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LIST OF ABBREVIATIONS

FAO	-	Food & Agriculture Organization
GIS	-	Geographic Information System
GPS	-	Global Positioning System
LGP	-	Length of Growing Period
LUPRD	-	Land Use Planning & Regulatory Department
MoA	-	Ministry of Agriculture
OWWDSE	-	Oromia Water Works Design & Supervision Enterprise
ToR	-	Terms of Reference
S, R	-	Sheet and Rill erosion
E_W	-	East to West
C/F	-	Common Fine
BS%	-	Base Saturation Percentage
$CaCo_3$	-	Calcium Carbonate
CEC	-	Cation Exchange Capacity
Cm	-	Centimetres
^{O}C	-	Degree Celsius
ds/m	-	Deci Siemens per Meter
EC	-	Electrical Conductivity
FAO	-	Food and Agriculture Organization
GWT	-	Ground Water Table
LUPRD	-	Land Use Planning and Regulatory Department
LUT	-	Land Utilization Type

EXCUTIVE SUMMARY

The soil survey of Laga Dhumuga Pump small scale Irrigation Based Development project is conducted at feasibility level to use of the information obtained as a basis for confirming/rejecting the irrigation potential, crop selections, irrigation designs and agricultural input requirements. The methodology has employed review of previous studies, interpretation of satellite imageries and topographic maps. Field auger observation was made on 200 by 200 m grid. Profile description and soil sampling for laboratory analysis, field testing of infiltration rate and hydraulic conductivity were conducted on representative sites.

On the basis of soil depth, slope and classified soil type, a total of eighteen soil mapping units (SMU) were identified. On the basis of profile morphology and development, and nature of the soil material and profile depth, the soils of the study area are identified as, Leptosols, Luvisols, Cambisols and Fluvisols. Low soil pH, shallow soil depth, soil texture and topography are the prominent characteristics of the soils restricting the suitability of the soils for surface irrigation and proposed crops.

From the total area surveyed (307.8ha), 231.85 ha or 75.3% of land are found to be suitable for surface irrigation development and 75.96 ha or 24.7 % of the land are not suitable for surface irrigation due to topography and soil depth.

The crop suitability evaluation indicated that Haricot beans, Maize, Sorghum, Onion, Pepper, Sweet Potato and Tomato can be cultivated by irrigation. Land evaluation for selected crops and the result is indicated that some, 0.74 ha moderately suitable (S2), 231.11ha marginally suitable (S3), 33.79 ha currently not suitable (N1) and 42.17 ha permanently not suitable for haricot beans cultivation by surface irrigation. Land evaluation for maize Some 231.85 ha marginally suitable (S3), 33.79ha currently not suitable (N1) and 42.17 ha permanently not suitable (N2) for surface irrigation. . Land evaluation for sorghum some 0.74 ha of land is moderately suitable (S2), 231.11 ha marginally not suitable (S3), 39.79 ha currently not suitable (N1) and 42.17 ha permanently not suitable (N2) respectively. Land evaluation for onion all 231.85 ha marginally suitable (S3), 33.79ha currently not suitable (N1) and 42.17 ha permanently not suitable (N2) for surface irrigation. Land evaluation for pepper some231.85 ha marginally suitable (S3), 33.79ha currently not suitable (N1) and 42.17 ha permanently not suitable (N2) for surface irrigation. Land evaluation for sweet potato some, 231.85 ha marginally suitable (S3), 33.79ha currently not suitable (N1) and 42.17 ha permanently not suitable (N2) for surface irrigation. Land

evaluation for tomato some, 231.85 ha marginally suitable, (S3), 36.82 ha and 75.96 ha currently not suitable (N2) for surface irrigation

For the sustained irrigation development, it is recommended that the low soil pH problems in the study area should be reduced by appropriate management practices such as application of lime pellet legume and molybdenum that increases the pH of the soil and selection of appropriate crops suitable for those limitations. The Cation exchange capacity of the soils is medium to very high. The exchange complex of the soils is dominated by Ca^{2+} and this is favourable to promote better soil structure and offset the deleterious effect of the sodicity. However, the relative proportion of Ca to Mg and K to Mg is moderately high to high and this may restrict the availability of both Mg and K to plants. Thus, application of K and Mg containing fertilizers should be consider in soil fertility management programs.

The organic matter content of the soils in the study area is medium to high and total nitrogen content of the soils is high. The analytical data also indicates low to medium available phosphorus in the soils of the study area. The low available P and N can be corrected by the application of N and P fertilizers. In order to increase the organic matter content leaving the crop biomass on the field is a practical measure and this will increase the fertility status of the soils, improve microbial activity and availability of micronutrients.

1. INTRODCTION

1.1. Back Ground

The Ethiopian economy is mainly dependant on agricultural production. The agricultural sector, however, is characterized by traditional practices and low productivity. One of main reasons for low productivity is the recurrent drought in the country. Thus, the government has decided to utilize all the available land and water resource of the country for the benefit of the community and to ensure sustainable development.

There is growing concern over food security in Ethiopia due to low inputs subsistent rain fed agriculture and precipitation variability in amount and distribution. The high dependency on rain fed farming in Ethiopia and the erratic rainfall nature in the drier part of the country require alternative ways of improving agricultural production. To address the food security, climatic vulnerability, and macro-economic issues, Ethiopia has developed its irrigation policy (MoWR, 2001a; MoWR 2001b; Seleshi, 2010; Oates et al., 2015). Irrigated agriculture with proper water management has many potential benefits in efforts to reduce climate vulnerability and improve productivity. The prime rationales for development of the irrigation sector in Ethiopia include increased productivity of land, reduced reliance on rainfall thereby mitigating vulnerability to variability in rainfall, reduced degradation of natural resources, increased exports, increased job opportunities, and promote dynamic economy for the nations (FEPA, 2004).

Therefore the government take attention both for small and large scale irrigation projects using surface and subsurface water potentials across the country. As part and parcel of these endeavours, various irrigation projects have been proposed in arid and semi arid areas of the pastoral community area of the country. In this regard, the regional states of Oromia possessing high surface and subsurface water potential and vast plain land suitable for irrigation development.

The soil survey and land evaluation of the Laga Dhumuga Pump small scale Irrigation Based Development Project was conducted at feasibility level to assess in detail the physical and chemical characteristics of the soils in the project area and to evaluate the suitability of the area for surface irrigation and selected crops.

Laga Dhumuga Pump small scale Irrigation Based Development Project is located in Arsi Zone of the Oromia Regional State. The area has gently undulating sloping to steep slope topography and covered by open bush, shrubs and wood land on some parts and other sides of the study area covered by cultivated land. The inhabitants of the area are pastoralists of Oromo people. They produce different variety of crops and other vegetables by using traditional irrigation methods. The present study area covers about 200 ha of net irrigable area as given in the TOR.

1.2. General Objectives

The main objective of the soil survey is to provide detail information about land and soils of the study area at feasibility level which may form as a basis for confirming/rejecting the irrigation potential, crop selections, irrigation designs, and identifying agricultural input requirements such as fertilizer applications, crop variety selection etc.

1.3. The specific objectives

- ✓ To identifying various topographic features, soil types and land use/cover to determine the spatial distribution of different soil types over the project area.
- ✓ To provide basic soil data to facilitate irrigation design work to be carried out in the project area.
- ✓ To offer detailed soil information of the command area as a ground for ratifying or rejecting the soils potential for irrigated agriculture.
- ✓ To examine and identify areas suitable for surface irrigation systems and producing their map.
- ✓ To produce soils and land suitability maps at scale of 1:10,000.

1.4. Scope of the Work

As per terms of reference (TOR), the soil survey has been carried out at an intensive level within all potential irrigable area of 200 ha.

The TOR calls for soil survey of the Laga Dhumuga Pump irrigation development project area and use of the information obtained as a basis for confirming/rejecting the irrigation potential, crop selections, irrigation designs and agricultural input requirements. Therefore, the survey was designed to conform to the following standards in the TOR:-

- ✓ An overall density of one auger observation pre 4ha.
- ✓ A grid auger survey technique for the whole command area using satellite interpreted units as a base map.
- ✓ Standard soil profile observations to a depth of 2 m unless restricted by lithic contact and auger observations to 1.2 m depth unless restricted by barrier layers.
- ✓ Soil samples (undisturbed and disturbed) to be collected from generic horizons for the analysis of soil chemical and physical properties, and soil moisture characteristics.
- ✓ Standard infiltration and hydraulic conductivity tests on representative sites have been carried out.
  - ✓ Soil and land characteristics description has been undertaken according to FAO guidelines (FAO, 2006).
  - ✓ To map at 1:10,000 scale of each land form /soil unit for sustainable irrigation development, and produce a map showing soil observation points for the project at appropriate scale.

2. PHYSICAL ENVIRONMENT OF THE AREA

2.1. Location and accessibility

Lega Dhumuga Pump small scale irrigation development project is located in Arsi Zone of the Oromia National Regional State. It is located in Shenen Kolu district and Bedeyi Kebele. It is found at a distance of about 325km from Finfinnee to the east direction. It is accessed by about 115km asphalt road from Finfinnee to Dhera Town; by 210km all-weather road from Dhera Town to Dhumuga (capital of Shenen Kolu Woreda) and about 3km dry weather road from Dhumuga to the project site. It lies between 8^{0}25’23.2654’’ and 8^{0}26’11.1764’’ latitude north and 40^{0}15’30.3627’’ and 40^{0}15’35.1277’’longitude East within altitudinal ranges of 1445 to 1617 masl. The gross project area is 307.8 ha.

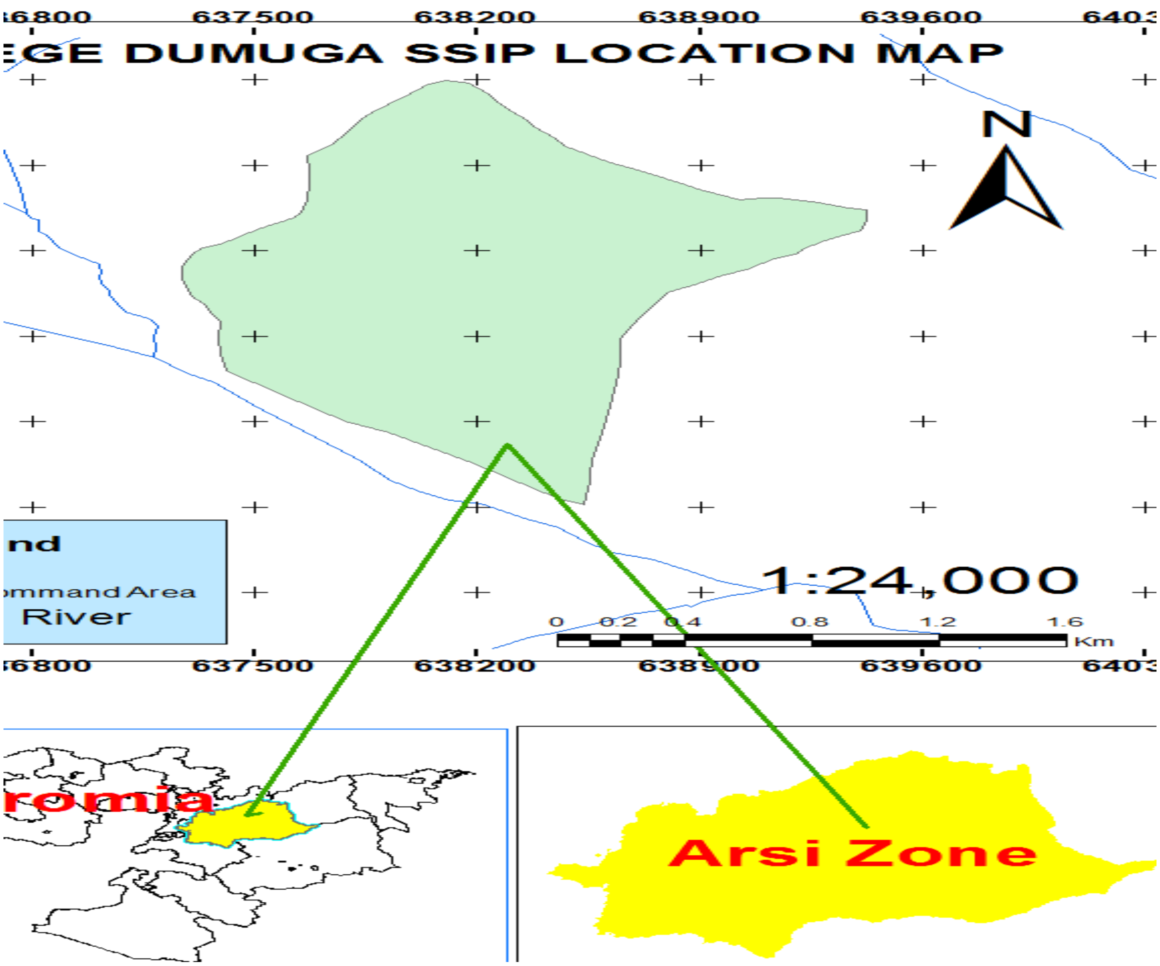


Figure 1 Location Map of the Project Area

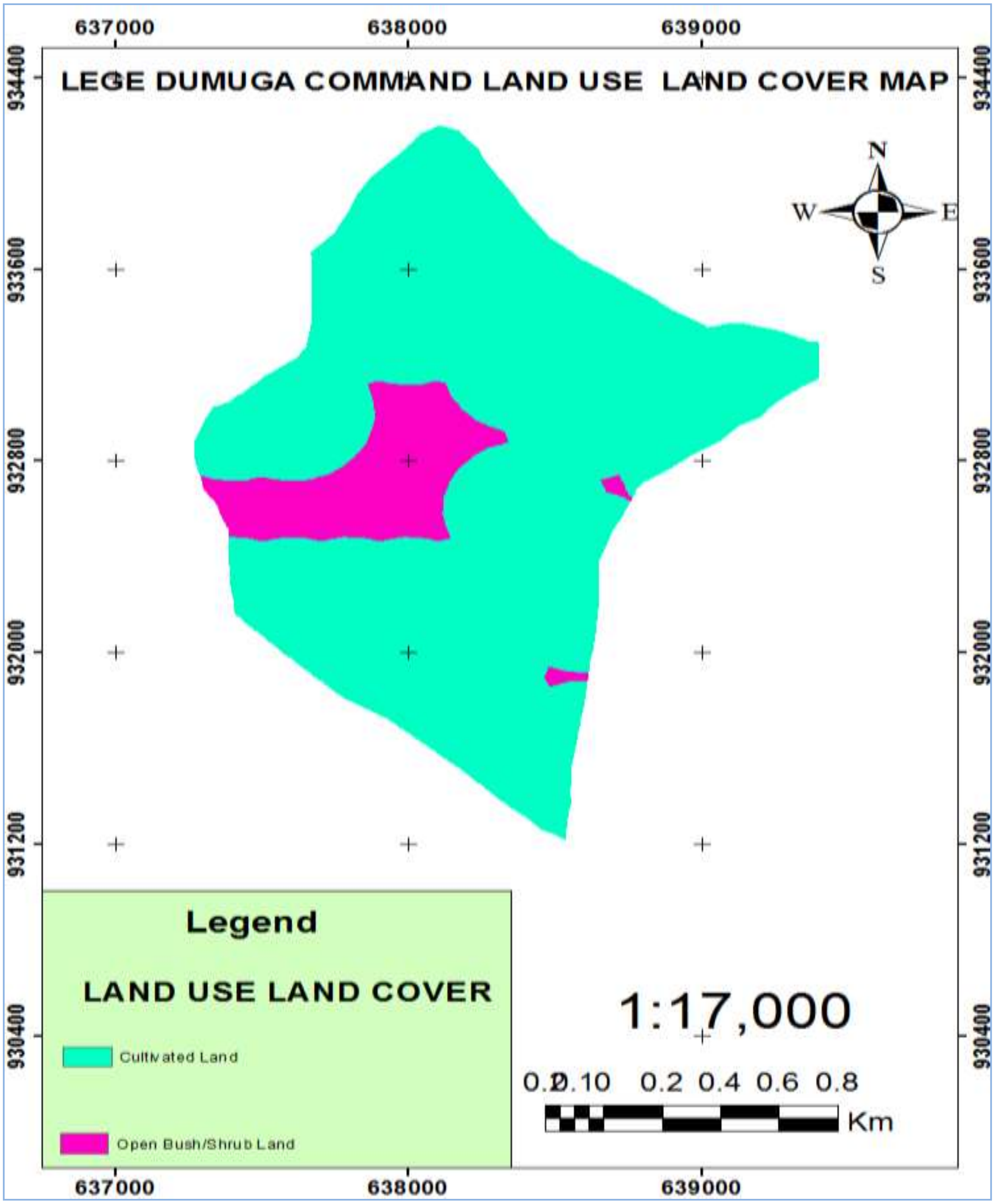
2.2. Physio grapy and Geology

The Laga Dhumuga Pump small scale irrigation project study area mainly found on moderately steep (15-30 per cent slope) to steep slope (30-60 per cent slope) and Undulating sloping (5-8 per cent slope) to rolling strongly sloping (8-15). The rest portion is gently undulating (2-5 per cent) slope. The project site is located in the central eastern Ethiopia. According to the regional geological map of the country, the geology of eastern Ethiopia is comprised of Precambrian metamorphic rocks, Mesozoic sedimentary rocks, Tertiary and Quaternary volcanic rocks and unconsolidated sediments. Minor occurrences of Late Paleozoic to Early Mesozoic sedimentary rocks underlie thick Mesozoic sedimentary succession (GSE, 1996).

2.3. Land use and land cover

The command area is under mixed crop cultivation and animal husbandry. Cereals (sorghum and maize), vegetables, (onion, cabbage, sweet potatoes, pepper), fruit (mango, banana, orange and papaya) cash crops (chat, coffee and sugar cane) are the major crops grown in the area. Open bush and shrubs land and cultivated land widespread in the area. The area are covered by 88.4% about 272.04 ha cultivated land and 11.6 % about 34.39ha grass land.

Figure 2 Land use and land cover map of the command area.



3. REVIEW OF PREVIOUS STUDY

3.1. General

Detailed soil survey for the present command area has not been carried out so far. However, some studies have been carried out at general level and semi detailed level. The general ones are countrywide studies that provided soils and landforms mapping at very low scales and which were largely based on imagery interpretation with a minimum of field verifications. On the other hand the semi detailed studies are basin wise and concentrated within the regional territory and analysis of land resource with prefeasibility level.

3.2. Assistance to Land use Planning Ethiopia Geomorphology and Soils

This document is one of the series produced during the course of the FAO/UNDP/ETH/78/003 project, Assistance to Land Use Planning, in the Land Use, Planning and Regulatory Department (LUPRD) of the ministry, of Agriculture (MOA), Ethiopia. One of the main objectives of the project has been the development of a master land use plan (MLUP) for agriculture in the country, based on the FAO agro ecological zones methodology for land suitability assessment (1978) developed for continental Africa.

The report summarizes the methods employed and the results obtained in generating the 1:1000 000 scales Geomorphology and Soils map of Ethiopia primarily in support of the requirement for a land resources database referred to above. Geomorphology and Soils data included in the map and legend and in these reports are derived from a geomorphic interpretation of 71 scenes of Land sat imagery, available surveys, field traverses, topographic maps, land use data and agro climatic information. Landscape units approximating small groups of land systems (Christian and Stewart, 1953), and individual land systems in some cases, were identified in this way. Each landscape unit identified contains a unique soil association. The report indicated that there is only one major soil such as Lithosols in the current command area (Laga Dhumuga). The report indicated that the soils in the sub basin are generally light textured, moderately acidic in pH, contain high Ca in the exchange complex and have low Cation exchange capacity (CEC) which similar with the study undertaken for current project area.

The above report provides valuable background information on the soils of the study area that confirm the current study which identified four major soil such as Leptosols Luvisols Cambisols and Fluvisols. Since it includes the entire area of the current project site and it is recent. However, the previous study scale was much smaller than the current study thus; detailed soil investigation complying with the TOR should be conducted for the present project area.

3.3 Wabi Shebelle River Basin integrated Development Master Plan Study Project

The Wabi Shebelle River basin integrated development master plan study project, soil final Phase II report, part 7 sector assessment, Volume 3-natural resources, Annex **A** Soil and land evaluation. The study was conducted by Water Works, Design and Supervision Enterprise in association with Metaferia Consulting Engineering and Water and Power Consultancy Services April, 2004 prepared soil report and soil map at1: 250,000 scale. The Wabi Shebelle river basin integrated development master plan study project located south eastern part of the country 5^0 to 9^0 30' North and 38^0 30' to 45^0 East(WWDSE,MCE & WAPCO,2004).The river basin falls 34% in Oromia, 65.8% in Somali, 0.01% in SNNP and 0.2% in Harari National Regional States. It has a total drainage area of about 202,220 km^2 .The overall objective of the study was to identify, describe & map the distribution of soils & terrain units of the basin at the scale of 1 :250000 & of the priority irrigation development areas at the scale of 1 :50000.

In line with WWDSE, MCE & WAPCOS (2004) a total of 4027 observation (3827 augers holes & about 200 profile pits) were dug, described & sampled 333 samples from representative horizons had been collected from modal profile for laboratory analysis. All data are stored in the database. In this study 15 FAO major soil groups identified in this reconnaissance soil survey of the basin. Calcisols, Cambisols, Leptosols, Solonchaks, Vertisols and Gypsisols cover 80 % of the entire river basin. The rest of the 10 major soil groups constitute about 20% of the basin. Since the previous study bounds the current project area, the review of the study is considered worthwhile as background information.

The report indicated that there are only two major soils such as Cambisols and Leptosols in the current command area (Laga Dhumuga). The report indicated that the soils in the sub basin are generally light textured, low in pH, contain high Ca in the exchange complex and have high Cation exchange capacity (CEC) which similar with the study undertaken for current project area.

The above report provides valuable background information on the soils of the study area. Since it includes the entire area of the current project site and it is recent. However, the previous study scale was much smaller than the current study thus; detailed soil investigation complying with the TOR should be conducted for the present project area.

3.4. Oromia Irrigation Potential Assessment Wabi Shebel Sub Basin

The soils in Wabi Shebel basin of Arsi and West Arsi have been studied by OWWDSE in 2017G.C for the purpose of assess the potential of the basin for irrigation. The soil investigation was carried out at semi detail level (1:50,000 scale) and covered about 2065587.7hectares within the slope of 0-15 % ha of the basin. To cover the basin in the slope range of 0-15% soil survey was conducted and 584 auger and pits observation at varies representative site was undertaken, out of these 84 soil profile pits described and 217 samples was taken from the pit for further physical and chemical analysis. Soil samples were taken from each horizon of the profile pits to analysis physical and chemical characteristics of soil which was carried out OWWDSE laboratory. The soil and land characteristics description was carried out according to FAO guidelines for soil description (FAO, 2006) and locations of all observation points were recorded by hand held GPS.

The semi detailed soil survey identified six major soils and 15 soil units and 88 soil mapping units. The major soil groups and soil units were classified based on the soil properties of the field and laboratory results are Luvisols, Nitisols, Vertisols, Leptosols, Cambisols and Fluvisol. In the basin, PH value shows variation with average record values of 6.5 to 7.4 which is slightly acidic to slightly alkaline. Under moderately acidic to acidic PH condition Phosphorous is liable to be fixed by Iron, Aluminium, and Manganaze.CEC value of most soils of the basin fall with rating value of high to very high.

Since the previous study bounds the current project area, the review of the study is considered worthwhile as background information.

The report indicated that there are only two major soils such as Leptosols and Cambisols in the current command area. The report indicated that the soils in the basin are generally light textured, slightly acidic to slightly alkaline in pH, contain high Ca in the exchange complex and have high Cation exchange capacity (CEC) which similar with the study undertaken for current project area.

