	0-25	13.28	5.69	0.74	1.23	5.87
	25-50	14.03	7.03	1.32	1.4	5.89
	50-100	13.83	5.61	1.29	1.71	7.62
	100-200	13.33	6.66	1.37	1.18	5.24
GSP-01	0-30	14.33	4.1	1.47	1.31	6.18
	30-60	15.01	5	2.39	1.35	5.68
	60-110	23.55	9.8	1.57	2.21	5.95
	110-200	13.74	5.87	1.64	1.94	8.37

3.4.4 Cationic ratios

The minimum ratio of calcium to magnesium (Ca: Mg) in most soils of the study area is 2 while maximum is 3.5 with an average value of 2.36 (TABLE 11), which indicated that the value in most case is at moderately low and less favorable and it corresponds to the lowest accepted limit. Hence, Ca availability may be reduced. Accordingly, as per [32] ratings, the results indicate Mg induced Ca deficiency in the soils. The values of K: Mg ratio varied from 0.06-0.48, and in accordance with the ratings by Loide V [33], Mg induced K deficiency is also expected in crop production on the soils. The results suggested the need for soil management to balance the cations for optimum crop production, although their absolute values are above the critical levels. Two percent of K: CEC ratio suggests a minimum level to avoid K deficiency and soils with more than 25% ratio is considered to be potassium rich soil. The minimum K: CEC ratio of the soil units in the project area its minimum is 0.01 and maximum is 0.05 with an average value of 0.03 (TABLE 11). Hence, all the soils in the areas under investigation have the ratio a minimum level ratio indicating that at the existing condition the soils of the command area will not have K deficiency.

TABLE 11. **Average value of Cations ratio of the proposed irrigation project.**

Profile No.	**Depth, cm**	**Cation ratio**		
		Ca/Mg	K:CEC	K/Mg
GSP-06	0-30	2	0.01	0.06
	30-70	2	0.01	0.09
	70-110	2.16	0.02	0.12
	110-200	2.17	0.03	0.2
GSP-03	0-25	2.33	0.02	0.13
	25-50	2	0.03	0.19
	50-100	2.47	0.03	0.23
	100-200	2	0.03	0.21
GSP-01	0-30	3.5	0.04	0.36
	30-60	3	0.05	0.48
	60-110	2.4	0.03	0.16
	110-200	2.34	0.04	0.28

3.5 Classification of the soils sccording to FAO - WRB System

All Pedons had deep, well-drained soil with an effective depth of 200^{+}cm; a subsurface horizon thicker than 30 cm with more than 30% clay; weak to strong angular blocky structure with shiny pedfaces; silt/clay ratio of <0.4 meeting the criteria for Nitic sub-surface horizon. The pedons had a diffused boundary between the surface and subsurface layers; without ferric, plinthic or vertic horizon and no gleyic color pattern starting within 100 cm of the surface meeting the requirements of Nitisols [34]. Furthermore, the subsurface layer started at 70 cm of GSP-06; had high dusky red (2.5 YR3/2 moist) to dark reddish brown (2.5YR3/4 dry) color; qualifying for rhodic prefix. Thus, the soils represented by this pedon were classified as Rhodic Nitisols (TABLE 12) in accordance with the World Reference Base for Soil Resources [34].

GSP-01 and GSP-03 pedons had well-structured dark surface horizons of more than 20 cm thickness having color values and chroma of less than 3 when moist. The surface layers of the pedons contained more than 0.6 percent of OC; base saturation (by 1M NH_4OAc, pH 7) of $\geq$ 50 percent or more throughout the horizons (TABLE 9 and 10) meeting the criteria for a Mollic diagnostic horizons. Thus, the soils represented by this pedon were classified as Mollic Nitisols (TABLE 12) in accordance with the World Reference Base for Soil Resources [34].

