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EXECUTIVE SUMMARY

The present study is initiated in order to provide essential soils and land related information (i.e., on land qualities and characteristics for irrigation development) for the investment feasibility study. This helps to identify potentials and constraints of the area and assigning the lands for its best use through land evaluation. Hence, the soil survey and land evaluation of Hedhesa Small Scale Irrigation Project was undertaken and mapped at scale of 1:10,000.

In general, soil survey and land evaluation was conducted on gross area of about 80hectares but during the survey it was noted that the surveyed area was more than the indicated command area. The final delineation of net command area is expected to be about 60 hectares.

1. INTRODUCTION

1.1 General

The soil study of irrigation project encompasses two themes, soils and land evaluation. These studies are conducted at a detailed level in line with FAO guidelines for irrigation design, agricultural input requirement analysis and crop selection. The overall objectives of the soil study are to investigate and identify different soil types of the scheme area and describe their physical and chemical properties. In addition, the land evaluation assessment, which is part of land resources study, aims to translate land resources data into an expression of suitability of land units for a defined use.

An irrigation project is required to be planned and designed such that it fits appropriately into the soil and land characteristics of the command areas along with the climatic factors, topographic features and socio-economic conditions. Therefore, detailed field soil surveys, laboratory tests and analysis of data and test results were undertaken to determine the soil and land characteristics which will form a basis for evaluating the land suitability for irrigated agriculture.

Hedhesa Small scale Irrigation project soil survey and land evaluation was carried out for the gross area of about 80ha. The identified command area soils are basically of two types, namely; Vertisols and Cambisols.

1.2 Objective

1.2.1 General Objective

The main objective of the soil survey was aimed to provide detail information on land and soils of command area of the project at feasibility level which may form as a basis for confirming, crop selections, irrigation designs, and agricultural input requirements such as fertilizer applications etc. The study was focused in identifying the various topographic forms, soil types, present land use assessment and evaluated the existing land use pattern and assessed the land and crop suitability for proposed irrigation.

1.2.2 Specific Objectives

- To determine the 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 surface irrigated agriculture.
- Produce soils and land suitability maps at high intensity (detailed) in the scale of 1:10,000.

1.3 Methodology

The methodological approach followed to carry out the study has been classified in to three stages of pre-field work, field work and post field works and each phase is briefly discussed below.

1.3.1 Pre-field Work

During this stage, reconnaissance field visit has been made and topographic map, were collected. Field soil survey guidelines, description sheets for auger boring and profile pits have been prepared. Then soils and land suitability maps at high intensity (detailed) was made in the scale of 1:10,000.

1.3.2 Field Work

Feasibility level soil surveying in the project area was carried out in April, 2018 during which 8 auger hole observations, 3 profile pits for detail analysis, infiltration and hydraulic conductivity analyses were made. Auger holes and profile pits observations were made, each to a depth of 1.2 m and 2m unless prevented at a shallower depth respectively. Soil profile pits are excavated to 2 m depth at representative sites in order to describe properly the main soil types identified as a result of auger hole field survey. The profile pits are more or less evenly distributed throughout the surveyed basin area as much as possible. Soil samples were taken from each significant soil horizon down to 2m depths for laboratory analysis, unless prevented by shallower depth.

Survey approaches followed standard soil survey procedures and classified according to Characterization of the soil type were made using different manuals and references such as FAO Guide Line For Soil Description FAO, 2006, World reference base for soil resources, FAO, 1998 and FAO, 2006. The system is used because it provide detail information on soil qualities and soil characteristics for the assessment of land performance when used for specific purpose.

Soil profile pits were dug to 200cm depths at representative sites, following transect lines. Soil samples were taken from each significant natural horizon's, for full physical, chemical, bulk density and available water holding capacity analyses and/or determination. in-situ infiltration (using double ring infiltrometer in triplicate at the representative profile pits) and hydraulic conductivity tests (using inverse auger hole method) were carried out. All observations were recorded on soil description sheets at each observation site and the following surface/ external characteristics and information were recorded.