The above report provides valuable background information on the soils of the study area. Since it includes the entire area of the current project site and it is recent. However, the previous study scale was much smaller than the current study thus; detailed soil investigation complying with the TOR should be conducted for the present project area.

3.5. Soil Genesis

Soil forming factors, such as parent material, climate, topography, organisms (fauna and flora) and time, are considered to be more or less independent from each other but have simultaneous interactions. All these soil forming factors result in soil formation and development in the command area. Therefore, the genesis of the soils identified in the area is the result of interactions between the different soil forming factors.

Climate influences soil development by affecting the degree of weathering. Climate and time are related, in that climatic (weathering) effects are most pronounced on stable surfaces, while on such surfaces past rather than current climates may account for the soil conditions. Thus, in areas where the climate is wetter, weathering and decomposition are pronounced giving rise to deep and well developed soils such as Luvisols and Nitisols. In areas where drier climates prevail, evaporation exceeds precipitation and accumulation rather than leaching occurs, so calcic and salt affected soils are dominant.

Topography plays an important role in soil genesis, primarily through modification due to the impact of climate. Thus, on steeper slopes water runoff rapidly retarding soil development. Where topography is steeper, soils are shallower and at the initial stages of soil profile development, because erosion has not given them time to develop. The major soil development related to steeper topography in this command is Cambisols and Leptosols. Soils developed on recent alluvial and colluvial deposits are often only at an initial stage of development, or are not developed at all, as evidenced by their weak structure and stratification resulting in Fluvisols. In flat, nearly flat, and undulating topography in lower landscape positions, imperfect to poorly drained soils, such as Vertisols are formed.

The influence of organisms is manifested in the amount of organic matter in the soils. Organisms also have an appreciable impact on weathering, and are critical to the recycling and release of plant nutrients. In areas under natural vegetation, organic matter tends to be high compared to cultivated areas.

Different rocks are composed of different mineral assemblages, which weather into different soil minerals. Parent material is important in soil development because different rocks are composed of different minerals which breakdown under weathering to various soil minerals. Basalt and other basic rocks are rich in ferromagnesian minerals which breakdown to clay minerals, resulting to clay textured soils. On the other hand, granites and gneisses are rich in quartz that does not break down readily by weathering. These rocks and other coarse textured rocks, such as sandstone, often result in sandy soils. Soil morphology is described using characteristics such as soil depth, colour, texture, consistence, structure and drainage.

4. METHODOLOGY

4.1. General

It is proposed to follow the procedure proposed by FAO guidelines for soil terrain mapping, taxonomic classification and description of the distribution of different soils at scale of 1:10,000.

4.2 Pre field work

The pre field work stage includes review of previous studies, identification of data gap and preparation of base map for soil and land survey and planning of the survey activities. Base map was prepared from different data source for soil and land survey to assist field data collection. For this purpose topographic map of 1:50,000 scale, Google earth image and digital elevation models (DEM) were interpreted by soil and GIS team and preliminary soil boundary was delineated. Then location, probable numbers and depth of pits, augers, deep boring observation points at grid level of 200x200m was distributed on base map and printed in hard copy with scale of 1:10,000 which would help during field soil survey activities. On the other hands field survey check list and field data collection formats for soil profile description, soil auger description, insitu infiltration and hydraulic conductivity tests recording sheet were prepared. Soil survey staffs with necessary experiences were assigned for the field work and the proforma which is used to record data in the field were prepared. All necessarily field equipment, materials, vehicles and others logistics required for soil survey were made available.

4.3. Field Work

The density of auger holes and profile pits observations is discussed in this section. The auger and profile pits sites were physically located on the land in the field by the help of GPS using predetermined coordinates on the base map. The site conditions of every auger and profile pit were carefully filled on the pages of the description sheets. In all observation sites, the most possible internal pedon of characteristics as well as others appropriate surface information's like UTM

coordinate and elevation (using GPS), topography, Land form, slope percentage, Micro topography, Land use and vegetation type, parent materials, presence of rock out crops and stones, surface crack and crusting, erosion status, surface drainage, flooding, permeability etc. were recorded. Besides, filling the site condition physical features was sketched on the description sheets to aid final mapping.

4.3.1. Soil Auger

At the field survey stage, all field soil investigations; soil sampling and verification of satellite imagery interpretation unit boundaries were carried out. Mainly we adopted grid survey methodology approach of (200m x 200m) to provide an optimal coverage for the description of the land units and soils of the command area by producing one auger observation per 4 ha. Every auger observation was done to 1.2m unless restricted by rock or water table. At each auger hole a mini-pit of 0.6m deep was hand dug which enables identification of major soils on the bases of their physical appearance of the subsoil such as Vertisols, Fluvisols and Cambisols. The soil survey for Laga Dhumuga Pump irrigation project command area was completed by 14 routine augers with a total of 81 auger description taken place. All site observation and soil data collected with their geographic coordinate for every auger point is given in Appendix three.

4.3.2. Soil Profile

Depending on soil mapping unit classified and defined from auger bores, four representative soil profiles were located and opened to at least 2.0m unless restricted by lithic contacts or ground water table and described in accordance with the FAO, 2006 “Guidelines for Soil Description”. Soil samples were taken from each horizon of the profile pits to analysis physical and chemical characteristics of soil which was carried out OWWDSE laboratory. Core sampling was made for one profile and was taken at every 30 centimetre intervals of natural horizon up to 90 centimetre depth of profile pits. Data was recorded on a standardized proforma to ensure completeness and uniformity of data collection. On-site, every profile pit description was preliminarily classified according to the “World Reference Base for Soil Resources” (2006) and final classification was made in the office after chemical analyses retrieved. The main significant horizons of representative profiles were sampled for laboratory analysis. Profile description data with their coordinate are given appendix two

4.3.3. Physical site tests

One site tests of infiltration rates and hydraulic conductivity were made at selected sites using a standard double ring inflitrometer and inverse auger hole method respectively in three replications on representative profile pits of the major soil types. A possible care which affect infiltration such as carefully removal of vegetation, insertion of both rings to required depth (15cm), maintaining the water level of the outer ring to the level of the inner ring, avoiding turbidity while putting water, etc. were well taken during the test. Both are required for irrigation planning, including selection of irrigation methods and irrigation scheduling. One representative site was selected for infiltration and hydraulic conductivity was done with three replications in the command area. Data recorded for infiltration rate and hydraulic conductivity with their time of intake are given in appendix 6.

For measurement of water content at various bars to determine soil available water capacity three undisturbed soil core samples were collected from major horizons of representative soil profile and the samples were sent to Oromia Water Works Design and Supervision Enterprise Laboratory Service (OWWDSELS). The core samples were analyzed for bulk density on dry weight basis and moisture content at (FC and PWP) by pressure plate extraction and the results are presented in appendix four II

A total of 81 auger observation,4 profile description, 3 undisturbed core samples from one representative profile, 1 infiltration measurements and 1 hydraulic conductivity measurement each in three replicate has been taken during field work. The locations and distribution soil survey data collected during field work are shown in figure 3 below.

Table 1 Soil survey data collected during the field work

S/N	Status	Number of observations
1	Total augers observation points	81
2	Soil profile description	4
3	Soil samples	10
4	Infiltration and hydraulic conductivity	1
6	Undisturbed core samples	3

4.4. Post Fieldwork

Prior and during this stage systematic reinterpretation of base map, field laboratory entry, analysis and interpretation of the result, final legend construction, final map preparation and report writing were be made.

4.4.1. Laboratory analysis

Soil samples collected from natural horizons of representative profile pits were analysed for usual physical and chemical characteristics. Bulk density and moisture characteristics were determined from core ring samples. This has been served for the purpose of soil classification and assessment of fertility level. The soil sample analysis were carried out at OWWDSE soil laboratory and all analysis except for bulk density determination were made on air dried and crushed to pass through 2 mm sieve size according to the procedure outlined by Van Reeuwijk (1993). The important physical and chemical parameters determined in the laboratories based on standard methods as follows.

A total of 10 disturbed soil samples from main horizons of 4 soil profile pits and 3 core undisturbed samples were collected and sent and analyzed by the Oromia Water Works Design and Supervision Enterprise Laboratory Service (OWWDSELS) in Addis Ababa. The import physical and chemical parameters determined in the laboratory, based on standard methods as follows:-

1. Particle size distribution will be determined by hydrometer methods following pre-treatment with H_2O_2 to remove organic matter and dispersion aided by Sodium hexametaphosphate.

2. Organic carbon (OC) will be determined by a wet combustion procedure of Walkley and Black methods.

3. Total nitrogen (TN) will be determined by the Kjeldah methods.

4. Soil PH will be measured in water and 1M KCL at soil /solution ratio of 1:2.5.

5. Cation exchange capacity (CEC) will be determined by saturation with (pH 7.0 ammonium acetate extraction, filtration) and subsequent replacement of NH_4^+ by NaCL extraction.

6. Exchangeable Ca and Mg measured by following ammonium acetate leachate using Atomic Absorption Spectrophotometer (AAS). Exchangeable Na and K have been measured by flame photometer.

7. Moisture volume at field capacity (1/3 atm) and at permanent wilting point (15 atm) by pressure plate extraction.

8. Available phosphorus content of the soil will be determined by 0.5M NaHCO3 methods of Olsen.

9. Available potassium, K (Morgan's solution and flame photometer).

10. Free $CaCO_3$ content of the soils will be determined by acid neutralization methods.

11. Electrical conductivity at saturated extract (ECe) will be determined at a soil/water ratio of 1:2:5.

From the above data other soil attributes have been derived, namely base saturation (BS), Organic Matter (OM) content, Exchangeable Sodium Percentage (ESP). All the laboratory results are presented in appendix four.

Calculated parameters

The following values of parameters are calculated from the available data as follows:

- Soil Organic Matter: assuming that organic matter forms 58% of organic carbon, SOM values are obtained by multiplying values of soil organic carbon by 1.724. The value is expressed in percentages.
- Cation ratio: this is the measurement of saturations of the soils with specific cations
- Exchangeable sodium percentage, ESP evaluated from Cation exchange capacity and exchangeable sodium.
- Available water holding capacity (AWC): this is a measure of easily available soil water to be absorbed by plant roots. Obtained by the deference between field capacity and permanent wilting point is multiplied by soil depth and bulk density of the soil and it is expressed by millimetre by meter.
- AWC = $\frac{(FC - PWP)\ x\ horizondepth\ x\ BD}{100}$
- Carbon nitrogen ratio (C:N): this measures the degree of mineralization of total nitrogen in relation to soil organic carbon level and it is obtained by dividing the value of percent organic carbon by the value of percent total nitrogen.

4.4.2. Data Compilation and Analysis

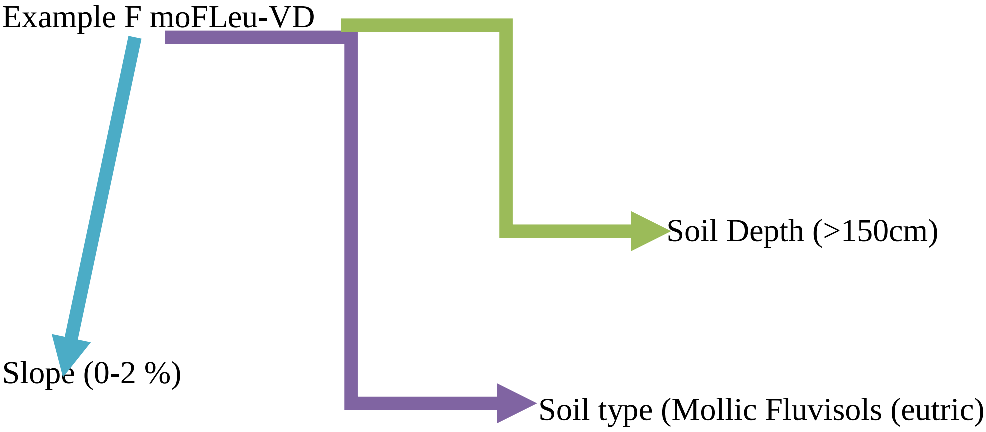
All the physical data collected in the field and the results from laboratory analysis were compiled and entered in the computer database using Microsoft Excel and GIS by data encoders and GIS experts. This facilitated the preparation of data collection points and their distribution in the command area using GIS software.

4.4.3. Mapping unit legend construction

Based on combination of fixed parameters of land resources and main determining factors of soils of the command area such as slope, soil type and soil depth, there are eleven soil mapping units (SMU) were identified. Thus, SMU were represented by three symbols (e.g. F moFLeu-VD= Flat land with Mollic Fluvisols (eutric) and having very deep soil profile).

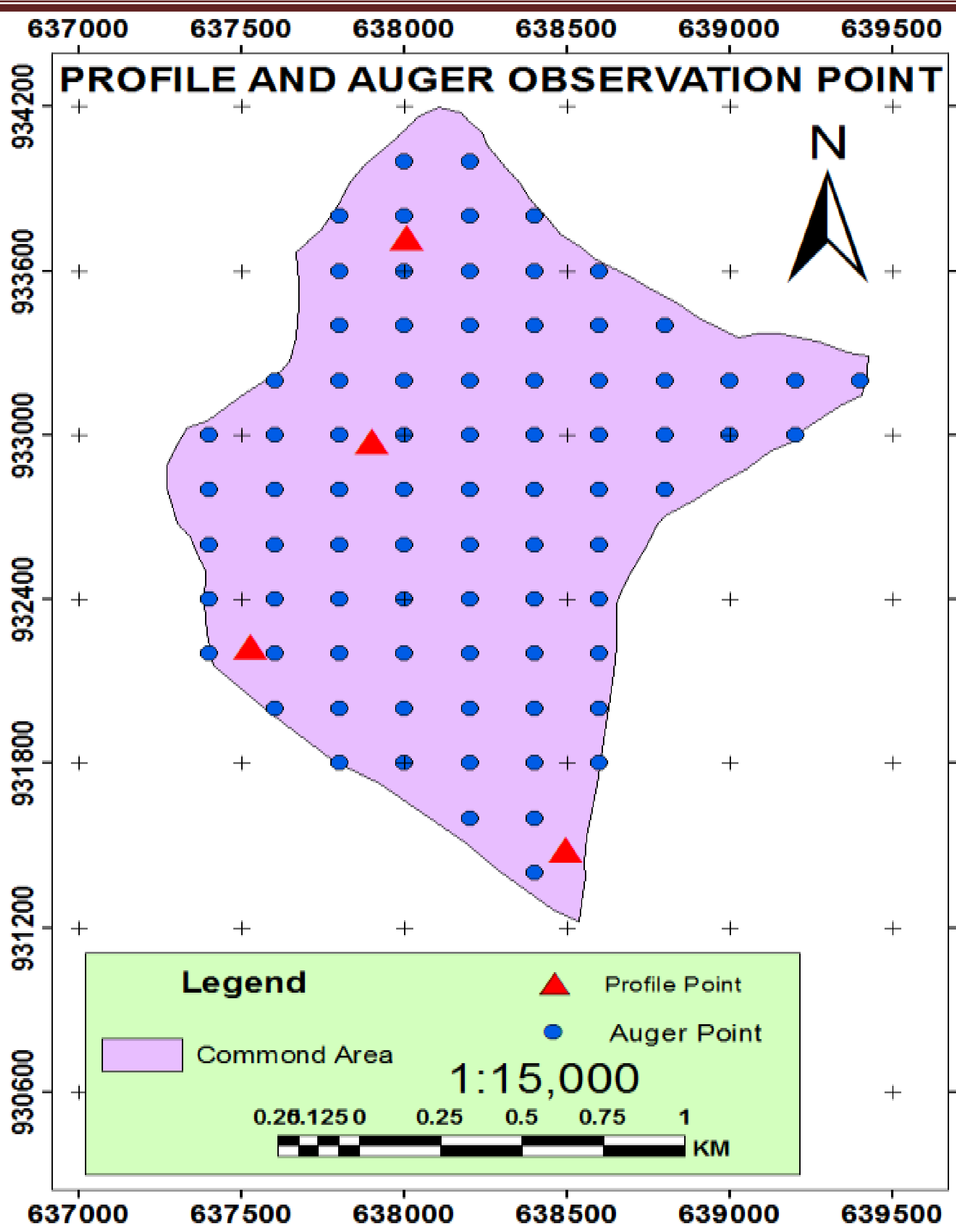
Legend construction for Soil Mapping Units

Example F moFLeu-VD



Location of auger observation points and soil profile pits are presented in Figure 3 below

Figure 3 Location of Auger and profile pit Observation Points


PROFILE AND AUGER OBSERVATION POINT
637000
637500
638000
638500
639000
639500
934200
933600
933000
932400
931800
931200
930600
N
Legend
Profile Point
Auger Point
Commond Area
1:15,000
0.250.125 0
0.25
0.5
0.75
1
KM

5. RESULT AND DISCUSSION

5.1. Soil Classification system

Soils of the area have been classified on hierarchical system at three levels, with increasing specific criteria used to differentiate soils up to the lowest level of the system. The classification was carried out according to FAO-2014 World Reference Base for Soil Resources. First level classification is based on diagnostic horizon; the second level is based on diagnostic properties; and the third level is subdivided on basis of diagnostic materials. Soil classification of the project area is based on field morphological characteristics, which can be observed and measured or inferred from field observations. In addition to the field morphological properties, physical and chemical properties were used to define the soil classes.

5.1.1. Major soil in the study area

According to FAO-2014 soil classification, the major soil unit in the project area are Leptosols, Luvisols, Fluvisols and Cambisols. These soils are the most common soil types in the study area. Detail description of these major soils and their soil types were listed in the following paragraphs and their laboratory physical and chemical characteristics of these major soils were presented in the following table 2 below.

5.1.1.1. Cambisols

Cambisols identified in the survey area is of comparatively recent alluvial origin and mostly found around rivers which immaturely developed and therefore it is classified as Cambisols. Cambisols are generally soils at an incipient stage in their formation with a cambic horizon.

Cambisols combine soils with at least an incipient subsurface soil formation. Transformation of parent material is evident from structure formation and mostly brownish discoloration, increasing clay percentage, and/or carbonate removal (WRB, 2014). In practice, a cambric horizon is any section of a soil profile situated between an A-horizon and a relatively unaltered C-horizon, that has soil structure rather than rock structure and a colour that differs from that of the C-horizon. It is not well possible to sum up all mineralogical, physical and chemical characteristics of Cambisols in one generalized account because Cambisols occur in such widely differing environments (FAO, 2001).

The Cambisols identified in the project area has weakly developed fine medium sized sub angular structure and sandy clay loam textured soil throughout with very dark brown colour.

The Cambisols of the command area is dominantly found on strongly sloping land with slope of greater than 5% and covers an area of 204.6 ha or 66.47 % which is covers the largest area of the command.

5.1.1.2. Leptosols

Leptosols are very shallow soils over continuous rocks and soils that are extremely gravelly and or stony (FAO, 2014). Leptosols are azonal soils and particularly common in mountainous region.

The Leptosols identified in the project area has weakly developed few sized sub angular blocky structure and loam textured soil throughout with some areas of sandy clay loam and dark brown colour. The Leptosols of the command area is dominantly found on steeply sloping land with slope of greater than 15 % and covers an area of 42.15 ha or 13.69 %.

5.1.1.3. Fluvisols

These major soil groups are found adjacent to the main rivers and streams that are subject to annual flooding receiving fresh sediments from each flood. Therefore, the soils show very little or no profile development. The soils are moderately very deep, well drained, medium to light textured and are stratified. Their colour is variable differing from yellowish brown to dark reddish brown. The extents of fluvisols in the command area are wide covering about 47.33or 15.38 ha of the command area and are classified as hyper *eutric*

5.1.1.4 Luvisols:

Luvisols are soils having an Agric horizon, which has base saturation of 50% or more at least in the lower part of B horizon. These soils are derived from different parent materials. They are found in areas where climate condition permits clay movement. They are occurring on flat to gently undulating surfaces. Luvisols are generally well drained deep to very deep and fine to medium textured loamy sandy to sandy clay loam soils. The Structure of Luvisols is moderately developed medium sub angular blocky over moderately to strongly developed medium to coarse sub angular blocky. Consistence is hard (dry), friable to firm (moist), slightly sticky and slightly plastic. Color of top soils is dark brown and dark reddish brown in the sub-soils. Luvisols of the command area cover about 4.45% or 13.71ha of the surveyed area and are classified as *Chromic*.

Table 2 Soil physical and chemical characteristics of major soils of the command area

SOIL CHARACTERESTICS	**MAJOR SOIL**							
	Cambisol		**Leptosols**		**Fluvisols**		**Luvisols**	
	top	**sub**	**Top**	**Sub**	**Top**	**sub**	**Top**	**sub**
PH –Water	5.5	4.7	5.6		5.6	6.1	5.7	5.9
E.C (ds/m)	0.04	0.03	0.10		0.09	0.11	0.11	0.06
PH –KCl	5	4.2	5.1		5.2	5.5	5	5.2
TEXTURE	SCL	CL	L		L	CL/C	LS	SCL
Na (Cmol(+)Kg-1)	0.04	0.01	0.09		0.07	0.2	0.09	0.1
K (Cmol(+)Kg-1)	0.27	0.04	0.57		0.52	0.3	0.72	1.1
Ca (Cmol(+)Kg-1)	19.82	16.1	6.63		10.19	13.4	18.5	3.8
Mg (Cmol(+)Kg-1)	1	1.15	3.73		2.16	4.5	1.46	1.6
SUM (Cmol(+)Kg-1)	21.13	17.39	11.02		12.94	18.4	20.77	6.5
CEC (Cmol(+)Kg-1)	40.5	34.4	18.5		16.9	22.6	41	7.9
BS (%)	52	51	60		76	81.1	51	81.5
T.N (%)	0.1	0.05	0.09		0.1	0.1	0.1	0.1
O.C (%)	1	0.57	1.19		1.34	1.1	1.41	0.5
O.M (%)	1.72	0.99	2.05		2.31	1.9	2.43	0.9
C/N ratio	10	11	13		13	12.3	14	10.5
Av.K (ppm)	106.2	17.2	222		202.6	123.5	278.4	418.1
Av.P (ppm)	7.96	0	0.52		5.9	1.35	8	0.02
P2O5 (%)	18.23	0	1.19		13.51	3.1	18.32	0.05
SAR	0.01	0.00	0.04		0.03	0.07	0.03	0.06
Ece(ds/m)	0	0	0		0.58	0.56	0	0
ESP (%)	0.1	0.03	0.77		0.77	1.06	0.77	1.06
Depth (cm)	25-50		<25		>150		>150	
Structure	SB	SB	GR		SB	SB	SB	SB
Flooding (F/D)	-	-	-		-	-	-	-
Consistency	SST/SPL	SST/SPL	NST/NPL		NST/NPL	ST/PL	NST/NPL	SST/SPL
Drainage	S/R	S/R	E/R		W/W	W/W	W/W	W/W
BD (g/cm3)	0	0	0		1.66	1.85	0	0
FC (%)	0	0	0		19.20	24.70	0	0
PWP (%)	0	0	0		11.10	15.65	0	0
AWC (mm/m)	0	0	0		40.34	50.18	0	0
Total porosity (%)	0	0	0		37.36	30.19	0	0
Air filled porosity (%)	0	0	0		18.16	5.49	0	0