TABLE 12. **The dominant soil units of the project command area.**

S/N	Soil Type	Area_ha	Area (%)
1	Mollic Nitisols	43.71	18.83
2	Rhodic Nitisols	188.46	81.17
		232.17	100.00

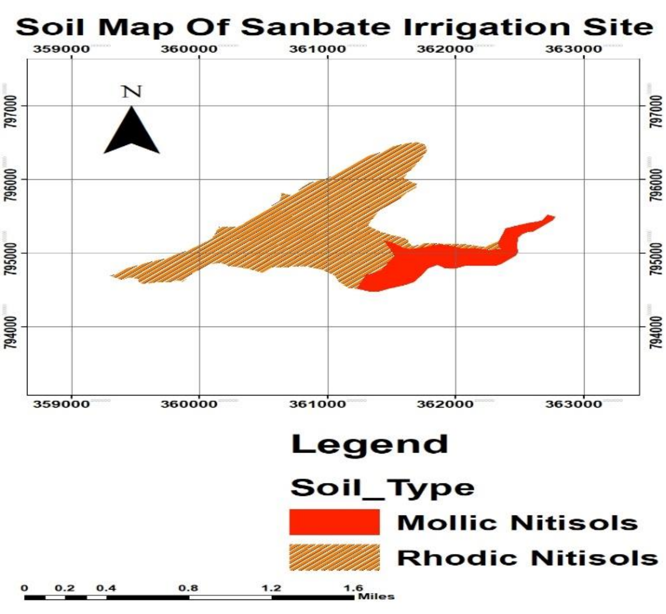

FIG. 3. **Soil Map of the proposed irrigation project.**

3.6 Soil mapping units

3.6.1 Description of soil mapping units

Delineation of the boundaries of different mapping units for irrigation concentrated on important boundary lines such as slope texture, workability, drainage, permeability, salinity/sodicity, soil surface characteristics, dominant land cover and use, micro-relief and stoniness. These are all highly relevant parameters for irrigation planning, design and management, rather than simple mapping of uniformity of soil types. However, majority of these parameters were found to be homogenous throughout the command area of the proposed irrigation project. Thus, it is only the soil unit, the slope class and physiographic position the land unit within the delineated command area of the project, were taken into consideration (FIG. 4).

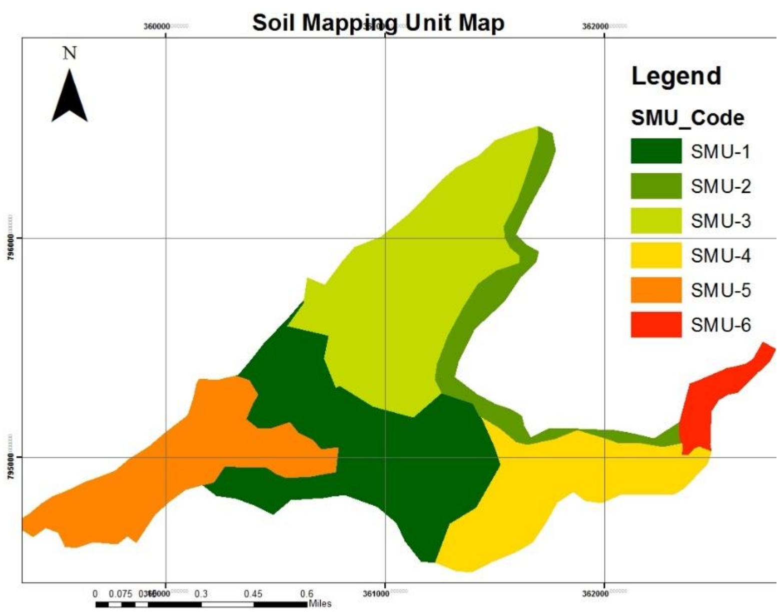

FIG. 4. **Soil map units of Sanbate Irrigation project command area.**

SMU-1

This soil mapping unit is occurred mainly located at the west and south west of the head work and covering the middle and extending to the lower end part of the irrigable command area. The soils of this mapping unit are developed on gently undulated and undulating, sloping land form with slope class range from 5% to 10%, and however this mapping unit is dominated by 5% to 8 % slope class. The soils of these mapping units are very deep; throughout the horizons dark reddish brown (2.5YR 3/4 and dark red (2.5YR 4/6) and dusk red (2.5YR) at the sub surface horizons'; the soil texture comprises silt clay loam at the top surface and clay texture class at the sub surface, with well to moderately well drainage class. the soils of this mapping unit has a medium rated infiltration rate(1.9 cm/hrs.) and moderately low hydraulic property (1.24 m/day).