- Land form and its use and/or land cover,
- Location of the site using hand GPS,
- Soil colour using Munsell color charts,
- Parent material, presence of micro-topography, surface features (cracks, stoniness, etc),
- Erosion status and control practices
- General pattern of drainage,

Moreover, some internal characteristics such as soil depth, texture, nodules (such as iron, manganese, etc) mottling, etc., were further evaluated. During profile pit analysis more information was recorded (i.e., from each horizon structural development and form, consistence, porosity (using magnifying hand lense), roots, cutans, slickenside, etc. From the analysis it is noted that, textural class determination by hand feel method in the field is different than laboratory result. Undisturbed core samples were sent to the laboratory for the determination of water holding capacity. Soil mapunits and observations within similar soil unit were used to characterize the mapping unit.

Table 1-1 Soil survey data collected during the field work

Data type	Number of observations
Total augers observation points	8
Number of soil pits observed	3
Number of soil sample collected for lab. analysis	11
Infiltration, hydraulic conductivity test sites	1

1.3.3 Post field work

Some of the major activities carried out were: detail scrutiny of field, laboratory and supporting documents; interpretation of obtained data, establishment of land suitability analysis and diagnostic criteria, preparation of soil and land suitability management units, etc. Some of the major activities carried out are highlighted hereunder.

1.3.4 Laboratory analysis

A total of 11 undisturbed core samples from representative horizons have been collected from soil pits profiles, for laboratory analysis. Oromia Water Works Design and Supervision Enterprise were undertaken soil fertility analysis for the following parameters:

- PH (1:2.5 water and potassium chloride);
- Electrical conductivity in saturation extract, when $P^H > 8.0$
- Cation exchange capacity (cmol(+) kg^{-1} soil Na, K, Ca, Mg);
- Available phosphorus (P_2O_5);
- Organic carbon %;
- Total nitrogen %;
- Texture
- Calcium carbonate

2. DESCRIPTION OF PROJECT AREA

2.1 Location

Hadessa irrigation project is found in Oromia Regional State, Arsi Zone, Shirka District and Jawiwachu kebele. The command area also has different land forms ranging from plain lands to gentle slope lands and the command area has 1924 and 2065 masl minimum and maximum elevation respectively. Moreover, the project site is far 20km distance from district capital.