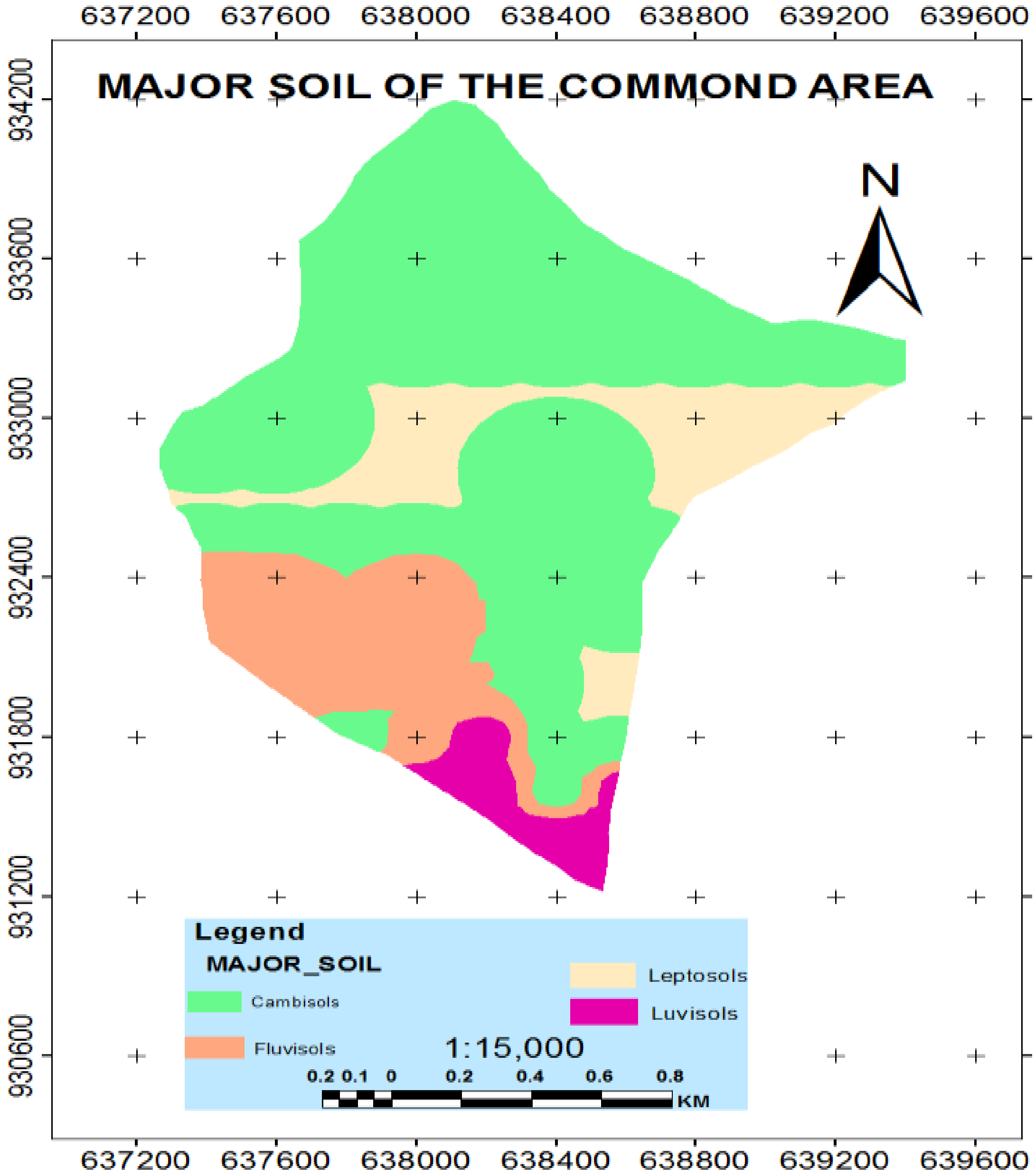


Figure 4 Major Soil Maps of the study area

5.2. Soil physical and chemical properties

5.2.1. Soil physical properties

Soil physical properties profoundly influence how soils function in ecosystem and how they can best be managed. Success or failure of agricultural and engineering projects often hinges on the physical properties of the soil used. The occurrence and growth of many plant species and the movement of water and solutes over and through the soil are closely related to soil physical properties. The physical properties directly describe the nature of soil solids and their impact on the soil water and air which reside in the pore spaces between the solid particles. Key terms and concepts related to soil physical properties include: soil texture, soil depth, soil structure, soil drainage, densities, porosity and water content. The soil physical characteristics of Laga Dhumuga Pump small scale irrigation development project are discussed below.

5.2.1.1. Effective Soil Depth

Effective soil depth is the depth of soil at which root growth of crops is strongly inhibited. Rooting depth being plant specific, the effective depth of soil is governed by such factors as the presence of cemented, toxic, compacted or indurate layers, hard rock or gravel layers. A high permanent water table may also control the effective soil depth, but this may change after drainage. The soil survey result shows that soil of the study area 13.69 %% very deep, 66.55% shallow, 19.75 very shallow.

Table 3: Effective soil depth and area coverage of the area

Depth (cm)	Area (ha)	Ha (%)
>150	60.8	13.69
25-50	204.84	66.55
<25	42.15	19.75
Total	307.79	100

5.2.1.2. Texture

Soil texture is a very important physical characteristic of the soils. The soil texture analysis is carried out in the field by feeling test and by the laboratory investigation by using hydrometer methods.

Soils of the project area are dominantly sandy clay loam textured throughout with some area of loam and loamy sandy texture in top soil and clay, clay loam and sandy clay loam texture in sub surface horizons.

5.2.1.3. Soil Drainage

Soil drainage relates the frequency and duration of periods when the soil is free of saturation or partially saturated. The soil drainage classes reflect the effect of climate, landscape and soil. Rainfall, seepage, internal vertical and lateral water movement and external surface run-off and run-on affect soil drainage. Based on this, soil drainage is classified as well drained, moderately well drained, imperfectly drained, poorly drained and very poorly drained

The majority of Soils drainage of the study area has, excessively drained, somewhat excessively drained and, well drained soil condition in Leptosols, cambisols, fluvisols and luvisols respectively.

5.2.1.4. Soil Structure and Compaction

Soils of the study area have dominantly granular and sub-angular structure on the surface and sub angular block structure in the sub-surface layers. The bulk density values of the soils range from 1.66 to 1.83 g cm^{-3}, and the average value is 1.75 g cm^{-3}. The bulk density values are within the acceptable range for agricultural sols. There is no cemented or compacted horizon within the soil solum. Thus, root development will not be restricted by soil compaction. The total porosity of the soils varies from 29.43 to 37.36 % and, it indicates that the soils of the area have favorable solid to void space proportion.

5.2.1.5. Consistence

Soils of the study area are loose to slightly hard when dry, very friable to friable when moist and none sticky and none plastic to slightly sticky and slightly plastic when wet.

5.2.1.6. Porosity

Total and air-filled porosity values are calculated from bulk density, field capacity and particle density data. The first two have been measured and a value of 2.65 g/cm3 has been adopted for particle density that normally assumed for most mineral agricultural soils (Landon, op. cit.). The following tables summarize the data by soil type for the top 0.9 m of soil, the main rooting zone.

Table 4 Average bulk density and porosity values by soil type.

Profile No.	Bulk density (g/cm^3)			Total porosity (%)			Air-filled porosity (%)		
	Topsoil	**0.3–0.6m**	**0.6–0.9m**	**Topsoil**	**0.3–0.6m**	**0.6-0.9m**	**Topsoil**	**0.3–0.6m**	**0.6-0.9m**
LGDP-1	1.66	1.87	1.83	37.36	29.43	30.94	18.16	3.33	7.64

Total porosity gives a general indication of soil compaction. In clayey soils a total pore space of about 50% or less may indicate some compaction. The analysis field data observations confirm that when dry, Vertisols are hard and other soils are slightly hard. However, when moist the Leptosols and Cambisols become very friable but Vertisols became firm. Air filled porosity is the total porosity minus the volume of moisture held at field capacity. Pores that are not filled by water contain air, and an estimate of their volume can give an indication of the aeration and drainage status of the soil. Very indicatively, a value of < 10% air capacity may indicate anaerobic conditions. In practice, though, the limit depends on soil temperature, continuity of pores, cracks, microbial activity and oxygen consumption by the plant can receive oxygen through stems and roots. All soils of the study area are well-aerated at field capacity.

5.2.1.7. Infiltration Rate

Infiltration rate refers to the measurement of vertical intake of water into a soil at a soil surface, and it is important parameters in design of irrigation developments and/or soil conservation. The results are also used in determining the most efficient methods of applying irrigation and in making runoff calculations.

The infiltration rate measurement was conducted by use of double ring inflitrometer, which consists of two metal cylinders. The method minimizes the errors due to lateral flow around the edges of the cylinder. It is expressed in centimetres per hour (cm/h). All tests were performed close to representative soil profiles. The result of the test indicates that soils of the study area have a mean infiltration rate of 3.6 cm/hr to 7.2 cm/hr with average value of 5.4 cm/hr and this implies that soils of the project area have suitable for gravity irrigation to marginally suitable deep percolation losses.

5.2.1.8. Hydraulic Conductivity

The hydraulic conductivity (or permeability) of soil is a volume of the water that passed through a unit cross-sectional area in time, given the difference in water potential. Hydraulic conductivity values are related to textural and structural characteristics of a soil.

It is expressed in cm/h or m/day. The presence of cracks and holes created by roots or animals increases the permeability.

The tests were carried out according to inverse auger-hole method, near to the representative soil profile. The test results indicate hydraulic conductivity of 0.18 to 0.37 m/day with average value 0.28 m/day for soils of the study area. The result indicates that, the water movement is very slow.

5.2.1.9. Field Capacity (FC)

If a soil, not under cultivation, is saturated and left to drain, the moisture stored in the pore space after drainage is known as field capacity. The moisture is held against gravity by a force known as moisture tension. The tension is expressed in equivalent atmosphere.

One atmosphere is equal to a section or negative pressure of 1 kg/cm^2 .At field capacity soil retains moisture at about 0.33 atmospheres. The field capacity of soil most necessarily depends on the soil texture. A fine textured soil will retain more water than a coarse textured soil. The field capacity value of soils in the current project area varies from 19.2 % to 26.1%.

5.2.1.10. Permanent wilting point (PWP)

Removal of soil moisture by crop roots reaches a stage when the soil particles exert a greater tension on the soil moisture than the crop roots can exert to extract the remaining moisture. When this condition is reached the soil is said to be at permanent wilting point. The corresponding soil moisture tension is about 15 atmospheres. The PWP of the project area ranged from 11.1 to 17.9 %.

5.2.1.11. Bulk density

Bulk-density of a soil is the weight of a known soil volume compared to the weight of an equal volume of water, or weight per unit volume. Bulk densities above 1.75g/cm^3 for sandy and 1.46 to 1.63 g/cm^3 for silt and clay are quoted as causing hindrance to root penetration.

To measure bulk density of the soils in project area, undisturbed soil samples taken by using PF core sampling cylinder were sent to Soil Laboratory. The bulk density of the soils in the study area is between 1.66 and 1.87 g/cm^3 with an average of 1.77 g/cm3 which is optimum.

5.2.1.12. Moisture Retention

The available water holding capacity (AWC) of the soils ranges from 40.34to 54.35 mm/m on a pedon basis and the average amount is 47.35 mm/m. The AWC content of the soils of the study area is low.

Table 5 Average available water capacity (AWC) and readily available water capacity (RAWC) value for the Representative profile of the soils of the study area.

Field code	depth_cm	Depth_mm	Texture	Fc	PWP	Bd	AWC_cm	AWC_mm	TAWC_mm/m	TRAWC_mm/m	class
LGDP-1	0-30	300	Loam	19.20	11.1	1.66	4.03	40.34	140.69	84.41	medium
	30-60	300	Clay	26.10	17.9	1.87	4.60	46.00			
	60-90	300	Clay loam	23.30	13.4	1.83	5.44	54.35			

5.2.1.13. Erosion Status in the Project Area

Indicators of soil erosion have been observed in the surveyed area. The study area is highly subjected to water erosion. Mild sheet erosion is distributed at the several locations and high level of rill erosion, gully erosion has been noticed at some locations in the project site.

5.2.1.14. Flooding

For the majority of the soil mapping units the flooding Status of the command area is generally known, there is no evidence of flooding hazards in command area.

5.2.2. Soil chemical properties

5.2.2.1. Soil Reaction: (pH)

Soil pH is important, as it is an indicator of acidity, neutrality or alkalinity in the soil. PH helps to determine the availability of nutrients to plants and toxicity of macro and micronutrients in the soil that ultimately control plant growth. PH water values do not have precise significance but some generalizations can nevertheless be made for interpretation purposes. Generally the pH water tolerance limits for different plants vary, but for most commercial crops a neutral range (PH Water value 6.6-7.3.) is most suitable. The soil pH significantly affects the availability of most of the chemical elements important to plants and microbes.

The overall pH value of the project area in soil-water suspension is 5.5 to 5.7 with an average 5.6 which increase from top to sub soil. This range of soil pH is normally termed as strongly acidic to moderately acidic soil. In the range of pH 5.5 to 7, hydroxyl aluminium polymers predominate among acids soil components, exchangeable acidity is virtually absent, and only none exchangeable and titrable acidity are present in measurable quantities. Although potential acidity depends on the equilibrium pH of the soil suspension, exchangeable aluminium normally occurs in significant amounts only at soil pH values less than about 5.5. Considering the optimum pH for many plant species to be 5.5 to 5.7 and absence of free exchangeable Al in this range, almost all percents of the pH of the soils in study area could be considered as suitable for most crop production

5.2.2.2. Electrical Conductivity (ECe)

Electrical Conductivity (ECe) measurements of the soil solutions are used as indicators of total quantities of soluble slats in the soil. The electrical conductivity is measured in a saturation of extract of the soil water suspension using a conductivity meter. Excess amounts of soluble salts in soils cause moisture stress and nutrient imbalance to plants. ECe values greater than 4dS/m are considered very restrictive to the growth and development of most field crops. The EC values of the soils in the study area range from 0.041 ds/m to 0.111 ds/m with an average of 0.083 ds/m with increase downward throughout the profile. This indicates that the salinity status of the soils in the study area is salt free not a potential limitation for irrigation development.

5.2.2.3. Cation Exchange Capacity

Cation exchange capacity (CEC) of soils is a measure of the nutrient retention capacity of soils and is a good indicator of soil fertility status. CEC greater than 45 Cmol (+) Kg^{-1} of soil is considered to be very high. The Cation exchange capacity of the soils in the study area varied from 16.9 to 41Cmol (+) Kg^{-1} with an average of 29.13 Cmol (+) Kg^{-1} of in top soil. The figure shows surface horizons of the CEC are medium to very high as compared to the sub surface horizons with the value of 7 Cmol (+) Kg^{-1} to 34.4Cmol (+) Kg^{-1} with an average 19.91Cmol (+) Kg^{-1} in the sub surface horizons low to high. The overall profile distribution of CEC was somewhat irregular; however in most cases it is lower in the subsoil than the surface soils. 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 needed amendment.

5.2.2.4. Percentage Base Saturation (PBS)

Base saturation (BS) is the proportion of the CEC accounted for by the basic exchangeable Cations (Ca, Mg, K and Na). PBS value of 50% or above are referred to as “Eutric” and classified as high, while values below 50% are referred as Dystric and classified as low level.

The BS of the soils in the study area is medium to high and it ranges from 51to 76 % with an average value of 61% in the in representative profiles. In all cases the sum of exchangeable basic Cations content of the soils in the study area is higher than the CEC. This value mainly attributed to the overestimation of Ca^{2+} as the soils contain free $CaCO_3$ which comes to solution during CEC determination.

What is equally important is not just the BS% but also the relative proportion of the basic Cations. For instance very excessive amount of exchangeable K can inhibit the uptake of Ca and Mg, and vice versa. The exchangeable Ca content of the soils in the study area is very high compared to the other exchangeable basic Cations. This may restrict the availability of Mg and K. Thus, this has to be taken into account during soil fertility management program.

5.2.2.5. Exchangeable Sodium Percentage (ESP) and Sodium Adsorption Ratio (Sodicity)

The presence of relatively higher amount of exchangeable Na in soils is known to have a deleterious effect on the physical soil condition. The level of the deleterious effect of Na is measured by the exchangeable sodium percentage (ESP), the proportion of the CEC accounted by the exchangeable Na. The ESP of most soils in the study area increases with soil depth and the value ranges from 0.22 % to 0.24% with an average of 0.23 % of the study area in top soil. ESP of most soils in the study area increases with soil depth with value of 0.52 % to 0.57 % with an average 0.55% in sub soil. The absolute amount of exchangeable Na content of the soils in the study area is low and it's not a potential limitation for irrigation development. Exchangeable Sodium Percentage (ESP) indicates Sodicity in the soil. Soils with ESP<15 is generally non-Sodic requiring no amendments, whereas soil with ESP> 15 are Sodic and requires amelioration method.

Sodic soils have an ESP >15, the ECe is <4 dS m^{-1}, and the lower limit of the saturation extract SAR is 13.

$$SAR = \frac{[Na^{+}]}{[[Ca^{2+} + Mg^{2+}]/2]^{1/2}}$$

The results of SAR in the project area ranges 0.021 to 0.026with the average 0.023on the top soil and 0.03 to 0.055 with an average 0.043 in the sub soil based on this classification the results obtained in the project area indicate that low level there is no problem of sodicity (sodium hazard) and salinity.

5.2.2.6. Organic Matter

Organic carbon is the principal storehouse for nutrients influencing soil structure and biological activity. It has been determined by using Walkley and Black method in the laboratory and has been expressed in percentage (%).

The overall organic carbon (C) content of the soil profiles ranges from 1 % to 1.41 %. In most cases the distribution of organic C over the entire profile is irregular.

The value of organic matter has been obtained by multiplying the organic carbon content by factor 1.724 assuming that the soil organic matter contains 1% to 1.41% of carbon. The overall organic matter content of the soils in the project area ranges from 1.72 % to 2.43 % with an average of 2.11 %. This indicates that fertility status of the soils is Medium to high so minimal application of organic and inorganic fertilizers are required for higher yields.

5.2.2.7. Total Nitrogen

Nitrogen is an essential nutrient element, which highly influences the plant growth. It is a constituent of chlorophyll, plant proteins and nucleic acid. The total nitrogen content of the project area has been determined by using Kjeldahl method in the laboratory. The total nitrogen content of soils in the project area ranged from 0.09% to 0.1 with an average 0.1%

for topsoil and 0.04 to 0.12% with an average 0.07% for subsoil, which shows that the content of Total Nitrogen is high and thus it may not require additional fertilizer application.

5.2.2.8. Available Phosphorus

Phosphorous is present in soils in both organic and inorganic forms. The inorganic form is usually more important as a plant nutrient. The phosphorus availability to plants therefore differs between different forms of phosphorus in soils. Available phosphorus is the amount of phosphorus readily available for nutrient absorption by plant roots. The available phosphorus content of the soils of the project area varies from 0.52 ppm to 8 ppm with average of 5.15ppm and 0.00 ppm to 2.36 ppm with an average 0.81 ppm in top and sub soil respectively where the value is low to medium both in top and sub soil. Generally the result shows available phosphorus rated as low to medium level so application of phosphorous related fertilizers should be needed.

5.2.2.9. Carbonates

Calcium carbonate ($CaCO_3$) affects both physical and chemical characteristics of soils. Moderate amount of calcium carbonate is known to encourage favourable soil structure and improve soil moisture characteristics. Excessive amount of carbonate, however, restricts root development and induce available Phosphorous, Iron and micronutrient deficiencies.

The calcium carbonate equivalent of >15 per cent is used in the FAO definition of Calcic horizon. High level of calcium carbonate >15 per cent affect the physical and chemical characteristics of a soil besides normal root penetration. The term Calcaric which refers to soils which are calcareous (show strong effervescence with 10 per cent HCL), in most of the fine earth or which contain more than 2% carbonate equivalent. The calcium carbonate content of most of the soils in the study area not affects the soil conditions.

5.2.2.10. Potassium to Magnesium Ratio (K: Mg)

If the ratio of potassium to magnesium is more than 2:1, magnesium uptake may be inhibited. The ratio of K: Mg recorded for the project area is between 0.19 and 0.27 for surface soil with an average of 0.23, indicating an optimum situation for production of most field crops, vegetables and fruits.

5.2.2.11. Calcium to Magnesium Ratio (Ca: Mg)

The ratio of calcium to magnesium (Ca: Mg) in most soils of the project area ranges from 5.31 to 6.63 with an average of 5.97 and rated as moderately high to high. Moderately high level of the ratio is suitable for availability phosphorous and at extreme level of the ratio lack of Mg nutrient is occurred and Ca will be taken in overdose. Calcium to magnesium ratio of the command area fall within suitable ranges and suitable for availability of prosperous.

5.2.2.12. Potassium to Cation Exchangeable Capacity Ratio (K: CEC)

If the ratio of K: CEC is less than two percent, it 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 project area was 0.02 and hence most of the soils in the project area have the ratio less than minimum level which indicates K deficiency.

5.2.2.13. Carbon to Nitrogen ratio (C: N)

C: N ratio is an indicator of the process of transformation of organic nitrogen to available nitrogen such as ammonium nitrite and nitrate. A minimum acceptable C: N ratio is a value less than 10:1 and C: N ratio of greater than 14:1 is considered as poor humification and low N. The C: N ratio of soils in the study area varies from 10 to 14.1 with an average of 12.4 and the value is within an acceptable range for transformation of organic nitrogen to available nitrogen

5.2.14. Exchangeable Calcium (Ca)

Normally calcium deficiency in a plant nutrient occurs only in soils of low CEC at PH of 5.5 or less, Calcium also effectively deficient at high PH level when there is excessive sodium content. Large input of potassium fertilizer or high natural potassium may however inhibit plant uptake of calcium in the soil having more neutral reaction. If other factors are conducive a level of 6 meq/100g soil of exchangeable calcium is generally sufficient to ensure crop production (FAO,

1979).The value of exchangeable calcium in the study area is 6.63cmol (+)/kg soil to 19.82cmol

(+)/kg soils with an average value of 13.6cmol (+)/kg in topsoil, indicates that high level.

5.2.15. Exchangeable Magnesium (Mg)

Exchangeable magnesium which is greater than 3cmol (+)/kg soil is believed to be adequate for plant nutrition. The amount of exchangeable magnesium reported for the soils of the study area varies from 1 to 3.73cmol (+)/kg soil with average value of 2.18cmol (+)/kg in top soil. The result shows that the level of Mg is low to high.

5.2.16. Exchangeable Potassium (K)

Potassium is an important plant nutrient and a great deal of study has been made of the amounts believed necessary for adequate plant growth. Values less than 0.1cmol (+)/kg soil are considered deficient, from 0.1 to 0.2cmol (+)/kg intermediate and greater than 0.2cmol (+)/kg adequate.

Soils of the study area have exchangeable K value ranging from 0.27 to 0.72 cmol (+)/kg soil, with an average value of 0.51 cmol (+)/kg in topsoil which indicates that the level of K is low to high.

5.2.17. Exchangeable Sodium (Na)

Sodium is not an essential plant nutrient; but some plants for potassium substitute can utilize it. On the other hand, when sodium is present in the soil in significant quantities, particularly in proportion to the other cations present it can have an adverse effect to both plant nutrition and physical conditions of the soils; however, no structural degradation was observed during the present field work. The value of the measured exchangeable Na falls in the range of 0.04 to 0.09cmol(+)/kg of soil, with mean value of 0.07cmol(+)/kg of in top soil indicating very low Na content of the soil and have no any adverse effect on growth of crops and physical properties of soil.

5.2.3. Description of soil mapping units

Soil mapping units have been identified based on slope, soil depth and soil type of the study area. Detailed description of these mapping units with respect to soil physical and chemical properties is given below. A total of eighteen SMU were identified on the basis of the above three criteria. The distribution of the eighteen SMU is presented in Figure 5 and summary of physical and chemical characteristics of the SMU are given in Table 6 below.

5.2.3.1. SMU-1 (S euLPol-V)

This soil mapping unit refers to soils having very shallow profile (<25cm) and in moderately steep slope of topography 15-30%.The soil texture loam throughout the soil depth. Soils in the mapping unit are excessively drained. The soils have weakly developed granular structure. The average infiltration rate (IR) varies from 3.6 to 7.2 cm/hr, which is categorized as suitable for gravity irrigation to marginally suitable and hydraulic conductivity (HC) the mapping unit ranges from 0.18 to 0.37m/day categorized as very slow to slow.