The soils are characterized by slightly to moderately acidic soil reaction (pH=5.73 to 5.93), very high CEC 45.17 to 41.03meq/100 g soil; moderately rated PBS(50.31 to 54.11%), very high available P 24.31 to 34.16mg/kg soil ;moderately (1.88 to 1.97%) organic carbon content throughout the depth ; moderate soil nitrogen(0.16%) at the top soil and moderated low at the sub surface(0.13 to 0.1;.with exchangeable sodium percentage rated as moderate (9.55% to 11.05%). The mapping unit is covered by intensively cultivated land, scattered settlements and gully. The major land use class is rain fed cultivation land use. It comprises of about 62.41ha (26.88%) of the total area. Soil profile code GSP-06 is the representative soil profile pit and classified as Rhodic Nitisols.

SMU-2

This soil mapping unit is occurred mainly on the upper part of the command area where the main canal route passes through. This mapping unit is mainly developed on undulating sloping and rolling slope land form with slope class (5%-15%). The soils of these mapping units are very deep to moderately deep soils; Except for its physiographic location of this mapping unit its soil property are similar with that of SMU-4 The mapping unit is covered by cultivated land, settlements, eroded area, and planted eucalyptus tree. It comprises of about 18.68 ha or about 18.05% of the total area.

SMU-3

The soils of this mapping unit are developed on a wide range of slope (5% to 15%) with slope dominant with less than 8%. The soils of these mapping units are very deep; throughout the horizons dusk red (2.5YR) to dark red (2.5YR 3/6); the soil texture comprises clay loam at the top surface and silt clay loam to clay texture class at the sub surface with well drainage class. The soils of this mapping unit has a medium rated infiltration rate (2.2 cm/hrs) and moderately slow hydraulic property (0.56 m/day).The soils are characterized by slightly acidic soil reaction (pH=6.04 to 6.11) throughout the profile depth, very high CEC 45.17 to 40.32 meq/100 g soil; moderately rated PBS (49.81 to 56.52.11%),very high available P 219.83 to 19.42 mg/kg soil; moderately (1.78 to 1.81%) organic carbon content throughout the depth; moderate soil nitrogen (0.18%) at the top soil and low at the sub surface (0.1 to 0.09) ,with exchangeable sodium percentage rated as low. The mapping unit is covered by intensively cultivated land, scattered settlements and planted eucalyptus tree and access road. The major land use class is rain fed cultivation land use. This mapping unit covers 66.44ha (28.62%) of the total area. Soil profile code GSP-03 is the representative soil profile pit and classified as Humic Nitisols.

SMU-4

This soil mapping unit is occurred mainly located at the upper part of the command area starting from the idle canal area and extends to SMU-1 boundary and it is bounded by the Sanbate River at its bottom part and by the main canal at its upper part. The soils of this mapping unit are developed on gently undulated and undulating, sloping land form with slope class range from 2 to 8%, and however this mapping unit is dominated by 5% to 8% slope class. morphologically the soils of these mapping units are very deep; throughout the horizons dark reddish (2.5YR 3/6) at the top soil horizon and dark reddish brown (2.5YR 3/4) at the sub surface horizons'; the soil texture comprises silt clay at the top surface and clay loam to clay and sandy clay texture class at the sub surface with well to moderately well drainage class. The soils of this mapping unit are characterized by slightly to moderately acidic soil reaction (pH=5.07 to 6.123), high to very high CEC (39.77 to 50.41meq/100 g soil); moderately rated PBS (52.41%) at the top surface and moderate to high (53.38% to 73.66%) at the sub surface, moderately ESP (6.18%) at the top and low to medium ESP (5.68% to 8.37%) at the sub surface layer. These soil mapping unit is highly characterized by its high available P 28.47 to 20.17 mg/kg soil; moderately (2.08% to 1.89%) organic carbon content throughout the depth; moderate soil nitrogen (0.13% to 0.12%) The mapping unit is covered by intensively cultivated land, scattered settlements. The major land use class is rain fed cultivation land use. This mapping unit covers 36.35 ha (15.66%) of the total area. Soil profile code GSP-01 is the representative soil profile pit and classified as Mollic Nitisols (Hyposodic).