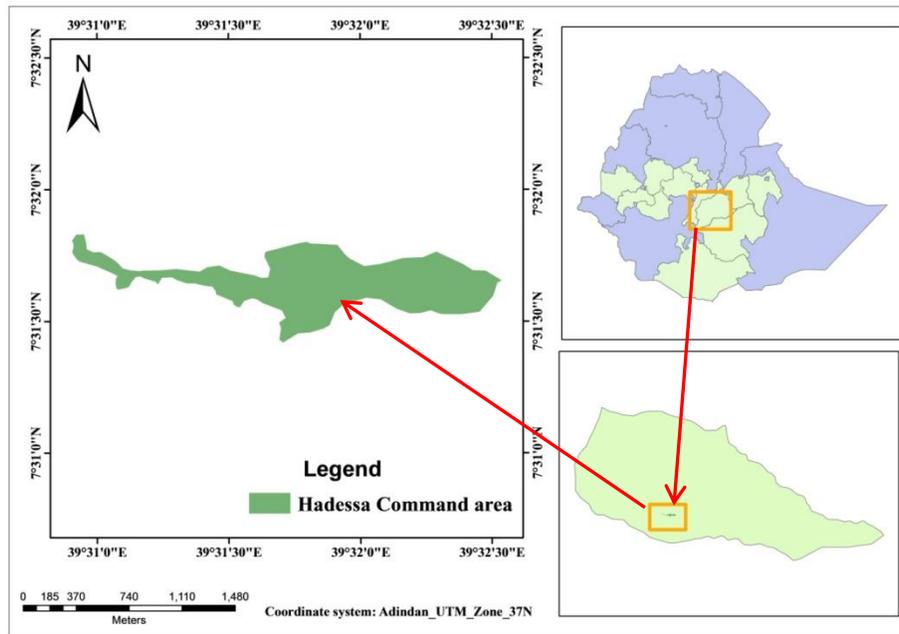


Figure 2-1: Location of Hadessa command area

2.2 Climate

Climate is the important factor determining the success or failure of agriculture. It influences agricultural operations from sowing of a crop to the harvest and particularly rain fed agriculture depends on the mercy of the weather. The crops are to be sown at the optimum period for maximum yield. In dry lands, the time of receipt of rainfall decides the sowing date. The study of climate helps to minimize the crop losses due to excess rainfall, cold/heat etc. It helps in forecasting pests and diseases, choice of crops, irrigation and other intercultural operations through short, medium and long-range forecasts. It helps to identify places with same climatic conditions (Agro climatic zones). This will enable to adopt suitable crop production practices based on the local climatic conditions. It also helps in the introduction of new crops and varieties, which are more productive than the native crops, and varieties. Bokoji Meteorological Station is the nearest station from which the climatic data were inferred.

2.3 Rainfall

Precipitation refers to the water (moisture) received in the form of rain, snow, hail, fog, dew or a combination of them. However, rainfall is the most important form of precipitation in the tropics and subtropics in which its efficiency is measured by its yearly amount, distribution and duration.

The area is characterized by bi-modal rainfall pattern that starting from mid February to mid-May is short rainy season and June to end of September the long rainy seasons. However, the rain fall pattern is characterized by erratic nature. Hence, the total average annual rain fall is calculated to be 990 mm. The maximum rainfall recorded in the month of July which is 198mm as shown in Table 2-1.

Table 2-1: Monthly and effective rainfall of study area

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
Rain (mm)	30	43	75	81	100	114	198	174	91	55	19	10	990
Eff (mm)	28.6	40	66	70.5	84	93.2	135	126	77.8	50.2	18.4	9.8	799

2.4 Temperature

The prevailing temperature considerably influences selection of crops and their growing periods. Optimum temperature plays an important role on the growth period and the production of crops. The mean maximum annual temperature of the area is 19°C and the mean minimum annual temperature is 6.8°C, in the month of January December respectively as illustrated in Table 3. Thus, in command area mostly low to moderate temperature ranges are occurred which is favorable for the growth of various crops in the areas illustrated in Table 2-2.

Table 2-2: Minimum, Maximum and Monthly Average Temperature

Month T °C	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
Min	6.3	7.2	8.2	8.3	7.6	6.9	7.1	6.7	6.6	6	5.5	5.1	6.8
Max	21	21	21	20	20	18	16	16	18	18	19	20	19
Ave	17	18	19	18	18	16	15	15	15	15	15	15	16

2.5 Topography

Topography is an important factor for the planning of any irrigation project as it influences method of irrigation, drainage, erosion, and cost of land development, mechanization, labor requirement, and choice of crops. Topographically most of the cultivated lands of the project area are found between levels to gently undulating lands. The command area begins after a few kilometers of ideal canal with in the villages around their homesteads crossing roads and different structures. In general, the command area divided in to three slope classes namely, 0-3, 3-8 and 8-15 percent.

Table 2-3: Slope Class and Area Coverage of Command Area

SN	Slope class	Area in (ha)	Area in (%)
1	0-3	9	15
2	3-8	15	25
3	8-15	36	60
	Total	60	100

2.6 Geological of Command Area

Geology of command area and along the main canal of the irrigation canal can be characterized by undifferentiated volcanic unit overlaid by soil layer. They are described below

Soil layer: In addition to exposure of soil layers within the command area, four (4) pits are dug. Soil layers of the area in its lateral distribution area black-brownish silty clay soil layer, silty clay soil of reddish brown soil layers. Each of them is described below, Silty-Clay soil Layer. It shows blackish-brown in color. This Silty-Clay soil Layer is distributed laterally from the out-let of the weir stretched for about 450m.