Laboratory result shows that the mapping unit has pH value of 5.6 which is moderately acidic and electrical conductivity results value 0.093 shows that the soil is salt free. Soils in this mapping unit have medium CEC value 18.5Cmol kg^{-1} .Medium BSP through the profile 60%.Organic matter content 2.05% which indicates that the mapping unit is characterised by medium level of organic matter and total nitrogen content is about 0.09 which is high. The soil mapping unit has medium Ca^{2+} throughout the profile 6.63, and the soils are none calcareous. The total extent of this mapping unit is 25.95ha or 8.43 % of the command area.

5.2.3.2. SMU-2 (S euFLol-VD)

This soil mapping unit refers to soils having very deep profile (>150cm) and in moderately steep slope of topography 15-30%.The soil texture loam in the top soil and clay to clay loam in the sub soil throughout the soil depth. Soils in the mapping unit are well drained. The soils have moderately developed sub angular blocky structure in both top and sub soil.

The average infiltration rate (IR) varies from 3.6 to 7.2 cm/hr, which is categorized as suitable for gravity irrigation to marginally suitable and hydraulic conductivity (HC) the mapping unit ranges from 0.18 to 0.37m/day categorized as very slow to slow.

Laboratory result shows that the mapping unit has pH value of 5.6 top soil and 6.1 in sub soil which is moderately acidic to slightly acidic and electrical conductivity results value 0.093 in top soil and 0.112 in sub soil shows that the soil is salt free. Soils in this mapping unit have medium to high CEC value 16.9 Cmol kg^{-1} top soils and 22.6 Cmol kg^{-1} in sub soil High BSP through the profile 76% in top soil and 81.1% in sub soil, organic matter content 2.31% in top soil and 1.9 in sub soil which indicates that the mapping unit is characterised by medium level of organic matter and total nitrogen content is about 0.1 in both top and sub soil which is high. The soil mapping unit has high Ca^{2+} throughout the profile 10.19 in top soil and 13.4 in sub soil, and the soils are none calcareous. The total extent of this mapping unit is 30.17 ha or 9.8 % of the command area.

5.2.3.3. SMU-3 (S chLVje-VD)

This soil mapping unit refers to soils having very deep profile (>150cm) and in moderately steep slope of topography 15-30%.The soil texture loam sandy in the top soil and sandy clay loam in the sub soil throughout the soil depth. Soils in the mapping unit are well drained. The soils have moderately developed sub angular blocky structure in both top and sub soil.

The average infiltration rate (IR) varies from 3.6 to 7.2 cm/hr, which is categorized as suitable for gravity irrigation to marginally suitable and hydraulic conductivity (HC) the mapping unit ranges from 0.18 to 0.37m/day categorized as very slow to slow.

Laboratory result shows that the mapping unit has pH value of 5.7 top soil and 5.9 in sub soil which is moderately acidic and electrical conductivity results value 0.111 in top soil and 0.059 in sub soil shows that the soil is salt free. Soils in this mapping unit have very high to low CEC value 41Cmol kg^{-1} top soils and 7.9 Cmol kg^{-1} in sub soil Medium to high BSP through the profile 51% in top soil and 81.5% in sub soil, organic matter content 2.43% in top soil and 0.9 in sub soil which indicates that the mapping unit is characterised by medium to low level of organic matter and total nitrogen content is about 0.1 in both top and sub soil which is high. The soil mapping unit has high to low Ca^{2+} throughout the profile 18.5 in top soil and 3.8 in sub soil, and the soils are none calcareous. The total extent of this mapping unit is 8.54 ha or 2.77 % of the command area

5.2.3.4. SMU-4 (S leCMol-S)

This soil mapping unit refers to soils having shallow profile (25-50cm) and in moderately steep slope of topography 15-30%.The soil texture sandy clay loam in the top soil and clay loam in the sub soil throughout the soil depth. Soils in the mapping unit are somewhat excessively well drained. The soils have moderately developed sub angular blocky structure in both top and sub soil.

The average infiltration rate (IR) varies from 3.6 to 7.2 cm/hr, which is categorized as suitable for gravity irrigation to marginally suitable and hydraulic conductivity (HC) the mapping unit ranges from 0.18 to 0.37m/day categorized as very slow to slow

Laboratory result shows that the mapping unit has pH value of 5.5 top soil and 4.7 in sub soil which is strongly acidic to very strongly acid and electrical conductivity results value 0.041 in top soil and 0.03 in sub soil shows that the soil is salt free. Soils in this mapping unit have very high to high CEC value 40.5 Cmol kg^{-1} top soils and 34.4 Cmol kg^{-1} in sub soil Medium BSP through the profile 52% in top soil and 51% in sub soil, organic matter content 1.72% in top soil and 0.99 in sub soil which indicates that the mapping unit is characterised by medium to low level of organic matter and total nitrogen content is about 0.1 in sub soil and 0.05 in sub soil which is high to medium. The soil mapping unit has high Ca^{2+} throughout the profile 19.82 in top soil and 16.1 in sub soil, and the soils are none calcareous. The total extent of this mapping unit is 117.08 ha or 38.04 % of the command area.

5.2.3.5. SMU-5 (R leCMol-S)

This soil mapping unit refers to soils having shallow profile (25-50cm) and in rolling, strongly sloping of topography 8-15%.The soil texture sandy clay loam in the top soil and clay loam in the sub soil throughout the soil depth. Soils in the mapping unit are somewhat excessively well drained. The soils have moderately developed sub angular blocky structure in both top and sub soil.

The average infiltration rate (IR) varies from 3.6 to 7.2 cm/hr, which is categorized as suitable for gravity irrigation to marginally suitable and hydraulic conductivity (HC) the mapping unit ranges from 0.18 to 0.37m/day categorized as very slow to slow

Laboratory result shows that the mapping unit has pH value of 5.5 top soil and 4.7 in sub soil which is strongly acidic to very strongly acid and electrical conductivity results value 0.041 in top soil and 0.03 in sub soil shows that the soil is salt free. Soils in this mapping unit have very high to high CEC value 40.5 Cmol kg^{-1} top soils and 34.4 Cmol kg^{-1} in sub soil Medium BSP through the profile 52% in top soil and 51% in sub soil, organic matter content 1.72% in top soil and 0.99 in sub soil which indicates that the mapping unit is characterised by medium to low level of organic matter and total nitrogen content is about 0.1 in sub soil and 0.05 in sub soil which is high to medium. The soil mapping unit has high Ca^{2+} throughout the profile 19.82 in top soil and 16.1 in sub soil, and the soils are none calcareous. The total extent of this mapping unit is 50.52 ha or 16.41% of the command area.

5.2.3.6. SMU-6(G euLPol-V)

This soil mapping unit refers to soils having very shallow profile (<25cm) and in gently undulating slope of topography 2-5%.The soil texture loam throughout the soil depth. Soils in the mapping unit are excessively drained. The soils have weakly developed granular structure. The average infiltration rate (IR) varies from 3.6 to 7.2 cm/hr, which is categorized as suitable for gravity irrigation to marginally suitable and hydraulic conductivity (HC) the mapping unit ranges from 0.18 to 0.37m/day categorized as very slow to slow.

Laboratory result shows that the mapping unit has pH value of 5.6 which is moderately acidic and electrical conductivity results value 0.093 shows that the soil is salt free. Soils in this mapping unit have medium CEC value 18.5Cmol kg^{-1} .Medium BSP through the profile 60%.Organic matter content 2.05% which indicates that the mapping unit is characterised by medium level of organic matter and total nitrogen content is about 0.09 which is high. The soil mapping unit has medium Ca^{2+} throughout the profile 6.63, and the soils are none calcareous. The total extent of this mapping unit is 0.42ha or 0.14 % of the command area.

5.2.3.7 SMU-7 (G euFLol-VD)

This soil mapping unit refers to soils having very deep profile (>150cm) and in gently undulating slope of topography 2-5%The soil texture loam in the top soil and clay to clay loam in the sub soil throughout the soil depth. Soils in the mapping unit are well drained. The soils have moderately developed sub angular blocky structure in both top and sub soil.

The average infiltration rate (IR) varies from 3.6 to 7.2 cm/hr, which is categorized as suitable for gravity irrigation to marginally suitable and hydraulic conductivity (HC) the mapping unit ranges from 0.18 to 0.37m/day categorized as very slow to slow.

Laboratory result shows that the mapping unit has pH value of 5.6 top soil and 6.1 in sub soil which is moderately acidic to slightly acidic and electrical conductivity results value 0.093 in top soil and 0.112 in sub soil shows that the soil is salt free. Soils in this mapping unit have medium to high CEC value 16.9 Cmol kg^{-1} top soils and 22.6 Cmol kg^{-1} in sub soil High BSP through the profile 76% in top soil and 81.1% in sub soil, organic matter content 2.31% in top soil and 1.9 in sub soil which indicates that the mapping unit is characterised by medium level of organic matter and total nitrogen content is about 0.1 in both top and sub soil which is high. The soil mapping unit has high Ca^{2+} throughout the profile 10.19 in top soil and 13.4 in sub soil, and the soils are none calcareous. The total extent of this mapping unit is 0.74 ha or 0.23 % of the command area.

5.2.3.8. SMU-8 (G leCMol-S)

This soil mapping unit refers to soils having shallow profile (25-50cm) and gently undulating slope of topography 2-5%.The soil texture sandy clay loam in the top soil and clay loam in the sub soil throughout the soil depth. Soils in the mapping unit are somewhat excessively well drained. The soils have moderately developed sub angular blocky structure in both top and sub soil.

The average infiltration rate (IR) varies from 3.6 to 7.2 cm/hr, which is categorized as suitable for gravity irrigation to marginally suitable and hydraulic conductivity (HC) the mapping unit ranges from 0.18 to 0.37m/day categorized as very slow to slow

Laboratory result shows that the mapping unit has pH value of 5.5 top soil and 4.7 in sub soil which is strongly acidic to very strongly acid and electrical conductivity results value 0.041 in top soil and 0.03 in sub soil shows that the soil is salt free. Soils in this mapping unit have very high to high CEC value 40.5 Cmol kg^{-1} top soils and 34.4 Cmol kg^{-1} in sub soil Medium BSP through the profile 52% in top soil and 51% in sub soil, organic matter content 1.72% in top soil and 0.99 in sub soil which indicates that the mapping unit is characterised by medium to low level of organic matter and total nitrogen content is about 0.1 in sub soil and 0.05 in sub soil which is high to medium. The soil mapping unit has high Ca^{2+} throughout the profile 19.82 in top soil and 16.1 in sub soil, and the soils are none calcareous. The total extent of this mapping unit is 1.11 ha or 0.36 % of the command area.

5.2.3.9. SMU-9 (T euLPol-V)

This soil mapping unit refers to soils having very shallow profile (<25cm) and steep slope of topography 30-60%.The soil texture loam throughout the soil depth. Soils in the mapping unit are excessively drained. The soils have weakly developed granular structure. The average infiltration rate (IR) varies from 3.6 to 7.2 cm/hr, which is categorized as suitable for gravity irrigation to marginally suitable and hydraulic conductivity (HC) the mapping unit ranges from 0.18 to 0.37m/day categorized as very slow to slow.

Laboratory result shows that the mapping unit has pH value of 5.6 which is moderately acidic and electrical conductivity results value 0.093 shows that the soil is salt free. Soils in this mapping unit have medium CEC value 18.5Cmol kg^{-1} .Medium BSP through the profile

60%.Organic matter content 2.05% which indicates that the mapping unit is characterised by medium level of organic matter and total nitrogen content is about 0.09 which is high. The soil mapping unit has medium Ca^{2+} throughout the profile 6.63, and the soils are none calcareous. The total extent of this mapping unit is 8.36 ha or 2.72 % of the command area.

5.2.3.10. SMU-10 (T euFLol-VD)

This soil mapping unit refers to soils having very deep profile (>150cm) and in steep slope of topography 30-60%The soil texture loam in the top soil and clay to clay loam in the sub soil throughout the soil depth. Soils in the mapping unit are well drained. The soils have moderately developed sub angular blocky structure in both top and sub soil.

The average infiltration rate (IR) varies from 3.6 to 7.2 cm/hr, which is categorized as suitable for gravity irrigation to marginally suitable and hydraulic conductivity (HC) the mapping unit ranges from 0.18 to 0.37m/day categorized as very slow to slow.

Laboratory result shows that the mapping unit has pH value of 5.6 top soil and 6.1 in sub soil which is moderately acidic to slightly acidic and electrical conductivity results value 0.093 in top soil and 0.112 in sub soil shows that the soil is salt free. Soils in this mapping unit have medium to high CEC value 16.9 Cmol kg^{-1} top soils and 22.6 Cmol kg^{-1} in sub soil High BSP through the profile 76% in top soil and 81.1% in sub soil, organic matter content 2.31% in top soil and 1.9 in sub soil which indicates that the mapping unit is characterised by medium level of organic matter and total nitrogen content is about 0.1 in both top and sub soil which is high. The soil mapping unit has high Ca^{2+} throughout the profile 10.19 in top soil and 13.4 in sub soil, and the soils are none calcareous. The total extent of this mapping unit is 1.7 ha or 0.55 % of the command area.

5.2.3.11. SMU-11 (T chLVje-VD)

This soil mapping unit refers to soils having very deep profile (>150cm) and in steep slope of topography 30-60%.The soil texture loam sandy in the top soil and sandy clay loam in the sub soil throughout the soil depth. Soils in the mapping unit are well drained. The soils have moderately developed sub angular blocky structure in both top and sub soil.

The average infiltration rate (IR) varies from 3.6 to 7.2 cm/hr, which is categorized as suitable for gravity irrigation to marginally suitable and hydraulic conductivity (HC) the mapping unit ranges from 0.18 to 0.37m/day categorized as very slow to slow.

Laboratory result shows that the mapping unit has pH value of 5.7 top soil and 5.9 in sub soil which is moderately acidic and electrical conductivity results value 0.111 in top soil and 0.059 in sub soil shows that the soil is salt free. Soils in this mapping unit have very high to low CEC value 41Cmol kg^{-1} top soils and 7.9 Cmol kg^{-1} in sub soil Medium to high BSP through the profile 51% in top soil and 81.5% in sub soil, organic matter content 2.43% in top soil and 0.9 in sub soil which indicates that the mapping unit is characterised by medium to low level of organic matter and total nitrogen content is about 0.1 in both top and sub soil which is high. The soil mapping unit has high to low Ca^{2+} throughout the profile 18.5 in top soil and 3.8 in sub soil, and the soils are none calcareous. The total extent of this mapping unit is 1.15ha or 0.37 % of the command area

5.2.3.12. SMU-12(T leCMol-S)

This soil mapping unit refers to soils having shallow profile (25-50cm) and steep slope of topography 30-60%.The soil texture sandy clay loam in the top soil and clay loam in the sub soil throughout the soil depth. Soils in the mapping unit are somewhat excessively well drained. The soils have moderately developed sub angular blocky structure in both top and sub soil.

The average infiltration rate (IR) varies from 3.6 to 7.2 cm/hr, which is categorized as suitable for gravity irrigation to marginally suitable and hydraulic conductivity (HC) the mapping unit ranges from 0.18 to 0.37m/day categorized as very slow to slow

Laboratory result shows that the mapping unit has pH value of 5.5 top soil and 4.7 in sub soil which is strongly acidic to very strongly acid and electrical conductivity results value 0.041 in top soil and 0.03 in sub soil shows that the soil is salt free. Soils in this mapping unit have very high to high CEC value 40.5 Cmol kg^{-1} top soils and 34.4 Cmol kg^{-1} in sub soil Medium BSP through the profile 52% in top soil and 51% in sub soil, organic matter content 1.72% in top soil and 0.99 in sub soil which indicates that the mapping unit is characterised by medium to low level of organic matter and total nitrogen content is about 0.1 in sub soil and 0.05 in sub soil which is high to medium. The soil mapping unit has high Ca^{2+} throughout the profile 19.82 in top soil and 16.1 in sub soil, and the soils are none calcareous. The total extent of this mapping unit is 30.96 ha or 10.06% of the command area.

5.2.3.13. SMU-13 (U euLPol-V)

This soil mapping unit refers to soils having very shallow profile (<25cm) and undulating slope of topography 5-8%.The soil texture loam throughout the soil depth. Soils in the mapping unit are excessively drained. The soils have weakly developed granular structure. The average infiltration rate (IR) varies from 3.6 to 7.2 cm/hr, which is categorized as suitable for gravity irrigation to marginally suitable and hydraulic conductivity (HC) the mapping unit ranges from 0.18 to 0.37m/day categorized as very slow to slow.

Laboratory result shows that the mapping unit has pH value of 5.6 which is moderately acidic and electrical conductivity results value 0.093 shows that the soil is salt free. Soils in this mapping unit have medium CEC value 18.5Cmol kg^{-1} .Medium BSP through the profile 60%.Organic matter content 2.05% which indicates that the mapping unit is characterised by medium level of organic matter and total nitrogen content is about 0.09 which is high. The soil mapping unit has medium Ca^{2+} throughout the profile 6.63, and the soils are none calcareous. The total extent of this mapping unit is 1.57 ha or 0.51 % of the command area

5.2.3.14. SMU-14 (U euFLol-VD)

This soil mapping unit refers to soils having very deep profile (>150cm) and in undulating slope of topography 5-8%The soil texture loam in the top soil and clay to clay loam in the sub soil throughout the soil depth. Soils in the mapping unit are well drained. The soils have moderately developed sub angular blocky structure in both top and sub soil.

The average infiltration rate (IR) varies from 3.6 to 7.2 cm/hr, which is categorized as suitable for gravity irrigation to marginally suitable and hydraulic conductivity (HC) the mapping unit ranges from 0.18 to 0.37m/day categorized as very slow to slow.

Laboratory result shows that the mapping unit has pH value of 5.6 top soil and 6.1 in sub soil which is moderately acidic to slightly acidic and electrical conductivity results value 0.093 in top soil and 0.112 in sub soil shows that the soil is salt free. Soils in this mapping unit have medium to high CEC value 16.9 Cmol kg^{-1} top soils and 22.6 Cmol kg^{-1} in sub soil High BSP through the profile 76% in top soil and 81.1% in sub soil, organic matter content 2.31% in top soil and 1.9 in sub soil which indicates that the mapping unit is characterised by medium level of organic matter and total nitrogen content is about 0.1 in both top and sub soil which is high. The soil mapping unit has high Ca^{2+} throughout the profile 10.19 in top soil and 13.4 in sub soil, and the soils are none calcareous. The total extent of this mapping unit is 6.17 ha or 2 % of the command area.

5.2.3.15. SMU-15(U leCMol-S)

This soil mapping unit refers to soils having shallow profile (25-50cm) and undulating slope of topography 5-8%.The soil texture sandy clay loam in the top soil and clay loam in the sub soil throughout the soil depth. Soils in the mapping unit are somewhat excessively well drained. The soils have moderately developed sub angular blocky structure in both top and sub soil.

The average infiltration rate (IR) varies from 3.6 to 7.2 cm/hr, which is categorized as suitable for gravity irrigation to marginally suitable and hydraulic conductivity (HC) the mapping unit ranges from 0.18 to 0.37m/day categorized as very slow to slow

Laboratory result shows that the mapping unit has pH value of 5.5 top soil and 4.7 in sub soil which is strongly acidic to very strongly acid and electrical conductivity results value 0.041 in top soil and 0.03 in sub soil shows that the soil is salt free. Soils in this mapping unit have very high to high CEC value 40.5 Cmol kg^{-1} top soils and 34.4 Cmol kg^{-1} in sub soil Medium BSP through the profile 52% in top soil and 51% in sub soil, organic matter content 1.72% in top soil and 0.99 in sub soil which indicates that the mapping unit is characterised by medium to low level of organic matter and total nitrogen content is about 0.1 in sub soil and 0.05 in sub soil which is high to medium. The soil mapping unit has high Ca^{2+} throughout the profile 19.82 in top soil and 16.1 in sub soil, and the soils are none calcareous. The total extent of this mapping unit is 4.94 ha or 1.6% of the command area.

5.2.3.16. SMU-16 (R euLPol-V)

This soil mapping unit refers to soils having very shallow profile (<25cm) and rolling, strongly sloping of topography 8-15%.The soil texture loam throughout the soil depth. Soils in the mapping unit are excessively drained. The soils have weakly developed granular structure. The average infiltration rate (IR) varies from 3.6 to 7.2 cm/hr, which is categorized as suitable for gravity irrigation to marginally suitable and hydraulic conductivity (HC) the mapping unit ranges from 0.18 to 0.37m/day categorized as very slow to slow.

Laboratory result shows that the mapping unit has pH value of 5.6 which is moderately acidic and electrical conductivity results value 0.093 shows that the soil is salt free. Soils in this mapping unit have medium CEC value 18.5Cmol kg^{-1} .Medium BSP through the profile 60%.Organic matter content 2.05% which indicates that the mapping unit is characterised by medium level of organic matter and total nitrogen content is about 0.09 which is high. The soil mapping unit has medium Ca^{2+} throughout the profile 6.63, and the soils are none calcareous. The total extent of this mapping unit is 5.85 ha or 1.9% of the command area

5.2.3.17. SMU-17 (R euFLol-VD)

This soil mapping unit refers to soils having very deep profile (>150cm) and in rolling, strongly sloping of topography 8-15%The soil texture loam in the top soil and clay to clay loam in the sub soil throughout the soil depth. Soils in the mapping unit are well drained. The soils have moderately developed sub angular blocky structure in both top and sub soil.

The average infiltration rate (IR) varies from 3.6 to 7.2 cm/hr, which is categorized as suitable for gravity irrigation to marginally suitable and hydraulic conductivity (HC) the mapping unit ranges from 0.18 to 0.37m/day categorized as very slow to slow.

Laboratory result shows that the mapping unit has pH value of 5.6 top soil and 6.1 in sub soil which is moderately acidic to slightly acidic and electrical conductivity results value 0.093 in top soil and 0.112 in sub soil shows that the soil is salt free. Soils in this mapping unit have medium to high CEC value 16.9 Cmol kg^{-1} top soils and 22.6 Cmol kg^{-1} in sub soil High BSP through the profile 76% in top soil and 81.1% in sub soil, organic matter content 2.31% in top soil and 1.9 in sub soil which indicates that the mapping unit is characterised by medium level of organic matter and total nitrogen content is about 0.1 in both top and sub soil which is high. The soil mapping unit has high Ca^{2+} throughout the profile 10.19 in top soil and 13.4 in sub soil, and the soils are none calcareous. The total extent of this mapping unit is 8.56 ha or 2.78 % of the command area.

5.2.3.18. SMU-18 (R chLVje-VD)

This soil mapping unit refers to soils having very deep profile (>150cm) and in rolling, strongly sloping of topography 8-15%.The soil texture loam sandy in the top soil and sandy clay loam in the sub soil throughout the soil depth. Soils in the mapping unit are well drained. The soils have moderately developed sub angular blocky structure in both top and sub soil.

The average infiltration rate (IR) varies from 3.6 to 7.2 cm/hr, which is categorized as suitable for gravity irrigation to marginally suitable and hydraulic conductivity (HC) the mapping unit ranges from 0.18 to 0.37m/day categorized as very slow to slow.

Laboratory result shows that the mapping unit has pH value of 5.7 top soil and 5.9 in sub soil which is moderately acidic and electrical conductivity results value 0.111 in top soil and 0.059 in sub soil shows that the soil is salt free. Soils in this mapping unit have very high to low CEC value 41Cmol kg^{-1} top soils and 7.9 Cmol kg^{-1} in sub soil Medium to high BSP through the profile 51% in top soil and 81.5% in sub soil, organic matter content

2.43% in top soil and 0.9 in sub soil which indicates that the mapping unit is characterised by medium to low level of organic matter and total nitrogen content is about 0.1 in both top and sub soil which is high. The soil mapping unit has high to low Ca^{2+} throughout the profile 18.5 in top soil and 3.8 in sub soil, and the soils are none calcareous. The total extent of this mapping unit is 4.02ha or 1.31% of the command area

Table 6 Physical and Chemical characteristics of Laga Dhumuga command area.