SMU-5

This soil mapping unit is occurred mainly located at the west and south west of the head work and covering the lower part of the command area. The soils of this mapping unit are developed on gently undulating, land form with slope class range from 0 to 5%, The soils of these mapping units are very deep; throughout the horizons dusk red (2.5YR3.2) and dark red to dark reddish brown at the sub surface horizons'; the soil texture comprises silt clay loam at the top surface and clay texture class at the sub surface clay throughout the profile and it was categorized as well to moderately well drainage class. The soils of this mapping unit has similar soil properties with that of SMU-1 soils The mapping unit is covered by intensively cultivated land and gully. The major land use class is rain fed cultivation land use. It comprises of about this mapping unit covers 40.93ha (17.63%) of the total area. Soil profile code GSP-08 is the representative soil profile pit and classified as Humic Nitisols.

SMU-6

This soil mapping unit is occurred mainly on the upper part of the command area where the main canal route passes through. This mapping unit is mainly developed on gently sloping and moderately steep slope land form with slope class (2%-30%). The soils of these mapping units are very deep to moderately deep soils; Except for its physiographic location of this mapping unit its soil property are similar with that of SMU-4. This soil mapping unit is covered by bad land (rock outcrop, gully eroded), planted eucalyptus and juniper tree. It comprises of about 7.36 ha or about 3.17% of the total area (TABLE 13 and FIG. 4).

TABLE 3. **SMU area coverage and its distribution.**

S/N	SMU_code	Soil Type	Area (ha)	Area (%)	Representative Profile pits
1	SMU-4	Mollic Nitisols	36.35	15.66	GSP-01
2	SMU-2	Mollic Nitisols	18.68	8.05	GSP-02
3	SMU-1	Rhodic Nitisols	62.41	26.88	GSP-06
4	SMU-3	Rhodic Nitisols	66.44	28.62	GSP-03
5	SMU-5	Rhodic Nitisols	40.93	17.63	GSP-07
6	SMU-6	Mollic Nitisols	7.36	3.17	GSP-08
			232.17	100.00	

4. Conclusion and Recommendations

The soil survey investigation has identified that the Humic Nitisols and Mollic Nitisols are the dominant soil unit of the project command area, where the Mollic Nitisols covers about 43.71ha (18.83%) and Humic Nitisols shares about 188.46 ha (81.77%) of the total command area of the project. The soils physical characteristics are mainly marked by the existence of silt clay, clay loam and silt clay loam at the top surface and clay loam and clay soil texture at the sub surface with deep to very deep soil depth, well to moderate drainage class, low to medium rated available water holding capacity, medium level rated infiltration capacity and moderately slow hydraulic conductivity of the soil. As far as the chemical properties are concerned, the soils of the command area is characterized by slightly moderately acidic, non-saline and low to moderately ESP with high to very high CEC, moderate to high rated level of PBS and with medium OC, low to moderate level of soil nitrogen and high rated of available P level. Besides these chemical and physical properties of these soils, the soils of the studied area are susceptible to erosion due to various biophysical factors. It has been noted that there is a moderate to severe erosion hazard occurrence i.e., sheet, rill and gully erosion some sites of the project area.

The current moderately acidic soil pH rate and the low to medium soil nitrogen and the moderate rate level of ESP will be the future constraints of the soils for their development unless an integrated fertility management is planned and implemented. Besides, the soil nutrient status constraint, the moderate to severe soil erosion status of the soils in the study area will also be a limiting factor in the development of the proposed irrigation project. In order to maintain soil fertility, nutrients removed from the soil by crop must be restored by the application of fertilizers and manure. Even if in a highly fertile soil reserve nutrient gets exhausted as crops are grown and harvested continually and needs replacement. Generally sustainable soil management system, which include continuous crop cover, mulching, and organic maturing with appropriate inorganic fertilizers should be practiced in order to maintain and to improve soil fertility and to control soil erosion.

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