It is possible to say this soil layer shows variability of thickness. It has a thickness of about 1.95m at the left flank of the weir and zero thickness is found at the gulley erosion, where the fractured rock is exposed, due to erosion. It has a thickness of 1.10m shows uniformity in texture. It has a thickness of 0.70m and followed by soil layer associated with dominated basaltic fragments.

Alluvial deposit: The deposit is mostly localized along the flank and floor of the river along low relief of the river course. This deposit is constituted form silt and boulders with some gravel, cobbles and pebble size fragments. Bed of silt with exposure thickness of 115cm and also basaltic boulder beds 65cm are found along the river course. In addition, lenses of alluvial deposits are also another form of occurrence of these deposits, which are reworked by the action of the river.

2.7 Land Use

The land use pattern of Shirka district and project area has exhaustively utilized the arable land mainly for rain fed agriculture. According to the data collected from the district agricultural office the area is allocated for cultivated land contribute 69.2 percent of the total the Kebele area.

Table 2-4: Land Use Type In District and Project Kebele

No	Land use	Total Area (ha)		% of Total	
		District	Jawiwachu Kebele	District	Jawiwachu Kebele
1	Arable land	27244	0	40.4	
2	Cultivated land	21566	478	32.0	69.2
3	Grazing land	1472	9	2.2	1.3
4	Forest land	12622	90	18.7	13
5	Settlement	3937	0	5.8	-
6	Other uses	648	101	1.0	14.6
	Total	67489	691	100.0	

Source: Shirka District Agricultural Development Office

2.8 Crop Production

In the project area, the short rainy season is used cultivate belg crops. The study area is endowed with favorable climate, soil and topography for cultivation of diverse crops. Maize is the most widely grown crops in the study area. Tef, maize, sorghum, wheat, beans which are used for food purpose and oil crops are also commonly grown crops in the district. However, farmers in the study area are not commonly growing fruits and vegetable. Perennial crops like forest coffee production is commonly grown in the study area mainly due to the presence of suitable agro-climatic and soil condition and it serve as a good source of income.

Table 2-5 Crop Pattern in the District and Study Area

SN	Crop type	Area (ha)	Yield/ ha	Price/ Qt	Remarks
1	Maize	370	45	500	Used fertilizers, local & selected seeds
2	Tef	1765	10	1500	Used fertilizers, local & selected seeds
3	Sorghum	2003	25	600	Used fertilizers, local seeds
4	Beans	1101	8	1500	Used local seeds
5	Wheat	11130	25	1200	Used fertilizers, local & selected seeds
6	Barley	2140	15	700	Used local seeds
7	Vegetables	200	-	-	Used fertilizers, local seeds

Source: District Agricultural Development Office

2.9 Soil Erosion Status

Soil erosion is widespread, but there is considerable variation in the degree of erosion from place to place in the study area. Erosion is most serious in the study area such that most areas are covered with gullies and bare surfaces. These features are good indicators of severe soil erosion in the woreda.

Soil erosion, on the other hand, is the movement of soil from one part of the land to another through the action of wind or water. Thus, soil erosion by water is caused by raindrop impact surface sealing, and crust formation leading to high runoff rate and amount, high runoff velocity on long and undulating slopes, and low soil strength of structurally weak soils with high moisture content due to frequent rains. Soil erosion by wind is caused by lack of vegetation cover, dry pulverized soils, strong wind speeds, and poor land management practices such as continuous tillage and over grazing.

2.9.1 Existing soil and water conservation

According to the woreda agricultural development office, the main soil and water conservation structural measures used on croplands comprise diversion ditches (cut-off drains), retention (infiltration) ditches, terraces and waterways. Supportive cultural measures such as grass or vegetative material for stabilizing the structures are also applied in project area.

3. DESCRIPTION OF SOIL

3.1 Soil Classification

Soil is one of our most natural resources. It is the heart of terrestrial ecology, and understanding of the soil system is key to success and environmental harmony of any human use of the land. To a great degree, the quality of the soil determines the nature of plant eco-systems and the capacity of land to support animal life and society.