S.No	Land characteristics	SOIL MAPPING UNITS																	
		S euL Pol-V	S euF Lol-VD	3 S chLV je-VD	4 S leC Mol-S	R leC Mol-S	G euL Pol-VD	G euF Lol-VD	G leC Mol-S	T euL Pol-V	T euF Lol-VD	T chLVj e-VD	T leC Mol-S	U euL Pol-V	U euF Lol-VD	U leC Mol-S	R euL Pol-V	R euF Lol-VD	R chL Vje-VD
1	SLOPE (%)	15_30	15_30	15_30	15_30	8_15	2_5	2_5	2_5	30_60	30_60	30_60	30_60	5_8	5_8	5_8	8_15	8_15	8_15
2	DEPTH (cm)	very shallow	very deep	very deep	moderately deep	moderately deep	very shallow	very deep	moderately deep	very shallow	very deep	very deep	moderately deep	very shallow	very deep	moderately deep	very shallow	very deep	very deep
3	PH (1:2.5)	5.60	5.60	5.70	5.50	5.50	5.60	5.60	5.50	5.60	5.60	5.70	5.50	5.60	5.60	5.50	5.60	5.60	5.7
4	EC (ds/m)	0.10	0.09	0.11	0.10	0.10	0.10	0.09	0.10	0.10	0.09	0.11	0.10	0.10	0.09	0.10	0.10	0.09	0.11
5	TEXTURE (class)	L	L	LS	SCL	SCL	L	L	SCL	L	L	LS	SCL	L	L	SCL	L	L	LS
6	Na (Cmol(+) Kg-1)	0.09	0.07	0.09	0.04	0.04	0.09	0.07	0.04	0.09	0.07	0.09	0.04	0.09	0.07	0.04	0.09	0.07	0.09
7	K (Cmol(+) Kg-1)	0.57	0.52	0.72	0.27	0.27	0.57	0.52	0.27	0.57	0.52	0.72	0.27	0.57	0.52	0.27	0.57	0.52	0.72
8	Ca (Cmol(+) Kg-1)	6.63	10.19	18.50	19.82	19.82	6.63	10.19	19.82	6.63	10.19	18.50	19.82	6.63	10.19	19.82	6.63	10.19	18.5
9	Mg (Cmol(+) Kg-1)	3.73	2.16	1.46	1.00	1.00	3.73	2.16	1.00	3.73	2.16	1.46	1.00	3.73	2.16	1.00	3.73	2.16	1.46
10	CEC (Cmol(+) Kg-1)	18.50	16.90	41.00	40.50	40.50	18.50	16.90	40.50	18.50	16.90	41.00	40.50	18.50	16.90	40.50	18.50	16.90	41
11	BS (%)	60.00	76.00	51.00	52.00	52.00	60.00	76.00	52.00	60.00	76.00	51.00	52.00	60.00	76.00	52.00	60.00	76.00	51
12	TN (%)	0.09	0.10	0.10	0.10	0.10	0.09	0.10	0.10	0.09	0.10	0.10	0.10	0.09	0.10	0.10	0.09	0.10	0.1
13	OC (%)	1.19	1.34	1.41	1.00	1.00	1.19	1.34	1.00	1.19	1.34	1.41	1.00	1.19	1.34	1.00	1.19	1.34	1.41
14	OM (%)	2.05	2.31	2.43	1.72	1.72	2.05	2.31	1.72	2.05	2.31	2.43	1.72	2.05	2.31	1.72	2.05	2.31	2.43
15	C:N ratio	13.00	13.00	14.00	10.00	10.00	13.00	13.00	10.00	13.00	13.00	14.00	10.00	13.00	13.00	10.00	13.00	13.00	14
16	Av.P (ppm)	0.52	5.90	8.00	7.96	7.96	0.52	5.90	7.96	0.52	5.90	8.00	7.96	0.52	5.90	7.96	0.52	5.90	8
17	Av.K (ppm)	222.00	202.60	278.40	106.20	106.20	222.00	202.60	106.20	222.00	202.60	278.40	106.20	222.00	202.60	106.20	222.00	202.60	278.4
	AREA (ha)	25.95	30.17	8.54	117.08	50.52	0.42	0.74	1.11	8.36	1.7	1.15	30.96	1.57	6.17	4.94	5.85	8.56	4.02
	Area (%)	8.43	9.80	2.77	38.04	16.41	0.14	0.23	0.36	2.72	0.55	0.37	10	0.51	2	1.6	1.9	2.78	1.31

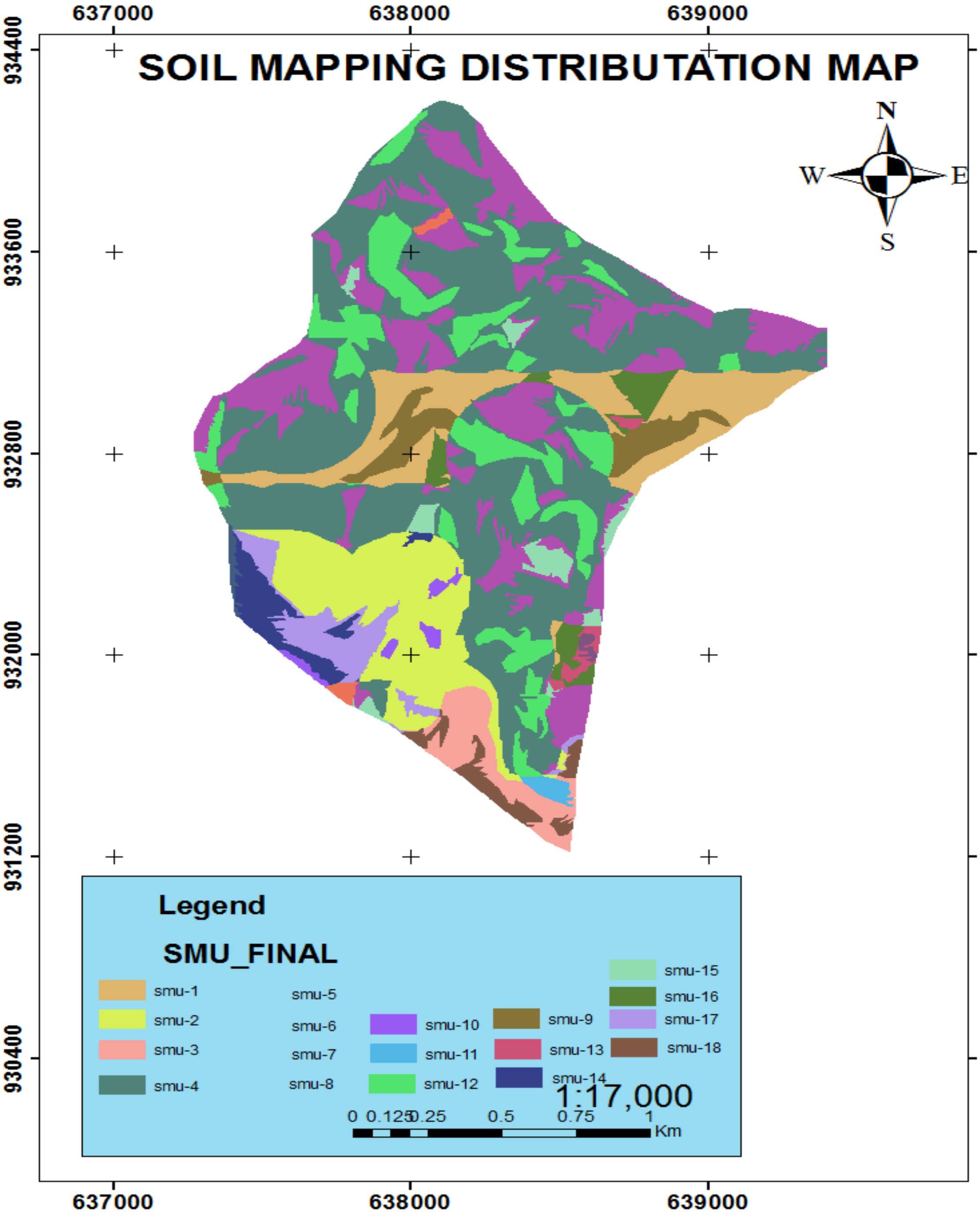


Figure 5 Spatial Distribution of Laga Dhumuga soil mapping units

6. LAND SUITABILITY EVALUATION

6.1. Introduction

The methodology for land suitability assessment is based upon the FAO Framework for Land Evaluation (FAO, 1976), where evaluation is the process of matching different environments against possible land use options. Land suitability is then defined as the fitness of a specific area of land for a specified kind of land use a so called land utilization type (LUT) under a stated system of management. Simply, to what extent is the land in questionable to support the LUT being considered? If the LUT appears profitable, the land is deemed suitable for it.

Land is assessed for its suitability for a LUT by a consideration of soil properties and site factors as they might affect the practicality and cost of development and maintenance, and the productivity of the land. The classification is implicitly or explicitly based on the economics of land development, although physical features are used as a basis for the economic rating. Classification is intended to reflect the payment capacity of the land, where different classes indicate decreasing payment capacity relative to increasing requirements for development and continued production. There is a cut-off point beyond which limitations of soil and/or site are so severe as to preclude any possibilities of successful sustained use at reasonable cost.

In semi-arid zones the concept of land suitable for irrigation being linked with positive economic benefits is problematical because the cost of supplying water, however good the land and the soil, usually outweighs the potential benefits to be derived from the range of possible enterprises. In simple terms, all land in the strict economic sense is hardly suitable for irrigated agriculture. This difficulty is usually circumvented by arguing that in semi-arid regions having a predominantly rural economy, soil and water are both scarce commodities and even if they are of poor quality their coexistence frequently justifies agricultural production, regardless of purely economic considerations. However, a realistic assessment should be provided of the ability of the project to satisfactorily develop land for irrigation because if such development cannot be properly achieved the livelihood of the local beneficiaries will be seriously jeopardized, this is not a risk that should be entertained.

Notwithstanding the above argument one can say that in the FAO system of land evaluation suitable land (S) is that on which sustained use in the defined manner is expected to yield benefits acceptable for the required capital and recurrent inputs (costs), without causing unacceptable risk to the environment. Unsuitable land (N) has characteristics that preclude its sustained use in the defined manner because of an unacceptable requirement of development or recurrent inputs (See Table 4).

6.2. General objective

The general objective of the study is to assess and delineate potentially suitable from non suitable land units for irrigation indicating constraints for use of the land.

6.3. Specific objectives:

The specific objective of this part of the land evaluations includes;

- To identify area of land suitable for irrigation agriculture development that is simultaneously confirmed to be technically feasible, economically viable, and socially acceptable
- Identification of the study area resource potentials and constraints for irrigated agriculture.
- Classification of land into suitability classes and subclasses according to limitations; suggesting alternative suitable uses.

6.4. Scope of work:

- Prepare land unit maps
- Compare the major land quality of the study area with land use environmental requirement of LUTs considered.
- Land suitability assessment of the study area for irrigation agriculture development based on LUTs considered.
- Prepare land suitability map at 1:10,000 scales for the LUTs considered

6.5. Procedures Followed

First, identification of land utilization types (LUTs): surface irrigation Based on these land utilization types, full data on land mapping units in terms of their land characteristics and land qualities (FAO, 1976, 1983; Dent & Young, 1981) were collected. This phase is concerned with surveys to collect data on land resources. The collected information on land resources is used to demarcate land mapping units. These land mapping units, whose land characteristics and qualities are described and are known, form the area of land units in the suitability evaluation (FAO, 1983, 1984, 1985).

In the second step the land use requirements for each land utilization type were defined (FAO, 1983; 1984; 1985). The land use requirements of each land utilization type were defined in terms of all forms of their requirements.

In the third step, matching of land qualities and/or land characteristics, with the requirements of land utilization types (FAO, 1983; 1984; 1985) were made. In determining the suitability classes the maximum limitation method was employed to combine individual ratings. The maximum limitation method is based on the law of the minimum, which considers the least favourable land characteristics and/or qualities limit the land use. This implies that any other amendments of the land would not improve its quality unless the most severe limiting factor is eliminated or at least reduced. Then, it distinguishes land suitability classes on the basis of the most severe limiting land characteristic (FAO, 1983).

In the fourth stage combining individual class determining factor ratings to obtain a tentative land suitability classification for each LUT on each land unit through the maximum limitation method was executed.

Finally, mapping of provisionally irrigable and non irrigable area were made as the final outcome.

6.6. Land Suitability Classes and Subclasses

The land suitability classes S1 to S3 indicate relative suitability, to reflect decreasing benefits relative to increasing requirements for continued production; either a greater cost is required to achieve the same yield or yields will be lower under the same costs.

A truly quantitative land suitability evaluation based on real economic assessment is difficult to make, due to scarcity or unreliability of data, uncertain pricing and marketing policies and highly fluctuating marketing conditions. Moreover, in areas where transport and infrastructure are poorly developed the proximity of an all-weather asphalt road or a large town (market) can make the surrounding land highly suitable in economic terms, far more suitable than the quality of land might indicate. More distant land might be far better physically for a defined use but less attractive economically simply because of its remoteness. Likewise, it may be preferable or more cost-effective to irrigate relatively poorer quality land close to a water source rather than pump and pipe water to better but more distant land. These considerations are not embodied in the FAO land classification but must be considered by the developer.

For each suitability class there are a number of sub-classes that reflect the type of limitations that restrict the suitability of the land unit. Note that S1 has no specific limitations. Limiting factors governing land suitability evaluation for irrigation in project area are:

- T Topography (micro topography, dissection)
- R Restricted root ability; limited depth to bedrock, coarse material and stoniness
- DW Poor drainage and shallow water table
- P Soil pH
- x Texture
- i Infiltration rate and hydraulic conductivity

Table 7 FAO recommended land class definitions

S/N	class	Designation	Definition
1	S1	Highly Suitable	Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level.
2	S2	Moderately Suitable	Land having limitations which in aggregate are moderately severe for sustained application of a given use. The limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on Class S1 land.
3	S3	Marginally Suitable	Land having limitations which, in aggregate, are severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified.
4	N1	Currently Not Suitable	Land otherwise suitable (S1 to S3) for sustained application of a given use but having a limitation(s) which, although possibly surmountable in time, cannot be corrected with existing knowledge at currently acceptable cost. The limitation(s) is so severe as to preclude successful sustained use of the land in the given manner at present.
5	N2	Permanently Not Suitable	Land having limitations that appear so severe as to preclude any possibilities of successful sustained use of the land in the given manner

6.7. Land Use Requirements, Land Characteristics and Land Qualities

6.7.1. Land Use Requirements

Having described the land use type which is surface irrigated agriculture, the next step is to define the land requirements for successful soil, crop and irrigation water management. It is the necessary or desirable conditions of the land for successful and sustained practice of a given land use such as agronomic management, land development, conservation requirements or limitations. In other words, land use requirements refer to the set of land qualities that determine the production and management conditions.

6.7.2. Land Characteristics

These are measurable properties of the physical, socioeconomic and environmental conditions directly related to land use. Land characteristics are made available through soil and land use surveys, socioeconomic survey, farming system surveys and environmental assessment. Some of the land characteristics and qualities are climate, topography, soil physical and chemical properties, soil fertility, salinity and alkalinity, etc.

6.7.3. Land Qualities

They are an attribute of land or their expressions as a diagnostic criterion, which limits the potential of land for a specified kind of use. They are derived from measured land characteristics.

Land characteristics, land qualities and class determining/limiting factors have been obtained from detail soil survey (feasibility level) and have been evaluated on how they affect the land for irrigation development. Critical limits have been given a suffix in suitability evaluation as discussed above to denote the main limiting factor or factors that affect the management of the soil mapping units.

Land use requirement for surface irrigation and land characteristics, land qualities and class determining/ limiting factors governing land suitability evaluation for irrigation are given in appendix 5 and 6 respectively.

6.8. Results of Land Suitability Evaluation

6.8.1. Land evaluation for surface irrigation

Matching and super imposing of the land use requirements and critical class limits with the land characteristics of the SMU have resulted in suitability classes. Initially matching proceeds for each land quality of land use for each soil mapping units. These individual ratings are then combined to give an overall suitability for the land units. To arrive at the final land suitability classification for proposed irrigation of the command area, possible remedial measures have to be considered relevant to soil fertility and socioeconomic conditions.

Evaluation of land use requirements for irrigated agriculture with soil and land characteristics, land qualities and limitations of each soil mapping unit in Laga Dhumuga Pump small scale irrigation project command area has given the irrigation land suitability class with its specific limitations requiring remedial measures for upgrading the land and soil suitability of each soil mapping units. The result of suitability evaluation for surface irrigation is shown in Table 8 below.

Table 8 results of surface irrigation suitability evaluation.

S/N	SMU code	Suitability class	AREA (ha)	AREA (%)
1	S euLPol-V	N2	25.95	8.43
2	S euFLol-VD	S3	30.17	9.8
3	S chLVje-VD	S3	8.54	2.77
4	S leCMol-S	S3	117.08	38.04
5	R leCMol-S	S3	50.52	16.41
6	G euLPol-V	N2	0.42	0.14
7	G euFLol-VD	S3	0.74	0.23
8	G leCMol-S	S3	1.11	0.36
9	T euLPol-V	N2	8.36	2.72
10	T euFLol-VD	N2	1.7	0.55
11	T chLVje-VD	N2	1.15	0.37
12	T leCMol-S	N2	30.96	10.06
13	U euLPol-V	N2	1.57	0.51
14	U euFLol-VD	S3	6.17	2
15	U leCMol-S	S3	4.94	1.6
16	R euLPol-V	N2	5.85	1.9
17	R euFLol-VD	S3	8.56	2.78
18	R chLVje-VD	S3	4.02	1.31

S/N	SMU code	Suitability class	AREA (ha)	AREA (%)
19	Total S1		*0.00*	
20	Total S2		*0.00*	
21	Total S3		*231.85*	
22	Total suitable		*231.85*	*75.3*
23	Total N1		*0.00*	
24	Total N2		*75.96*	
25	Total not suitable		*75.96*	*24.7*
26	Total Area		*307.8*	*100*

According to the result given in Table 8 above the main limiting factors of the soils of Laga Dhumuga Pump small irrigation project command area are topography, soil depth, and soil texture and soil acidity. About 231.85ha or 75.6% was found to be marginally suitable (S3) due to the limiting factors slope, texture and low soil pH, and. from the total command area of 307.8 ha, 231.85ha or 75.6% is found to be suitable and 75.96 ha or 24.7% is unsuitable due to soil depth limitation ,slope and rock surface.

The marginally suitable mapping units(S3) (S euLPol-V, S euFLol-VD, S chLVje-VD,S leCMol-S,R leCMol-S,G euLPol-VD,G euFLol-VD,G leCMol-S,U euFLol-VD,U leCMol-S,R euFLol-VD andR chLVje-VD) are generally limited by topography, soil depth and soil texture however special consideration should be take while developing this soil mapping units as their slope rise up to 30%. These lands are evaluated as suitable since the area is currently under development and hence continued with irrigation but special attention should be given as it should be assisted with soil and water conservation works to reduce soil loss when the water distributed from the reservoirs to the command area by using pump.

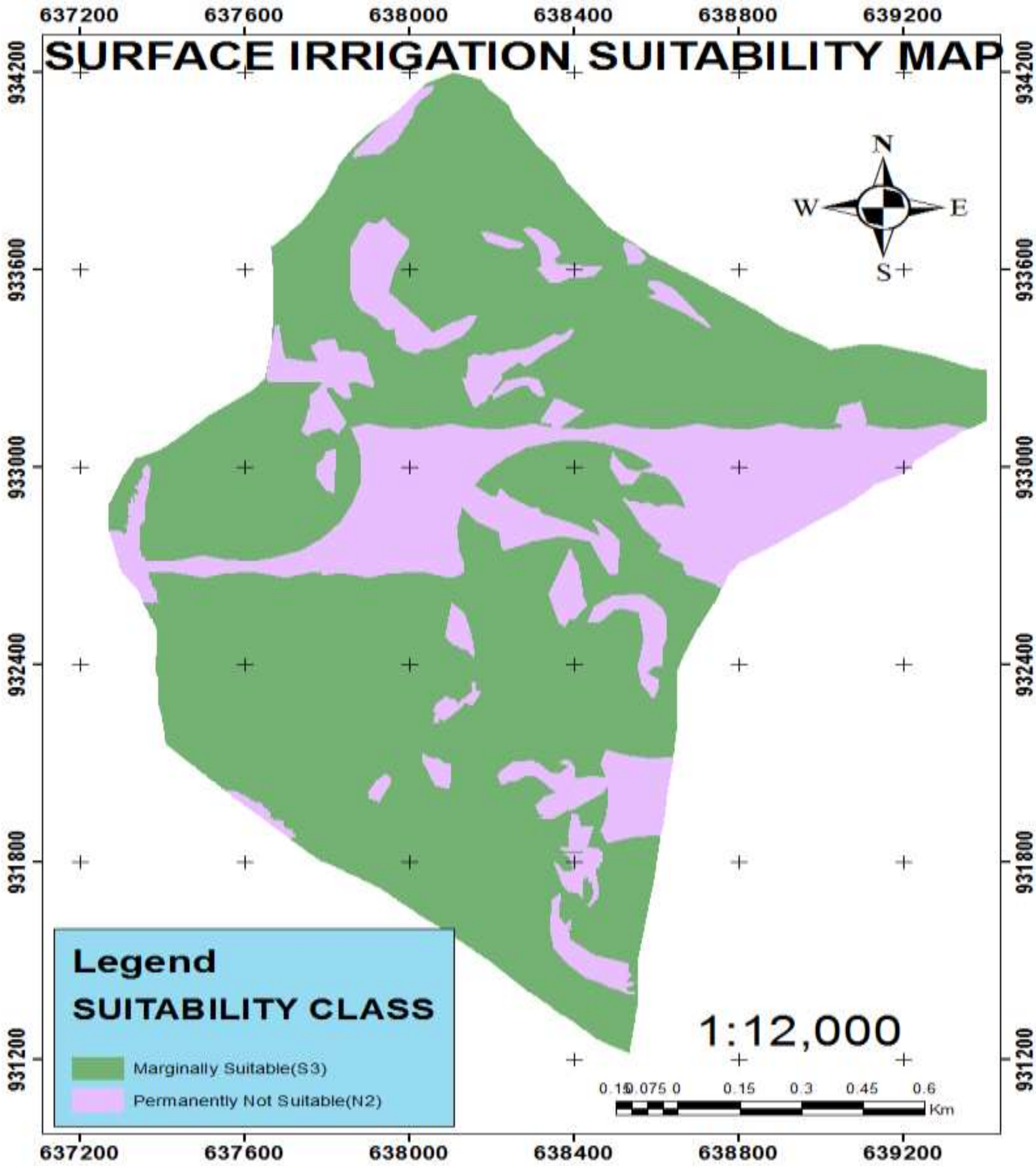


Figure 6 Surface Irrigation Suitability Map

6.8.2. Land Evaluation for Selected Crops

6.8.2.1. Proposed Crops

Crops and cropping patterns have been selected based on existing conditions, climate, and requirement of individual crops for daily consumption and income generation for the community. The major proposed crops are Maize, Sorghum, Haricot Beans Onion, Pepper, Sweet Potato and tomato.

6.8.2.2. Crop Requirements

A crop requirement is an optimum land and soil characteristics and qualities required to achieve average and high yield plus a potential for improvement in the future as more experience and management capacity is gained. Crop requirements for proposed and selected crops for the project have been reviewed and analyzed for suitability under medium input level.

6.8.2.3. Results of Crop Suitability Evaluation

Crop suitability evaluation for the proposed crops has been done to investigate alternative viable cropping pattern. It enables planners and managers including farmers, to consider all practicable alternative cropping patterns. Crop suitability evaluation for the proposed crops under a medium level of management has been considered.