The nature and properties of soil discussed with the general principles of:

- ❑ Classification of soils in terms of diagnostic and characteristics, which to the greatest extent possible is measurable and observable in the field..
- ❑ Selection of diagnostic and characteristics takes into account their relationship with soil forming process.
- ❑ World reference base is used as a guideline to be comprehensive and which enables to accommodate fair classification approach (i.e., it allows precise characterization and classification of individual soil profiles)

The parent material of the Hadhessa project area canal can be characterized by undifferentiated volcanic unit overlaid by soil layer. A soil of the survey area has been categorized with the individual soil type specific criteria using to differentiate the soils to the lowest possible level. Soil classification was in accordance to FAO and the World Reference Base for soils Resources classification approaches, which are mostly based on recognition of diagnostic horizons, properties, materials, etc.

Soil classification of the project area is based on field morphological characteristics, which can be observed and measured or inferred from field observations. Furthermore, physical and chemical properties such as textural classes, content of calcium carbonate, physiological position, drainage characteristics of that particular soil, soil depth, etc were used to specifically define the soil. The major soils that have been identified in the irrigation command area are Vertisols and Cambisols.

4. SOIL PHYSICAL AND CHEMICAL PROPERTIES

4.1 Soil Physical Properties

Soil physical properties profoundly influence how soils functions in an ecosystem and how they can best be managed. The physical properties discussed in this report related to the solid particles of the soil and the manner in which they are aggregated. Moreover, the physical or morphological characteristics of the horizons (layers) of a soil profile are visually observed, measured and recorded in the field. These characteristics include: colour, texture, structure, clay skins, consistence, horizon boundaries, roots, pores, etc. Some of the major physical characteristics are briefly discussed in relation to the main soils of the study area as follows.

4.1.1 Soil Color

Soil colour provide valuable clue to the nature of other soil properties and conditions of organic matter content, water content, presence of oxidation states, etc). Soil colour name are given according to the Munsell soil colour charts nomenclature edition. The control section of the major soils in the study area for the Vertisols have the colour of typically Very dark grayish brown the soil had few or common distinct yellowish brown to dark brown mottles. However, the colour for the Cambisols soils are very dark grayish brown.

4.1.2 Effective Soil Depth

Vertisols are dominantly deep to very deep soils in the basin and thus do not pose any serious constraint in so far as plant rooting depth is concerned. However, some of the other soil units within the command area, the Cambisols have very shallow to shallow effective soil depths and thus may have limited agricultural value.

4.1.3 Texture

Soil texture is the most basic characteristics of a soil to influence its basic qualities. Texture influences qualities such as infiltration, moisture and nutrient retention, vulnerability to erosion, drainage, workability, etc. Soil texture of the command area is described in Table 4-1.

Table 4-1: Soil Textural Class of Command Area

SN	Field ID	Depth (cm)	UTM Coordinates			Particle Size Distribution, %			
			X	Y	Z	Sand	Silt	Clay	Soil Class
1	Pit-1	0-30	557973	832016	2055	23	18	59	Clay
		30-70				29	24	47	Clay
		70-100				41	26	33	Clay loam
2	Pit-2	0-32	558354	831766	2032	27	24	49	Clay
		32-70				31	36	33	Clay loam
		70-105				41	32	27	Loam
		105-200				47	32	21	Loam
3	Pit-3	0-25	559207	831874	1934	41	36	23	Loam
		25-70				31	26	43	Clay
		70-104				21	20	59	Clay
		104-200				25	22	53	Clay

4.1.4 Soil Structure

Soil structure is characterized in terms of the shape (or type), size and distinctness (grade) of the peds. In the field the relative size (fine, medium and coarse) and degree of development or distinctness of the peds (grade such as strong, moderate or weak) is described. Although, Vertisols the principal sub-soil structure was found to be coarse strongly developed angular type. However Cambisols have weak to strongly developed angular blocky, occasionally prismatic in the topsoil over moderate angular blocky to massive in the subsoil.

4.1.5 Consistence

Vertisols offer extremes of consistence, they are very hard when dry and very sticky and plastic when wet. Extreme hardness when dry and stickiness and loss of traffic ability when wet, permit tillage and seedbed preparation only within a very narrow range of moisture contents. The cultivation of Vertisols when too dry or too wet may therefore result in poor tilth due to cloddy or puddled structure, respectively. However, the consistence of Cambisols is hard when dry, friable to firm when moist and slightly sticky and slightly plastic when wet.

4.1.6 Soils Drainage

The Vertisols and some soil units with vertic properties are poorly to imperfectly drained, due mainly to the finer textured clay and /or topographic position. Cambisols have moderately well to well drained due to their favorable structural aggregation.

4.1.7 Bulk Density (BD)

Bulk density is determined by the dry weight of 100ml undisturbed core sample taken at field in moist conditions. Due to the relatively higher organic matter content of the surface soils, the bulk densities in the surface soil have lower values than subsurface soils. The overall BD values indicate that the soils in the study area are not compact and thus do not restrict root crops development and water movement. The bulk density of the soils in the study area is found between 1.36 and 1.50gm/cm³ and the average value being 1.43gm/cm³.

4.1.8 Porosity

While bulk density present is a satisfactory measure of state of compaction of a soil, knowledge of soil particle density allows the porosity and void ratio to be calculated; the latter two being of more interest to crop production and consolidation of soils respectively (Dekkev, 1991.) An adequate supply of soil solution and soil air especially oxygen to plant roots is essential for plant growth. Soil solution and air are stored and transported within the soil pores. Also plant roots exist in the soil pores. Harrod (1975) found out that sandy soils with a total pore space less than 40% are liable to restrict root growth. Accordingly, porosity nature of the project soil was found in between 49% and 53% for clay loam and clay texture respectively (Annex 2).

4.1.9 Infiltration Characteristics

This is the vertical intake of water into a soil, usually at the soil surface. Its measurement forms a vital part of many surveys involving irrigation development or soil conservation, e.g. in determining the most efficient method(s) of application of irrigation water, crop water demands and in runoff calculations. It is also an important component of the hydrologic cycle crucial to most hydrologic processes e.g. soil water content, runoff and soil erosion. Knowledge of infiltration process is therefore a prerequisite for efficient soil and water management. Infiltration rate is dependent on many factors among them vegetation, slope, bulk density and initial soil moisture.

The infiltration rate is mainly governed by conditions at or near the soil surface. Numerous formulations have been proposed over the years in repeated attempts to express infiltration rate as a function of time or of the total quantity of water infiltrated into the soil. Therefore, depending on command soil class the infiltration rate was failed in 0.8 and 0.5 cm/h for clay loam and clay type respectively (Annex 2)

4.1.10 Hydraulic Conductivity

The hydraulic conductivity of a soil is the ability of a soil to conduct water. It defines the volume of water which will pass through unit cross-sectional area of a soil in unit time, given a unit difference in water potential (hydraulic head). It is of considerable importance since it gives an indication of the rate of movement of water to plant roots, the flow of water to drains and wells and the evaporation of water from the soil surface. Comparison made of the hydraulic conductivity rates of different soil horizons gives a guide to water movement and possible drainage problems within soil profiles.

The water retention function is primarily dependent upon texture and structure. Storage of water by soils is a result of attractive forces between the solid and liquid phases. The solid (matrix) forces enable the soil to hold water against forces or processes such as gravity, evaporation, uptake by plant roots. Therefore, based on soil laboratory result the project soil was failed in 1.25m/day for clay and 1.35m/day clay loam, which is failed in moderate hydraulic conductivity ratings.

4.1.11 Field Capacity (FC)

Field capacity of a soil is the maximum water content the soil will hold following free drainage. FC is the upper limit of available soil moisture under irrigation. It does not therefore correspond to a fixed soil-water potential, but instead represents the condition of each individual soil after the larger pores have drained freely under gravity. The field capacity of the soils of the study area falls in between of 27% to 35% and supported by (Annex 2).