Matching and superimposing crop requirements under irrigation with soil and land characteristics, land qualities and limitations of each soil mapping unit has given the irrigated crop suitability class. Hence almost all the proposed crops which are: maize, sorghum, haricot beans, sweet potato, pepper, onion, and tomato are found to be moderately and marginally suitable under irrigation with different extent of suitable area. There are also unsuitable mapping units for some of the proposed crops due to soil depth limitation and slope.

Table 9 Results of crop suitability evaluation under irrigation

S/N	SMU_Code	Proposed crops							AREA	
		Haricot beans	Maize	Sorghum	Onion	Pepper	Sweet Potato	Tomato	ha	%
1	**S euLPol-V**	N1	N1	N1	N1	N1	N1	N2	25.95	8.43
2	**S euFLol-VD**	S3	S3	S3	S3	S3	S3	S3	30.17	9.8
3	**S chLVje-VD**	S3	S3	S3	S3	S3	S3	S3	8.54	2.77
4	**S leCMol-S**	S3	S3	S3	S3	S3	S3	S3	117.08	38.04
5	R leCMol-S	S3	S3	S3	S3	S3	S3	S3	50.52	16.41
6	**G euLPol-V**	N1	N1	N1	N1	N1	N1	N2	0.42	0.14
7	**G euFLol-VD**	S2	S3	S2	S3	S3	S3	S3	0.74	0.23
8	**G leCMol-S**	S3	S3	S3	S3	S3	S3	S3	1.11	0.36
9	**T euLPol-V**	N2	N2	N2	N2	N2	N2	N2	8.36	2.72
10	**T euFLol-VD**	N2	N2	N2	N2	N2	N2	N2	1.7	0.55
11	**T chLVje-VD**	N2	N2	N2	N2	N2	N2	N2	1.15	0.37
12	**T leCMol-S**	N2	N2	N2	N2	N2	N2	N2	30.96	10.06
13	**U euLPol-V**	N1	N1	N1	N1	N1	N1	N2	1.57	0.51
14	**U euFLol-VD**	S3	S3	S3	S3	S3	S3	S3	6.17	2
15	**U leCMol-S**	S3	S3	S3	S3	S3	S3	S3	4.94	1.6
16	**R euLPol-V**	N1	N1	N1	N1	N1	N1	N2	5.85	1.9
17	R euFLol-VD	S3	S3	S3	S3	S3	S3	S3	8.56	2.78

S/N	SMU_Code	Proposed crops							AREA	
		Haricot beans	Maize	Sorghum	Onion	Pepper	Sweet Potato	Tomato	ha	%
18	**R chLVje-VD**	S3	S3	S3	S3	S3	S3	S3	4.02	1.31
18	Total S1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.95	8.43
19	Total S2	0.74	0.00	0.74	0.00	0.00	0.00	0.00		
20	Total S3	231.11	231.85	231.11	231.85	231.85	231.85	231.85		
21	Total suitable	231.85	231.85	231.85	231.85	231.85	231.85	231.85		
22	Total N1	33.79	33.79	33.79	33.79	33.79	33.79	0.00		
23	Total N2	42.17	42.17	42.17	42.17	42.17	42.17	75.96		
24	Total not suitable	75.96	75.96	75.96	75.96	75.96	75.96	75.96		
25	Total Area	307.8	307.8	307.8	307.8	307.8	307.8	307.8		

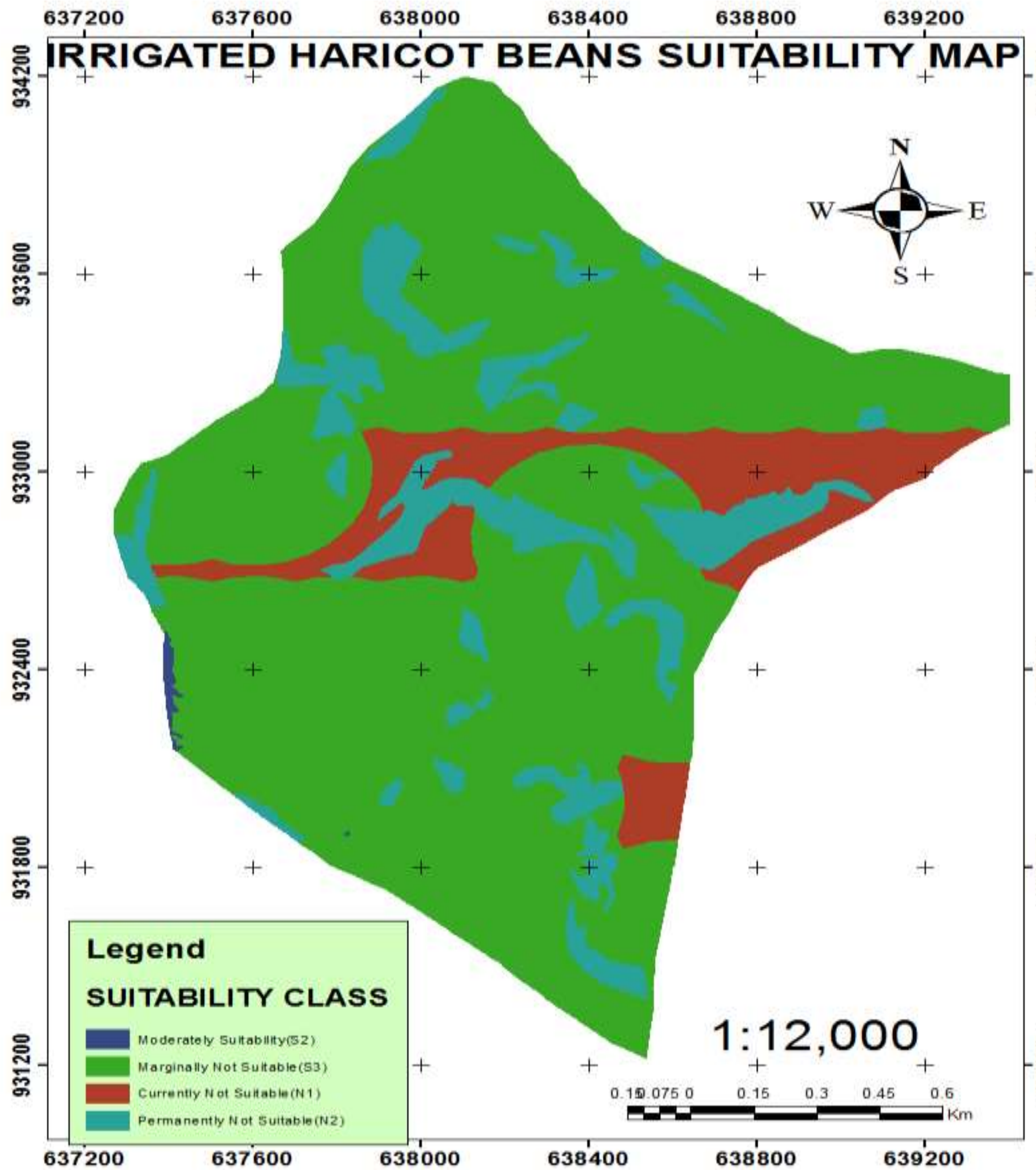


Figure 7 Suitability map of Haricot Beans

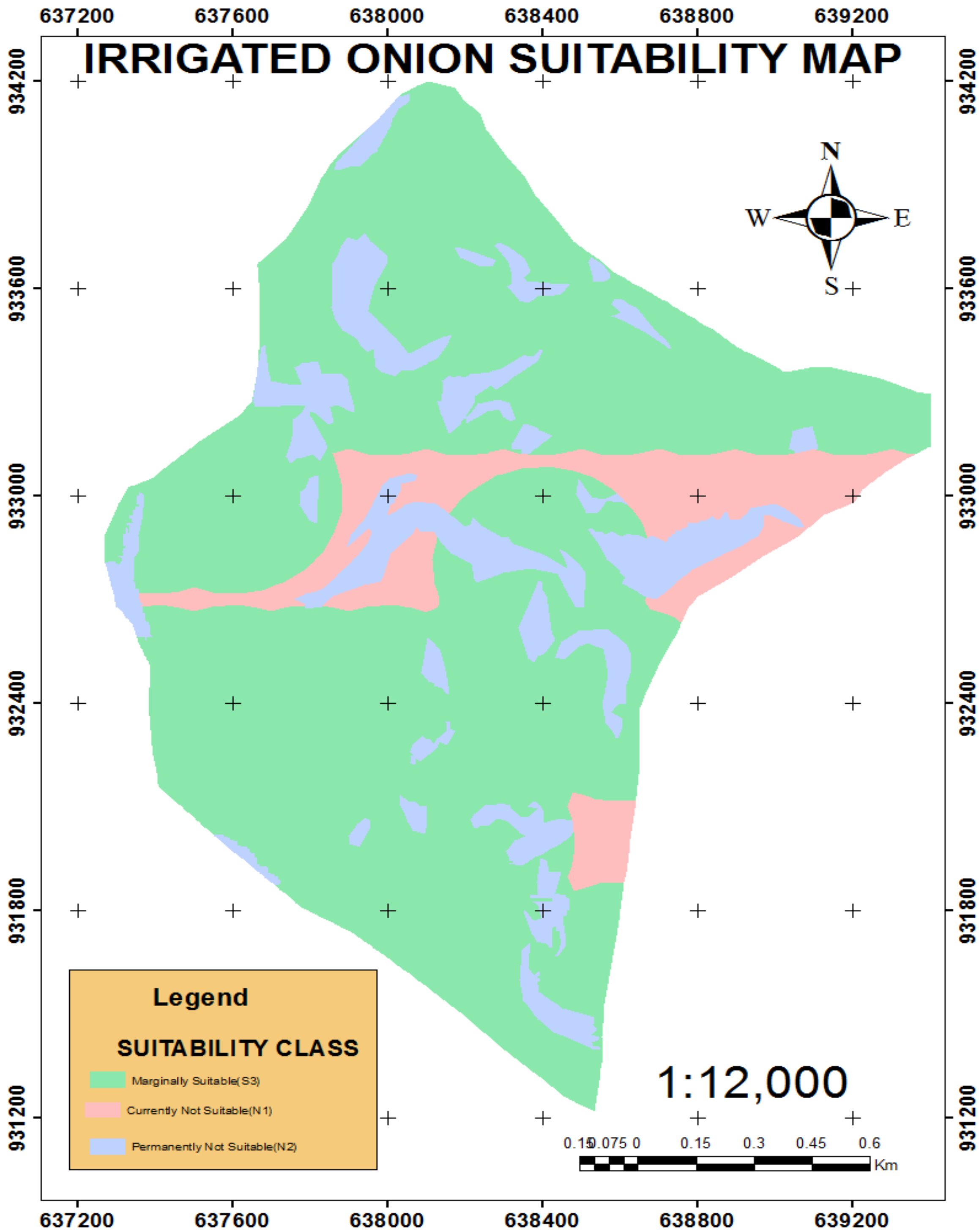


Figure 8 Suitability map of Onion

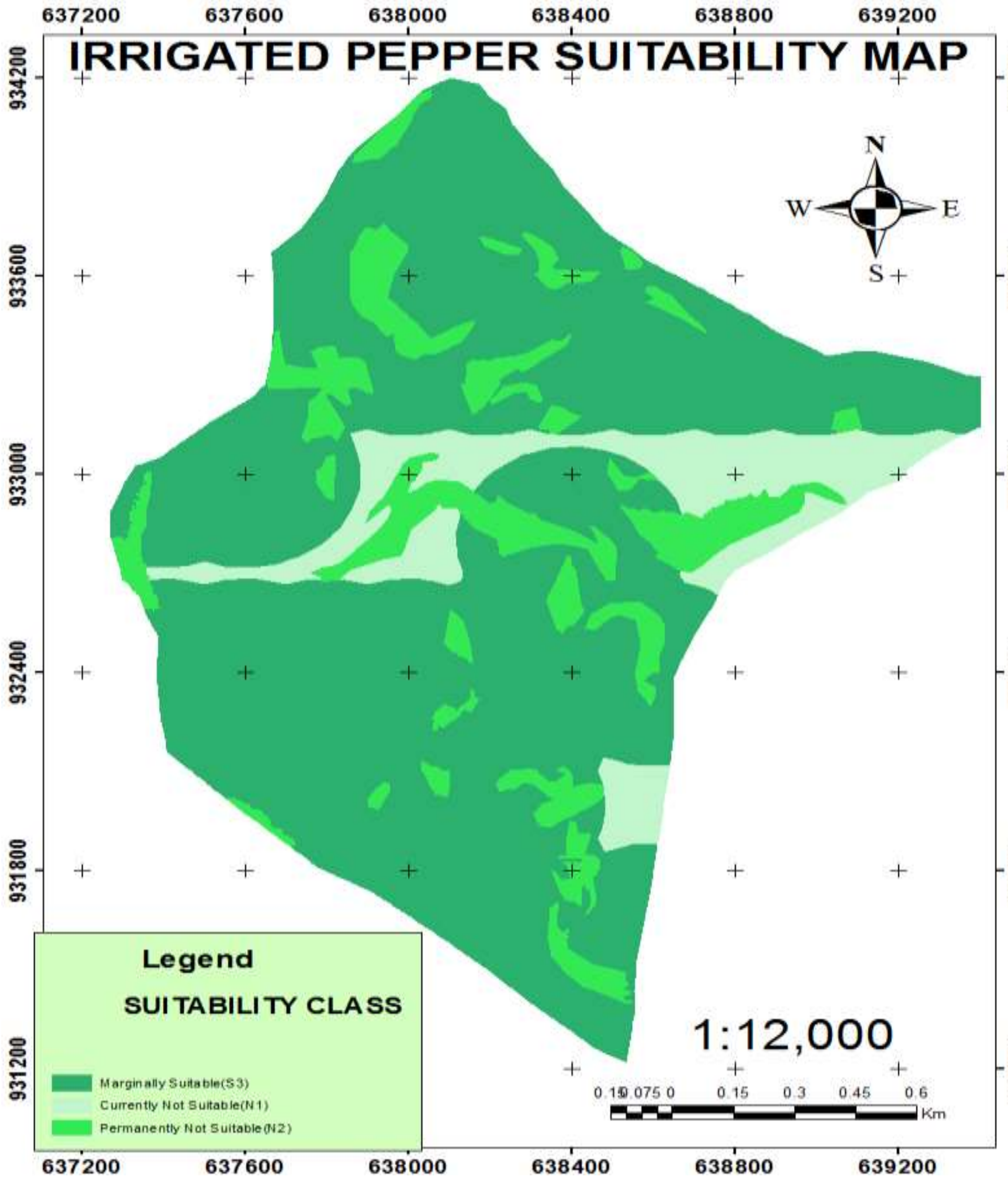


Figure 9 Suitability map of Pepper

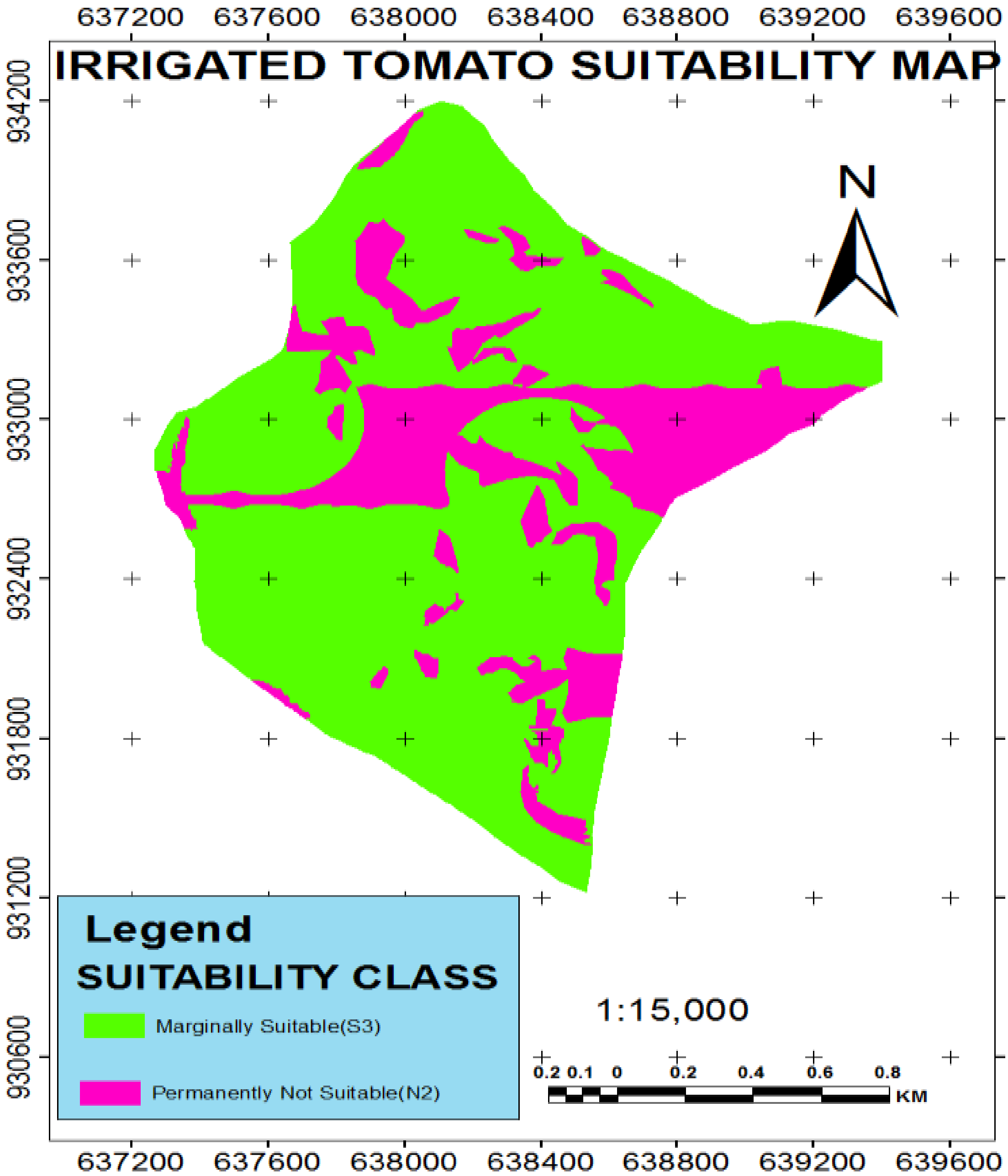


Figure 10 Suitability map of Tomato

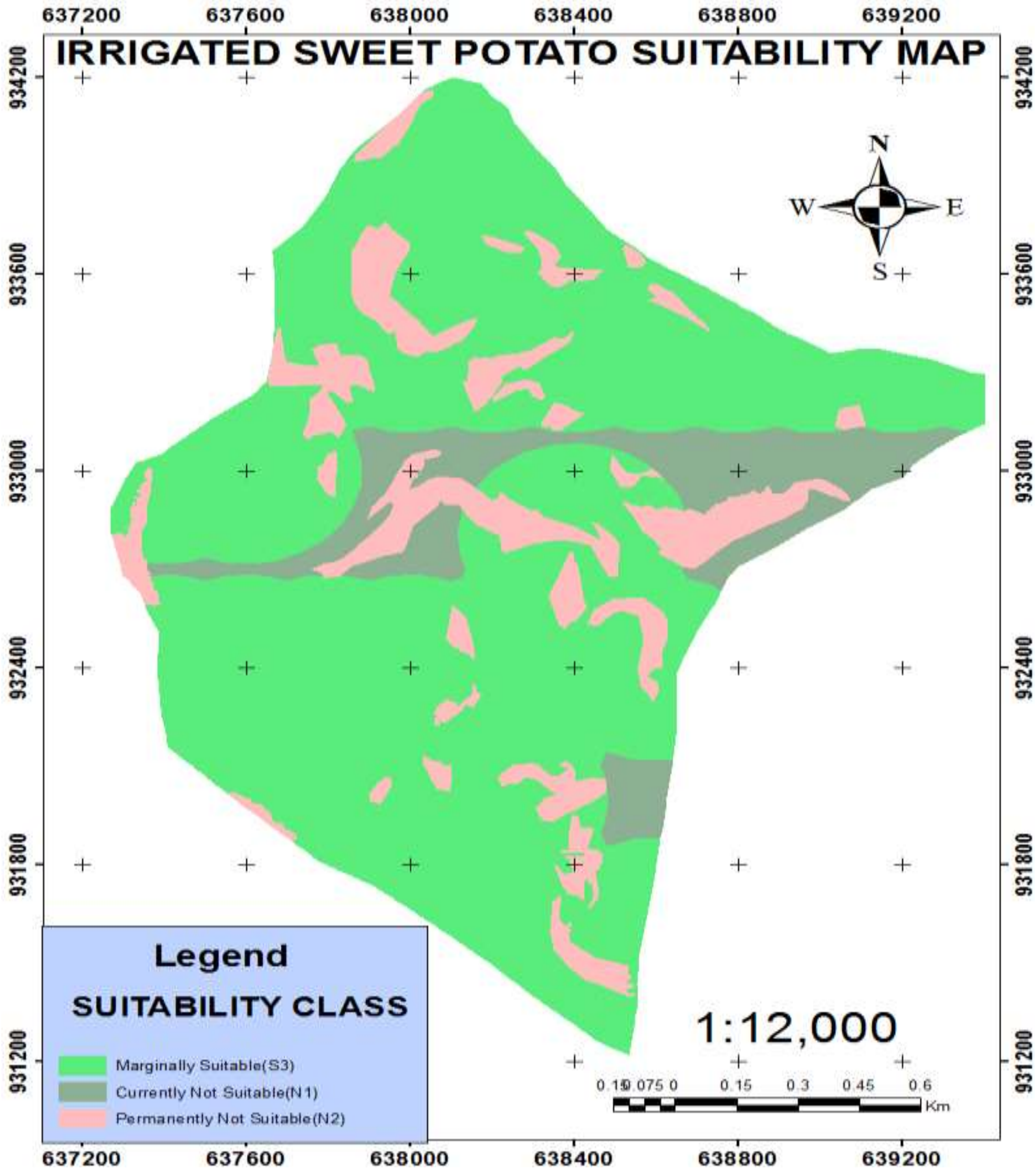


Figure 11 Suitability map of Sweet Potato

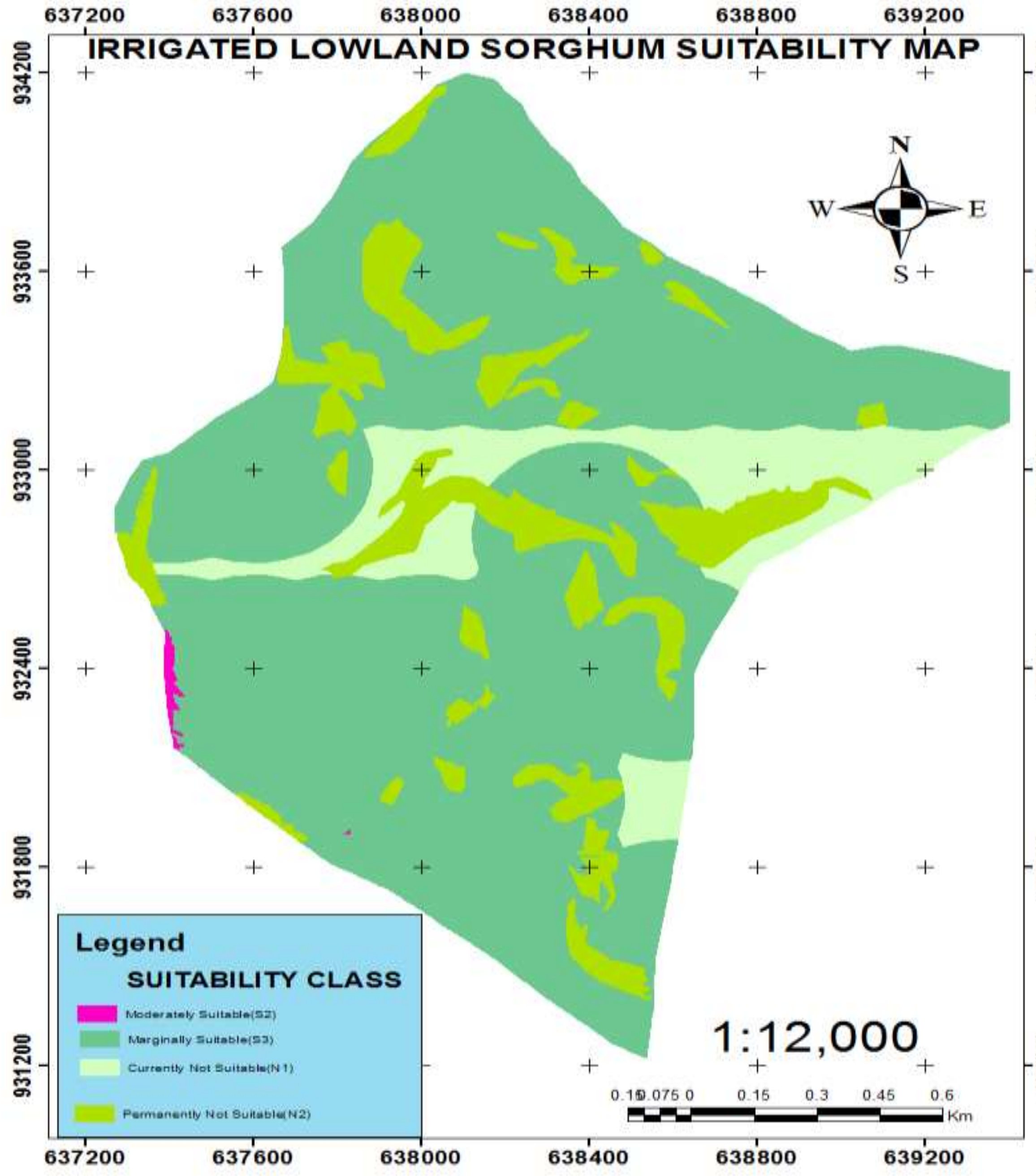


Figure 12 Suitability map of Lowland Sorghum

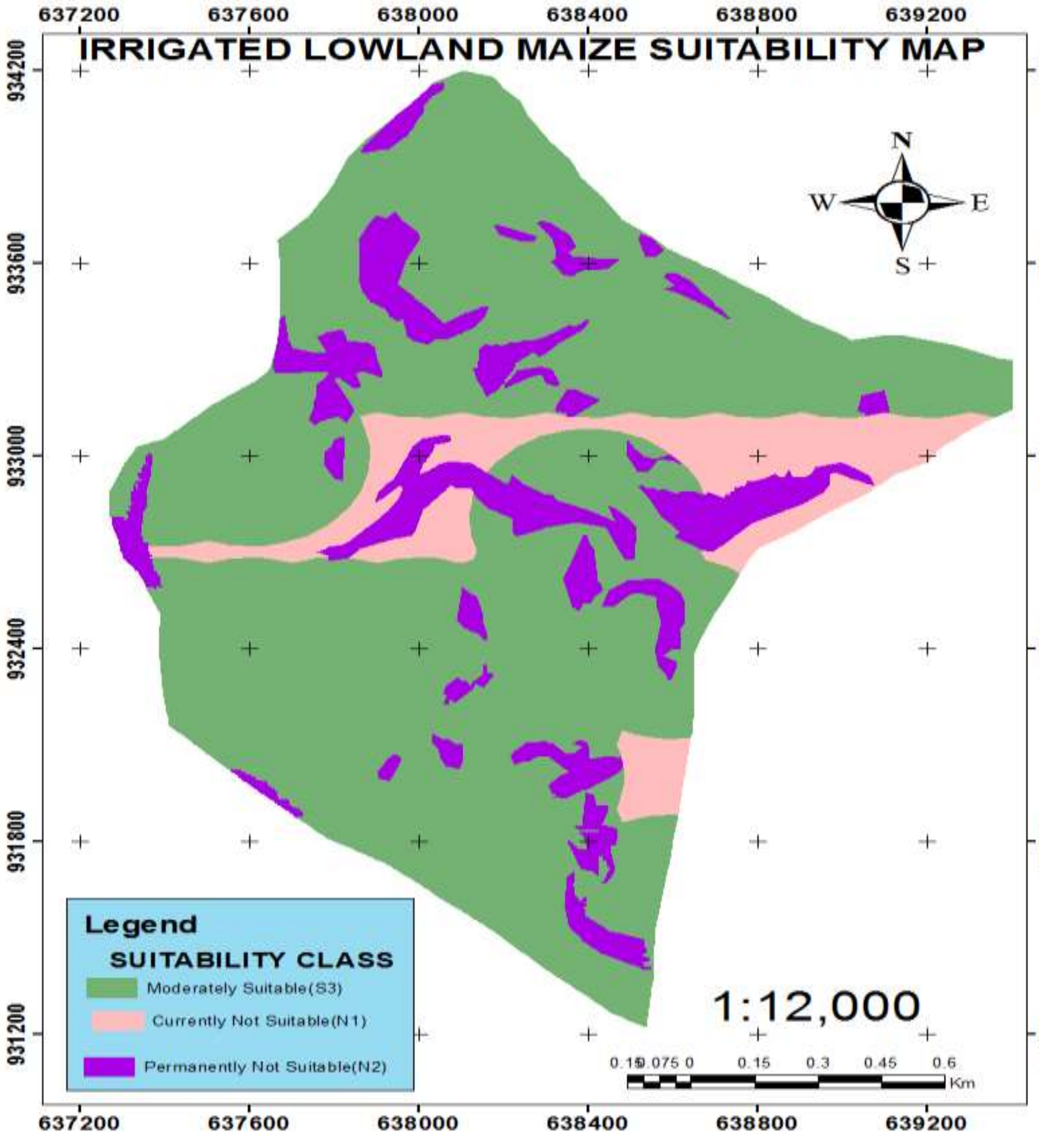


Figure 13 Suitability map of Lowland Maize

7. CONCLUSION AND RECOMMENDATION

7.1. Conclusion

The soil survey of Laga Dhumuga Pump small scale irrigation project was conducted at feasibility (detailed) level to evaluate and map suitable area for irrigation and proposed crops and to delineate areas which are not suitable for the irrigation development.

To achieve the objective of the study standard and recommended detailed level of soil survey methodology was followed including review of previous studies, interpretation of satellite imageries and topographic maps. Field auger observations, profile descriptions, soil sampling and field tests (IR and HC) were conducted. The soil survey data collected resulted in an observation density of 1 per 4 ha in which 81 auger observation points and 4 profile descriptions were including with laboratory analysis was done. Finally four FAO major soil types were identified and mapped at 1: 10,000 scales.

Based on the major soil types identified and the slope on which they occur, eighteen soil mapping units were established including which more or less similar soil and land characteristic and constraints have.

From the total area surveyed (307.8ha), 231.85 ha or 75.3% of land are found to be suitable for surface irrigation development and 75.96 ha or 24.7 % of the land are not suitable for surface irrigation due to topography, soil depth and soil texture.

The crop suitability evaluation indicated that Haricot beans, Maize, Sorghum, Onion, Pepper, Sweet Potato and Tomato can be cultivated by irrigation. Land evaluation for selected crops and the result is indicated that some, 0.74 ha moderately suitable (S2), 231.11ha marginally suitable (S3), 33.79 ha currently not suitable (N1) and 42.17 ha permanently not suitable for haricot beans cultivation by surface irrigation. Land evaluation for maize Some 231.85 ha marginally suitable (S3), 33.79ha currently not suitable (N1) and 42.17 ha permanently not suitable (N2) for surface irrigation. . Land evaluation for sorghum some 0.74 ha of land is moderately suitable (S2), 231.11 ha marginally not suitable (S3), 39.79 ha currently not suitable (N1) and 42.17 ha permanently not suitable (N2) respectively. Land evaluation for onion all 231.85 ha marginally suitable (S3), 33.79ha currently not suitable (N1) and 42.17 ha permanently not suitable (N2) for surface irrigation. Land evaluation for pepper some231.85 ha marginally suitable (S3), 33.79ha currently not suitable (N1) and 42.17 ha permanently not suitable (N2) for surface irrigation. Land evaluation for sweet potato some, 231.85 ha marginally suitable (S3), 33.79ha currently not suitable (N1) and 42.17 ha permanently not suitable (N2) for surface irrigation. Land evaluation for tomato some, 231.85 ha marginally suitable, (S3), 36.82 ha and 75.96 ha currently not suitable (N2) for surface irrigation

For the sustained irrigation development, it is recommended that the low soil pH problems in the study area should be reduced by appropriate management practices such as application of lime pellet legume and molybdenum that increases the pH of the soil and selection of appropriate crops suitable for those limitations. The Cation exchange capacity of the soils is medium to very high. The exchange complex of the soils is dominated by Ca^{2+} and this is favourable to promote better soil structure and offset the deleterious effect of the sodicity. However, the relative proportion of Ca to Mg and K to Mg is moderately high to high and this may restrict the availability of both Mg and K to plants. Thus, application of K and Mg containing fertilizers should be consider in soil fertility management programs.

The organic matter content of the soils in the study area is medium to high and total nitrogen content of the soils is high. The analytical data also indicates low to medium available phosphorus in the soils of the study area. The low available P and N can be corrected by the application of N and P fertilizers. In order to increase the organic matter content leaving the crop biomass on the field is a practical measure and this will increase the fertility status of the soils, improve microbial activity and availability of micronutrients.

7.2. Recommendation

The most limiting land characteristic in soils Laga Dhumuga Pump small irrigation project is high slope gradient, soil texture and shallow soil depth. Concerning topography, although lands having slope gradient greater than 8% is not suitable theoretically under surface irrigation, the farmers experience in different areas show that this lands are developed under irrigation using different irrigation techniques like adequate conservation practice. Considering those indigenous knowledge of the farmers and by integrating conservation measures with the agricultural irrigation practice, the suitability evaluation was done for lands have slope up to 30% due to the water pumped to high elevation in the reservoirs and distributed in the canal by gravity. However, there is a need to apply more and efficient conservation measures to use those sloping land for surface irrigation.

Thus, possible soil and water conservation interventions such as bench terracing need to be applied in lands with slope >8 % which helps to converts a steep slope into a series of steps, with nearly horizontal benches to reduce velocity of runoff, reduce soil erosion and the decline in crop yields. Moreover, level soil bund as an alternative conservation measure can also be applied for those cultivated lands with a slope of 5-8 % which further helps to reduce and stops the velocity of runoff and consequently reduces soil erosion. As a result, those soil mapping units that are not suitable for surface irrigation due to slope gradient will be amended accordingly.

- Erosion control mechanisms like bench terraces and others structures should be applied in the study area to mitigate erosion of soil by water due to high slope gradient.
- To maintain and improve soil fertility judicious inorganic fertilizer application with farm yard manure should be applied.
- In farming areas improved agronomic practices specific to the site condition is recommended, because it is essential for controlling soil productivity, increases its water holing capacity, provide take full advantage of fertilizer, prevent the unbalanced depletion of plant nutrients improving soil condition, cover, soil and water conservation, plant protection, yields and counter acts developments of the toxic substance, if any.

8. SOIL MANAGEMENT AND RECLAMATION

8.1. Soil Physical Condition and Land Management

The soils of the study area in general have few limitations in their physical properties that restrict development of irrigated agriculture. But soil mapping unit(R euLPol-V,U euLPol-V, T leCMol-S,T chLVje-VD,T euFLol-VD,T euLPol-V,G euLPol-V and S euLPol-V)has a coarse texture, very shallow depth and steep slope which limits suitability of surface irrigation and selected crops in the study area.

Major soils of the study area are well drained, medium textured, have good structure and very friable to friable consistence which is favourable for farm operation and root development.

Watershed Development Measurements should be applied due to the command area in steep slope by pumping irrigation water to reservoirs and then distributed to the canal by gravity to the command area to prevent soil erosion.

8.2. Soil Fertility Management

The pH of the soils in the study area is lower than the preferred range for most crops. This may limit the availability of some nutrients. The Cation exchange capacity of the soils is very low to high. The exchange complex of the soils is dominated by Ca^{2+} and this is favourable to promote better soil structure and offset the deleterious effect of the sodicity. However, the relative proportion of Ca to Mg and Ca+Mg to K is moderately high and this may restrict the availability of both Mg and K to plants. Thus, application of K and Mg containing fertilizers should be consider in soil fertility management programs.

The organic matter content of the soils in the study area is medium to high and total nitrogen content of the soils is medium to high. The analytical data also indicates low to medium available phosphorus in the soils of the study area. The low available P and N can be corrected by the application of N and P fertilizers. In order to increase the organic matter content leaving the crop biomass on the field is a practical measure and this will increase the fertility status of the soils, improve microbial activity and availability of micronutrients.

In order to maintain soil fertility nutrients removed from the soil by crop must be restored by the application of fertilizers and manure. Even in a highly fertile soil reserve nutrient gets exhausted as crops are grown and harvested continually and needs replacement.

To maintain organic carbon mulching of crop residues after harvesting should be practiced with application of manure and compost. The use of plant species that are capable of fixing atmospheric nitrogen can improve soil fertility and reduce dependency on chemical fertilizer. In addition improved agriculture practices such as crop rotation, alley cropping and the use of green manure provide accessory nutrient pool for plant growth. The application of organic matter also improves the CEC of the soil. Crop rotation is recommended, as it is essential for improving soil productivity. An alternate appropriate crop in accordance with a pre-established schedule help to keep the soils in good biological condition and to control the erosion risk, increase its water holding capacity, provides to take full advantage of fertilizer, prevent the unbalanced depletion of plant nutrients and counteract development of the toxic substances, if any.

During the application of inorganic fertilizers balanced dose of macro-nutrient particularly NPK should be added in the form of fertilizers, but it has to be taken into account the availability of nutrient already present in the soil, crop requirement and other factors.

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15. World reference base for soil resources (WRB), a framework for international classification, correlation and communication, 2006.

16. World reference base for soil resources (WRB), a framework for international classification, correlation and communication, 2014.\\

10. APPENDICES

Appendix 1: Summary of recommended criteria for soil chemical data interpretation

DESCRIPTION	UNIT	RANGE	RATING
PH	Water	<4.5	Extremely acid
		4.5-5.0	Very Strongly acid
		5.1-5.5	Strongly acid
		5.6-6.0	Moderately acid
		6.1-6.5	Slightly acid
		6.6-7.3	Neutral
		7.4-8.0	Slightly alkaline
		8.1-9.0	Strongly alkaline
		> 9.0	Very strangely alkaline
Electrical conductivity (EC)	mmhos/ cm	<2	Salt free
		2-4	Slightly saline
		4-8	Moderately saline
		8-15	Strongly saline
CEC	meq/100gm	>40	Very high
		25-40	High
		15-25	Medium
		5-15	Low
		<5	Very low
Base saturation (BS)	per cent	<20	Low
		20-60	Medium
		>60	High
Exchangeable Cations			
Ca	meq/100g of soil	>20	High
		10-20	High
		1-10	Medium

DESCRIPTION	UNIT	RANGE	RATING
		2-5	Low
		<2	Very Low
Mg	meq/100g of soil	>8	Very High
		3-8	High
		1.5-3	Medium
		0.5-1.5	Low
		<0.5	Very Low
K	meq/100g of soil	>1.2	Very High
		0.6-1.2	High
		0.3-0.6	Medium
		0.1-0.3	Low
		<0.1	Very Low
Na	meq/100g of soil	>2	Very High
		0.7-2	High
		0.3-0.7	Medium
		0.1-0.3	Low
		<0.1	Very low
Organic matter (OM)	per cent	>5	Very high
		3-5	High
		1-3	Medium
		<1	Low
Total nitrogen (T.N)	per cent	<0.05	Very Low
		0.05-0.125	low
		0.125-0.225	medium
		0.225-0.3	high
		>0.3	Very high
Available phosphorous (A.V.P)	ppm	>15	High

DESCRIPTION	UNIT	RANGE	RATING
		5-15	Medium
		<5	Low
Caco3	meq/100gm	<1	Low
		1-4	Medium
		4-10	High
		>10	Very high
Organic carbon (OC)	per cent	>20	Very high
		10-20	High
		4-10	Medium
		2-4	Low
		<2	Very low
Exchangeable Sodium Percentage (ESP)	per cent	<2	Low
		2-8	Medium
		8-15	High
		15-27	Very high
		>27	Extremely high
Ca: Mg Ratio	Ratio	>40	Extremely high
		12-40	Very high
		6-12	High
		3.5-6	Moderately high
		2.5-3.5	Moderately low
		1.5-2.5	Low
		<1.5	Very low
K : Mg	Ratio	>2 :1	Mg uptake bay be inhibited
		<3 :2	Field crop recommended level
		<1 :1	Vegetable and sugar beet
		<3 :5	Fruit and green house crops

DESCRIPTION	UNIT	RANGE	RATING	
(Ca+Mg)/K		>40	Very high	Overdose Ca+Mg or lack of K
		25-40	High	Fertilizer response no need
		15-25	optimal	Fertilizer response unlikely
		5-15	Lack of Ca or Mg	Fertilizer response probable
		<5	low	Fertilizer response most likely

Source: 1- Booker Tropical soil manual (1991

Appendix 2: Typical profile descriptions

LAGA DHUMUGA SMALL SCALE IRRIGATION PROJECT SOIL PROFILE DESCRIPTION

Profile code: *LGDP-1*
Date: *06/12/18*
Author(s): *Terefe/Bikila*
Region:-Oromia
Zone: *Arsi*
Woreda: *Shanen Kolu*
Soil classification FAO (2006): *Fluvisols*
Human influence: *Ploughing, Irrigation*
Land form: *Plateau terrace*
Surface coarse fragments: *None*
Position: *Medium*
Slope class: *5-8%*
Slope aspect: *North to south*
Drainage external: *Well drained*
Surface Cracking; None
Moisture condition: 0-200 cm dries
Erosion status: *Splash/Rill*
Fertilizers: *Unknown*

Mapping unit: SMU **Status:** *PS*
Long. In utm (E):*637489*
Lat. in utm (N):*932222*
Elevation: *1466m*
Parent material: *Alluvial*
Rock Types: - *Limestone*
Effective soil depth: *Very deep*
Rock out crops: *None*
Depth to bed rock: None
Micro topography: *Animal tracks*
Surface sealing: *None*
Drainage class: *Well drained*
Ground water: *None*
Flooding: *None*
Land use: *Cultivated land*
Vegetation types: *Open wood land*
Existing crops: *Sorghum, Maize*

0-30cm Clear and smooth boundary; dry moisture status; dark yellowish brown (10YR3/4) dry colour ,dark brown (10YR3/3) moist colour; none mottling; loam texture; few, fine medium coarse fragments; moderate, fine to medium, sub-angular blocky; fine crack; hard (dry), friable to firm(moist), slightly sticky and slightly plastic (wet) consistency; none cutanic features; non-cemented & non-Compacted; none mineral nodules; common, fine medium root: many, fine medium pores; none calcareous.

30-60cm Clear and smooth boundary; dry moisture status; very dark greyish brown (10YR3/2) dry colour ,very dark gray (10YR3/1) moist colour; none mottling; clay texture; none coarse fragments; strong, fine to medium, sub-angular blocky; none crack; slightly hard (dry), friable (moist),sticky and plastic (wet) consistency; none cutanic features; non-cemented & non-Compacted; none mineral nodules; few, fine medium root: common, fine medium pores; none calcareous.

60-120cm Clear and smooth boundary; dry moisture status; dark yellowish brown

(10YR4/4) dry colour , brown (10YR4/3) moist colour; none mottling; clay loam texture; none coarse fragments; strong, fine to medium, sub-angular blocky; none crack; slightly hard (dry), friable (moist),sticky and plastic (wet) consistency; none cutanic features; non-cemented & non-Compacted; none mineral nodules; very few, fine root: common, fine medium pores; none calcareous.

120-200cm Dry moisture status; black (10YR2/2) dry colour , very dark brown (10YR2/1) moist colour; none mottling; clay loam texture; none coarse fragments; strong, fine to medium, sub-angular blocky; none crack; slightly hard (dry), friable (moist),sticky and plastic (wet) consistency; none cutanic features; non-cemented & non-Compacted; none mineral nodules; none root: common, fine medium pores; none calcareous.

Umbric surface horizon and fluvic sub surface horizon

Profile code: *LGDP-2*
Date: *04/12/18*
Author(s): *Terefe/Bikila*
Region:-Oromia
Zone: *Arsi*
Woreda: *Shanen Kolu*
Soil classification FAO (2006): *Cambisols*
Human influence: *Ploughing*
Land form: *medium gradient mountain*
Surface coarse fragments: *common*
Position: *Medium*
Slope class: *15-30%*
Slope aspect: *West to East*
Drainage external: *well*
Surface Cracking; None
Moisture condition: 0-50 cm dry .
Erosion status: *Splash/Rill/Gully*
Fertilizers: *Unknown*

Mapping unit: SMU **Status:** *PS*
Long. In utm (E):*638006*
Lat. in utm (N):*933721*
Elevation: *1599m*
Parent material: *Insitu*
Rock Types: - *Limestone*
Effective soil depth: *Shallow*
Rock out crops: *few*
Depth to bed rock: 50cm
Micro topography *Animal tracks*
Surface sealing: *None*
Drainage class: *well drained*
Ground water: *None*
Flooding: *None*
Land use: *Cultivated land*
Vegetation types: *Open wood land*
Existing crops: *Sorghum, Maize*

0-25cm Clear and smooth boundary dry moisture status; brown (7.5YR4/4) dry colour ,dark brown (7.5YR3/2) moist colour; none mottling; sandy clay loam texture; fine, fine medium coarse fragments; weak, fine to medium, sub-angular blocky; none crack; loose (dry),very friable(moist), slightly sticky and slightly plastic (wet) consistency; none cutanic features; non-cemented & non-Compacted; none mineral nodules; common, fine medium root: many, fine medium pores; none calcareous.

30-50cm Dry moisture status; strong brown (7.5YR5/6) dry colour; brown (7.5YR5/4) moist colour; none mottling; clay loam texture; none coarse fragments; weak fine to medium sub angular blocky structure; none Crack; loose(dry);very friable (moist), slightly sticky and slightly plastic (wet) consistency; none cutanic features; none cemented; none mineral nodules; few, fine root: common, fine to medium pores; none calcareous.

Umbric surface horizon and cambic sub surface horizon

.**Profile code:** *LGDP-3*

Mapping unit: SMU **Status:** *PS*

Date: *04/12/18*

Long. In utm (E):*637899*

Author(s): *Terefe/Bikila*

Lat. in utm (N):*932975*

Region:-Oromia

Elevation: *1545m*

Zone: *Arsi*

Parent material *Insitu weathered*

Woreda: *Shanen Kolu*

Rock Types: - *Limestone*

Soil classification FAO (2006): *Leptosols*

Effective soil depth: *Very shallow*

Human influence: *Ploughing*

Rock out crops: *few*

Land form: *medium gradient mountain*

Depth to bed rock: 25cm

Surface coarse fragments: *common*

Micro topography *Animal tracks*

Position: *Medium*

Surface sealing: *None*

Slope class: *15-30%*

Drainage class: - *excessively drained*

Slope aspect: *East to West*

Ground water: *None*

Drainage external: *Rapid*

Flooding: *None*

Surface Cracking; None

Land use: *Cultivated land*

Moisture condition: 0-25 cm dry **.**

Vegetation types: *Open wood land*

Erosion status: *Splash/Rill/Gully*

Existing crops: *Sorghum, Maize*

Fertilizers: *Unknown*

0-25cm Dry moisture status; brown (7.5YR4/4) dry colour ,dark brown (7.5YR4/3) moist colour; none mottling; loam texture; none coarse fragments; weak, fine to medium, sub-angular blocky; none crack; loose (dry),very friable(moist), slightly sticky and slightly plastic (wet) consistency; none cutanic features; non-cemented & non-Compacted; none mineral nodules; common, fine medium root: many, fine medium pores; none calcareous.

Profile code: *LGDP-4*
Date: *07/12/18*
Author(s): *Terefe/Bikila*
Region:-Oromia
Zone: *Arsi*
Woreda: *Shanen Kolu*
Soil classification FAO (2006): *Luvisols*
Human influence: *Ploughing*
Land form: *medium gradient mountain*
Surface coarse fragments: *few*
Position: *Medium*
Slope class: *15-30%*
Slope aspect: *North to south*
Drainage external: *well*
Surface Cracking; None
Moisture condition: 0-200 cm dry .
Erosion status: *Splash/Rill*
Fertilizers: *Unknown*

Mapping unit: SMU **Status:** *PS*
Long. In utm (E):*638521*
Lat. in utm (N):*931559*
Elevation: *1518m*
Parent material: *Insitu weathered*
Rock Types: - *Limestone*
Effective soil depth: *Very deep*
Rock out crops: *None*
Depth to bed rock: None
Micro topography: *Animal tracks*
Surface sealing: *None*
Drainage class: *well drained*
Ground water: *None*
Flooding: *None*
Land use: *Cultivated land*
Vegetation types: *Open wood land*
Existing crops: *Sorghum, Maize*

0-30cm Clear and smooth boundary dry moisture status; reddish brown (5YR4/4) dry colour , dark reddish brown (5YR4/6) moist colour; none mottling; loamy sandy texture; none coarse fragments; moderate, fine to medium, sub-angular blocky; none crack; slightly hard (dry),very friable(moist), slightly sticky and slightly plastic (wet) consistency; none cutanic features; non-cemented & non-Compacted; none mineral nodules; many, fine medium root: many, fine medium pores; none calcareous.

30-110cm Clear and smooth boundary dry moisture status; yellowish brown (5YR4/6) dry colour; reddish brown (5YR4/3) moist colour; none mottling; sandy clay loam texture; none coarse fragments; moderate fine to medium sub angular blocky structure; none Crack; loose(dry);friable (moist), slightly sticky and slightly plastic (wet) consistency; none cutanic features; none cemented; none mineral nodules; common, fine to medium root: common, fine to medium pores; none calcareous.

110-200cm Dry moisture status; dark red (2.5YR4/8) dry colour; dark red (2.5YR3/6) moist colour; none mottling; sandy clay loam texture; none coarse fragments; moderate fine to medium sub angular blocky structure; none Crack; loose(dry);friable (moist), slightly sticky and slightly plastic (wet) consistency; none cutanic features; none cemented; none mineral nodules; none root: common, fine to medium pores; none calcareous.

Umbric surface horizon and luvic sub surface horizon

Appendix 3: Location of geographical coordinate for soil profile description and Auger observation

I. Auger

Field No	X	Y	Field No	X	Y	Field No	X	Y
LGDA_1	638400	931400	LGDA_37	637600	932800	LGDA_73	638200	933600
LGDA_2	638200	931600	LGDA_38	637800	932800	LGDA_74	638400	933600
LGDA_3	638400	931600	LGDA_39	638000	932800	LGDA_75	638600	933600
LGDA_4	637800	931800	LGDA_40	638200	932800	LGDA_76	637800	933800
LGDA_5	638000	931800	LGDA_41	638400	932800	LGDA_77	638000	933800
LGDA_6	638200	931800	LGDA_42	638600	932800	LGDA_78	638200	933800
LGDA_7	638400	931800	LGDA_43	638800	932800	LGDA_79	638400	933800

LGDA_8	638600	931800	LGDA_44	638800	932800	LGDA_80	638000	934000
LGDA_9	637600	932000	LGDA_45	637400	933000	LGDA_81	638200	934000
LGDA_10	637800	932000	LGDA_46	637600	933000			
LGDA_11	638000	932000	LGDA_47	637800	933000			
LGDA_12	638200	932000	LGDA_48	638000	933000			
LGDA_13	638400	932000	LGDA_49	638200	933000			
LGDA_14	638600	932000	LGDA_50	638400	933000			
LGDA_15	637400	932200	LGDA_51	638600	933000			
LGDA_16	637600	932200	LGDA_52	638800	933000			
LGDA_17	637800	932200	LGDA_53	639000	933000			
LGDA_18	638000	932200	LGDA_54	639200	933000			
LGDA_19	638200	932200	LGDA_55	637600	933200			

LGDA_20	638400	932200	LGDA_56	637800	933200
LGDA_21	638600	932200	LGDA_57	638000	933200
LGDA_22	637400	932400	LGDA_58	638200	933200
LGDA_23	637600	932400	LGDA_59	638400	933200
LGDA_24	637800	932400	LGDA_60	638600	933200
LGDA_25	638000	932400	LGDA_61	638800	933200
LGDA_26	638200	932400	LGDA_62	639000	933200
LGDA_27	638400	932400	LGDA_63	639200	933200
LGDA_28	638600	932400	LGDA_64	639400	933200
LGDA_29	637400	932600	LGDA_65	637800	933400
LGDA_30	637600	932600	LGDA_66	638000	933400
LGDA_31	637800	932600	LGDA_67	638200	933400

LGDA_32	638000	932600	LGDA_68	638400	933400
LGDA_33	638200	932600	LGDA_69	638600	933400
LGDA_34	638400	932600	LGDA_70	638800	933400
LGDA_35	638600	932600	LGDA_71	637800	933600
LGDA_36	637400	932800	LGDA_72	638000	933600

II. Profile

Profile No	X	Y
LGDP-1	637526	932227
LGDP-2	638006	933721
LGDP-3	637899	932975
LGDP-4	638495	931485

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Appendix 4: Soil Survey Format for Soil auger observation

Field No. ________________ Author__________________Status__________

Project site________________ Date________________

Observation site location __________ **GPS N**: __________ ___**E:** _____________

Surface crust________________Erosion

Cracking____________________A) At site__________________Land use ____________

Elevation____________________B) At surrounding___________Crop grown_______

Drainage Class/Ext_______ Micro topography___________Crop grown since when__

Land Form_________________Seepage___________________-Range Land

Flooding F/D________________SMU________________________Over grazing__________

Position______________________Slope Class________________Bush encroachment____

GWTD (cm) __________________Slope aspect/direction____ -Vegetation type_________

Permeability_______________Rock out crop_______________Dominant species______

Parent material____________Surface Stone/gravel______ Invasive species_______

Human Influence__________

Depth(cm)						
Moisture Status	D/T					
Color	Dry					
	Moist					
Mottles	Abundance					
	Size					
	Contrast					
Texture						
Coarse Fragment	Abundance					
	Size					
Topsoil Structure	Grade					
	Size					
	Type					
Consistency	Dry					
	Moist					
	Wet					
Cementation	Grade					

Mineral nodules	Abundance					
	Color					
	Hardiness					
	Nature					
	Kind					
Carbonate						
Field PH						
Field EC						

Diagram and/or comment of the site	Diagram and/or comments between sites

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Appendix 5: Soil Survey Format for Soil Profile Observation

Field No. _______________ Author_________________Status_________

Project site_______________ Date_______________

Observation site location _________ **GPS N**:_________ ___**E**: ____________

Surface crust__________ ____Erosion

Cracking _________________ A) At site_______________Land use ___________

Elevation____________ ______ B) At surrounding_____ __ Crop grown_______

Drainage Class/Ext________Micro topography_________Crop grown since when__

Land Form___________ ____ Seepage_________________-Range Land

Flooding F/D__________ ___SMU________________ _____Over grazing__________

Position__________________Slope Class________________Bush encroachment____

GWTD (cm) _________ ____Slope aspect/direction_____ -Vegetation type_________

Permeability_________ _____Rock out crop___________ ____Dominant species______

Parent material__________ Surface Stone/gravel__________Invasive species_______

Human Influence__________

Horizon symbol						
Depth(cm)						
Boundary						
Moisture Status	D/T					
Color	Dry					
	Moist					
Mottles	Abundance					
	Size					
	Contrast					
Texture						
Coarse Fragment	Abundance					
	Size					

Structure	Grade					
	Size					
	Type					
Crack						
Consistency	Dry					
	Moist					
	Wet					
Cutans	Abundance					
	Size					
	Nature					
Cementation	Grade					
Mineral nodules	Abundance					
	Color					
	Hardiness					
	Nature					
	Kind					
Root	Abundance					
	Size					
Pores	Abundance					
	Size					
Carbonate						
Sample						

Diagnostic horizon (surface) _______________ Sub surface __________________

Diagnostic property ______________________ Depth to paralitic contact__________

FAO field classification____________________ Final Classification______, Diagram_________________ Remark/Comment ________________________________

Appendix 6: Soil physical and chemical laboratory analysis results

I. Soil chemical laboratory analysis results

LAB No	Profile No.	Depth (Cm)	P^H - Water	E.C	P^H - KCl	Particle Size Distribution			TEXTURAL CLASS
						Sand	SILT	CLAY	
			1:2.5	ds/m	1:2.5	%	%	%	
2439/18	**LGDP-1**	**0-30**	**5.6**	**0.093**	**5.2**	**37**	**38**	**25**	**Loam**
2440/18		**30-60**	**5.7**	**0.080**	**5.1**	**21**	**36**	**43**	**Clay**
2441/18		**60-110**	**5.9**	**0.070**	**5.4**	**29**	**36**	**35**	**Clay loam**
2442/18		**110—200**	**6.6**	**0.186**	**6.0**	**25**	**36**	**39**	**Clay loam**
2443/18	**LGDP-2**	**0-25**	**5.5**	**0.041**	**5.0**	**69**	**10**	**21**	**Sandy clay loam**
2444/18		**25-50**	**4.7**	**0.030**	**4.2**	**31**	**32**	**37**	**Clay loam**
2445/18	**LGDP-3**	**0-25**	**5.6**	**0.099**	**5.1**	**51**	**36**	**13**	**Loam**
2446/18	**LGDP-4**	**0-30**	**5.7**	**0.111**	**5.0**	**85**	**8**	**7**	**Loamy sand**
2447/18		**30-110**	**5.8**	**0.052**	**5.2**	**59**	**8**	**33**	**Sandy clay loam**
2448/18		**110-200**	**5.9**	**0.066**	**5.2**	**61**	**8**	**33**	**Sandy clay loam**
LAB NO	Na	**K**	**Ca**	**Mg**	**SUM**	**CEC**	**BS**	**EX. Acidity**	**Ex. Al3+**
	Cmol(+)Kg^{-1}						**%**	**Cmol(+)Kg-1**	
2439/18	**0.07**	**0.52**	**10.19**	**2.16**	**12.94**	**16.9**	**76**	_	_
2440/18	**0.18**	**0.36**	**15.77**	**5.22**	**21.54**	**25.5**	**84**		
2441/18	**0.14**	**0.21**	**10.19**	**3.63**	**14.18**	**17.8**	**80**	_	_
2442/18	**0.17**	**0.38**	**14.25**	**4.62**	**19.42**	**24.5**	**79**	_	_
2443/18	**0.04**	**0.27**	**19.82**	**1.00**	**21.13**	**40.5**	**52**	**0.40**	**0.00**
2444/18	**0.10**	**0.04**	**16.10**	**1.15**	**17.39**	**34.4**	**51**		_

LAB No	Profile No.	Depth (Cm)	P^H - Water	E.C	P^H - KCl	Particle Size Distribution			TEXTURAL CLASS
						Sand	SILT	CLAY	
			1:2.5	ds/m	1:2.5	%	%	%	
2445/18	0.09	0.57	6.63	3.73	11.02	18.5	60	_	_
2446/18	0.09	0.72	18.50	1.46	20.77	41.0	51	_	_
2447/18	0.04	0.93	5.11	2.15	8.23	8.70	95	_	_
2448/18	0.07	1.23	2.47	1.01	4.77	7.0	68	_	_

LAB NO	T.N	O.C	O.M	C/N	Av.K	Av.P	P_2O_5	$CaCO_3$	
	%	%	%		PPM	PPM		%	gram kg^{-1}
2439/18	**0.10**	**1.34**	**2.31**	**13**	**202.60**	**5.90**	**13.51**	_	_
2440/18	**0.09**	**1.04**	**1.80**	**12**	**139.60**	**0.32**	**0.73**	_	_
2441/18	**0.07**	**0.97**	**1.67**	**14**	**82.70**	**1.38**	**3.16**	_	_
2442/18	**0.12**	**1.32**	**2.28**	**11**	**148.20**	**2.36**	**5.40**	_	_
2443/18	**0.10**	**1.00**	**1.72**	**10**	**106.20**	**7.96**	**18.23**	_	_
2444/18	**0.05**	**0.57**	**0.99**	**11**	**17.2**	**0.00**	**0.00**	_	_
2445/18	**0.09**	**1.19**	**2.05**	**13**	**222.00**	**0.52**	**1.19**	_	_
2446/18	**0.10**	**1.41**	**2.43**	**14**	**278.40**	**8.00**	**18.32**	_	_
2447/18	**0.06**	**0.60**	**1.03**	**10**	**360.00**	**0.04**	**0.09**	_	_
2448/18	**0.04**	**0.45**	**0.78**	**11**	**476.10**	**0.00**	**0.00**	_	_

II. Soil physical test

LAB NO	Field Code	Depth(cm)	BD(g/cm3)	F. Capacity (%)	P.W.P (%)
2455/18	LGDP-1	0-30	1.66	19.20	11.1
2456/18		30-60	1.87	26.10	17.9
2457/18		60-90	1.83	23.30	13.4

Appendix 7: Soil infiltration and permeability test

I-Infiltration

Double Ring Inflitrometer Field Data							**Project: LGDSSIP**	**Site:LGDP-1**	
					GPS Reading		**Land Form:LT**		
Date:01/12/18					**N:932227**		**Slope Class:8_15**	**Micro Topography: AT/AB**	
Author: Bikila					**E:637526**		**Soil Type: FL**		
					Elevation:1466				
Depth of insertion of ring(cm):10cm								Replication No.:1	
					Pre-wetting time (hrs):				
Local time(hr :mins)	**Time Interval (mins)**	**Interval(hr) columon 2 ÷ 60mins**	**Cumu lative time (mins)**	**Cumu lative time (hr),**	**Depth of water in infiltrome ter(cm)**	**Intake(cm)**	**Cumula tive intake (cm/hr)**	**Infiltration rate (cm/hr)**	
								Immediate (instantaneous)	**Mean**
1	**2**	**3.00**	**4**	**5**	**6.0**	**7**	**8**	**9=7/3**	**10=8/5**
02:46	0	0.00	0	0	46.6	0.0	0		
	5	0.08	5	0.08	44.5	2.1	2.1	25.20	25.20
	5	0.08	10	0.17	43.2	1.3	3.4	15.60	20.40
	5	0.08	15	0.25	41.8	1.4	4.8	16.80	19.20
	5	0.08	20	0.33	40.6	1.2	6.0	14.40	18.00
	5	0.08	25	0.42	39.8	0.8	6.8	9.60	16.32
	5	0.08	30	0.50	38.9	0.9	7.7	10.80	15.40
	5	0.08	35	0.58	38.1	0.8	8.5	9.60	14.57
	RE				46.6				
	5	0.08	40	0.66	45.7	0.9	9.4	10.80	14.17
	5	0.08	45	0.75	44.6	1.1	10.5	13.20	14.06
	10	0.17	55	0.92	42.6	2.0	12.5	11.76	13.64
	10	0.17	65	1.08	40.6	2.0	14.5	12.00	13.38
	10	0.17	75	1.25	39.6	1.0	15.5	6.00	12.40
	10	0.17	85	1.42	38.3	1.3	16.8	7.80	11.86
	RE				46.6				
	15	0.25	100	1.67	44.1	2.5	19.3	10.00	11.56
	15	0.25	115	1.92	41.9	2.2	19.0	8.80	9.90
	15	0.25	130	2.17	40.0	1.9	18.7	7.60	8.62
	15	0.25	145	2.42	38.4	1.6	18.4	6.40	7.60
	RE				46.6				
	20	0.33	165	2.75	43.5	3.1	21.5	9.30	7.81
	20	0.33	185	3.09	40.7	2.8	24.3	8.40	7.87
	20	0.33	205	3.42	38.3	2.4	26.7	7.20	7.81

Double Ring Inflitrometer Field Data		**Project: LGDSSIP**	**Site:LGDP-1**
	GPS Reading	**Land Form:LT**	
Date:01/12/18	**N:932227**	**Slope Class:8_15**	**Micro Topography: AT/AB**
Author: Terefe	**E:637526**	**Soil Type: FL**	
	Elevation:1466		

Depth of insertion of ring(cm):10cm									
				Pre-wetting time (hrs):				Replication No.:2	
Local time (hr:mins)	**Time Interval(mins)**	**Interval (hr)column 2 ÷ 60mins**	**Cumulative time(mins)**	**Cumulative time(hr),**	**Depth of water in infiltrometer(cm)**	**Intake(cm)**	**Cumulative intake (cm/hr)**	**Infiltration rate (cm/hr)**	
								immediate(instantaneous)	**mean**
1	**2**	**3.00**	**4**	**5**	**6.0**	**7**	**8**	**9=7/3**	**10=8/5**
02:47	0	0.00	0	0	286.6	0.0	0		
	5	0.08	5	0.08	283.5	3.1	3.1	37.20	37.20
	5	0.08	10	0.17	281.5	2.0	5.1	24.00	30.60
	5	0.08	15	0.25	279.8	1.7	6.8	20.40	27.20
	RE				286.6				
	5	0.08	20	0.33	285.4	1.2	8.0	14.40	24.00
	5	0.08	25	0.42	284.0	1.4	9.4	16.80	22.56
	5	0.08	30	0.50	282.4	1.6	11.0	19.20	22.00
	5	0.08	35	0.58	281.4	1.0	12.0	12.00	20.57
	5	0.08	40	0.67	280.1	1.3	13.3	15.60	19.95
	5	0.08	45	0.75	279.2	0.9	14.2	10.80	18.93
	RE				286.6				
	5	0.08	50	0.83	285.9	0.7	14.9	8.40	17.88
	5	0.08	55	0.92	284.6	1.3	16.2	15.60	17.67
	5	0.08	60	1.00	283.8	0.8	17.0	9.60	17.00
	5	0.08	65	1.08	282.8	1.0	18.0	12.00	16.62
	5	0.08	70	1.17	281.8	1.0	19.0	12.00	16.29
	5	0.08	75	1.25	281.1	0.7	19.7	8.40	15.76
	5	0.08	80	1.33	280.2	0.9	20.6	10.80	15.45
	5	0.08	85	1.42	279.3	0.9	21.5	10.80	15.18
	5	0.08	90	1.50	278.3	1.0	22.5	12.00	15.00
	RE				286.6				
	10	0.17	100	1.67	285.5	1.1	23.6	6.60	14.16
	10	0.17	110	1.83	284.3	1.2	24.8	7.20	13.53
	10	0.17	120	2.00	283.5	0.8	25.6	4.80	12.80

	10	0.17	130	2.17	282.5	1.0	26.6	6.00	12.28
	10	0.17	140	2.33	281.6	0.9	27.5	5.40	11.79
	10	0.17	150	2.50	280.5	1.1	28.6	6.60	11.44
	20	0.33	170	2.83	279.0	1.5	30.1	4.50	10.62
	20	0.33	190	3.17	277.8	1.2	31.3	3.60	9.88
	20	0.33	210	3.50	276.6	1.2	32.5	3.60	9.29

Double Ring Inflitrometer Field Data				Project: LGDSSIP		Site:LGDP-1			
				GPS Reading		Land Form:LT			
Date:01/12/18				N:932227		Slope Class:8_15		Micro Topography: AT/AB	
Author: Terefe				E:637526		Soil Type: FL			
				Elevation:1466					
Depth of insertion of ring(cm):10cm				Pre-wetting time (hrs):				Replication No.:3	
Local time (hr:mins)	**Time Interval (mins)**	Interval **(hr) columon 2 ÷ 60mins**	**Cumulative time (mins)**	**Cumulative time (hr),**	**Depth of water in infiltrometer (cm)**	**Intake (cm)**	**Cumulative intake(cm/hr)**	**Infiltration rate(cm/hr)**	
								Immediate (instantaneous)	**mean**
1	**2**	**3.00**	**4**	**5**	**6.0**	**7**	**8**	**9=7/3**	**10=8/5**
02:56	0	0.00	0	0	276.6	0.0	0		
	5	0.08	5	0.08	274.4	2.2	2.2	26.40	26.40
	5	0.08	10	0.17	273.1	1.3	3.5	15.60	21.00
	5	0.08	15	0.25	272.0	1.1	4.6	13.20	18.40
	5	0.08	20	0.33	270.8	1.2	5.8	14.40	17.40
	5	0.08	25	0.42	270.0	0.8	6.6	9.60	15.84
	5	0.08	30	0.50	269.0	1.0	7.6	12.00	15.20
	5	0.08	35	0.58	268.2	0.8	8.4	9.60	14.40
	RE				276.6				
	10	0.17	45	0.17	274.6	2.0	10.4	12.00	62.40
	10	0.17	55	0.34	272.9	1.7	12.1	10.00	35.94
	10	0.17	65	0.50	271.2	1.7	13.8	10.20	27.42
	10	0.17	75	0.67	269.7	1.5	15.3	9.00	22.84
	10	0.17	85	0.84	268.5	1.2	16.5	7.20	19.72
	RE				276.6				
	15	0.25	95	1.67	274.3	2.3	18.8	9.20	11.26
	15	0.25	110	1.92	272.3	2.0	20.8	8.00	10.83
	15	0.25	125	2.17	270.3	2.0	22.8	8.00	10.51
	15	0.25	140	2.42	268.5	1.8	24.6	7.20	10.17
	RE				276.6				
	20	0.33	160	2.75	273.1	3.5	28.1	10.50	10.21
	20	0.33	180	3.09	270.8	2.3	30.4	6.90	9.85
	20	0.33	200	3.42	268.7	2.1	32.5	6.30	9.50

II. Hydraulic Conductivity

Saturated hydraulic conductivity measurement form		**Project: LGSSIP**	**Site: LGDP-1**
Date: 01/12/18	**GPS Reading**	**Land form : LT**	
	N:932227	**Slope: 8_15**	
Author: Terefe	**E: 637526**		
	Elevation: 1466	**Soil Type: FL**	**Micro topography:-AT/AB**
Depth of insertion of auger (cm)	Radius(cm): 4		Depth of insertion of auger (cm)

Replication No. 1					Replication No. 2					Replication No. 3				
Depth(cm) :90					Depth(cm):90					Depth(cm) 90				
ti, sec	**h'(t1),cm**	**h(ti),cm**	**h(t1+r/2),cm**	**Hydraulic Conductivity (m/day)**	**ti,sec**	**h'(t1),cm**	**h(ti),cm**	**h(t1+r/2),cm**	**Hydraulic Conductivity (m/day)**	**ti, sec**	**h'(t1),cm**	**h(ti),cm**	**h(t1+r/2),cm**	**Hydraulic Conductivity (m/day)**
0	0				0	0				0	0			
60	19	71	73	**0.27**	30	7	83	85	**0.18**	30	7	83	85	**0.37**
120	28	62	64		60	10	80	82		60	10	80	82	
180	31	59	61		120	15	75	77		120	14	76	78	
480	33	57	59		300	22	68	70		300	20	70	72	
780	35	55	57		600	30	60	62		600	24	66	68	
1380	45	45	47		2100	31	59	61		1200	39	51	53	
2280	50	40	42		3600	33	57	59		2100	46	44	46	
3180	54	36	38							3600	53	37	39	
4380	55	35	37											