4.1.12 Permanent Wilting Point

Permanent wilting point is the soil moisture content at which plants can no longer obtain enough moisture to meet evapo-transpiration requirements and remain wilted unless water is added to the soil. In other way round, the permanent wilting point (PWP) is arbitrary defined as the soil moisture content at which the leaves of sunflower plants wilts permanently, i.e. when they do not recover their turgor if subsequently placed in a saturated atmosphere.

The permanent wilting point is taken as the lower limit of available water so that water in drier soil is assumed to be not available to plants. The PWP of project area soils varies from 13 to 17% (Annex 2).

4.2 Soil Chemical Characteristics

Soil chemical properties were tested in the laboratory and the detail description is presented. A discussion of the data is presented here under Table 4-2.

Table 4-2: Soil Laboratory Test Result

S N	Field Id	Depth (cm)	pH (H ₂ O)	E.C ds/m	O.M (%)	T.N (%)	Av.P (ppm)	BS (%)	C.E. C (meq /100g)	Exchange bases				Textural
										Mg ⁺⁺	Ca ⁺⁺	Na ⁺	K ⁺	
1	Pit 1	0-30	7.4	0.200	2.21	0.12	0.07	72	66.9	9.33	37.08	0.15	1.80	Clay
		30-70	7.5	0.147	2.65	0.13	0.07	69	63.6	8.75	33.35	0.35	1.50	Clay
		70-100	7.3	0.113	1.52	0.09	0.03	71	51.2	7.23	26.75	0.55	1.70	Clay loam
2	Pit 2	0-32	7.3	0.305	2.43	0.11	0.04	73	53.7	8.88	28.15	0.12	1.85	Clay
		32-70	7.7	0.235	1.54	0.09	0.05	74	53.4	7.79	29.54	0.39	1.63	Clay loam
		70-105	8.0	0.228	1.40	0.07	0.01	72	53.3	6.74	28.57	1.02	1.81	Loam
		105-200	8.0	0.218	1.29	0.07	0.01	89	45.5	8.17	29.93	0.54	1.75	Loam
3	Pit 3	0-25	8.1	0.257	3.52	0.13	0.09	53	66.6	8.88	46.49	0.10	0.84	Loam
		25-70	8.3	0.391	2.21	0.1	0.07	75	74.1	14.47	39.18	1.74	0.32	Clay
		70-104	8.5	0.427	1.79	0.11	0.05	58	63.6	15.2	36.7	3.41	0.45	Clay
		104-200	8.2	0.306	1.16	0.07	0.01	95	52.4	12.11	33.09	3.85	0.75	Clay

The chemical properties of characteristics of the soils were tested in the laboratory and the detail analytical are presented. A discussion of the data is presented hereunder.

4.2.1 Soil Reaction (pH, H₂O (1:2:5))

The soils pH of the study area recorded 7.3 to 8.1 pH values on the top soils (i.e., 0 to 32 cm soil depth), which falls within moderately alkaline and 7.5 to 8.3 in the sub soil (i.e., 30-70 soil depth) rated as topsoil. It should be noted that When the pH level is between 7 and 8.5 the availability of phosphorous and boron decreases and deficiency of other micro-nutrients may be liable. Therefore, proper attention should be given based on the crop to be grown and application of natural and artificial fertilizer is essential.

4.2.2 Electrical Conductivity (EC 1:2:5 Water)

This is a measure of the total soluble salt concentration in the soil solution. A high degree of correlation exists between the EC and osmotic pressure of soil-water extract. If its amount is greater than 4ds/m, the soil is to be saline and difficult for crop production. Therefore, the laboratory results confirmed that the E.C values for topsoil recorded 0.2 to 0.3 ds/m (i.e., 0 to 32 cm soil depth) and 0.14 to 0.3ds/m in the sub soil (i.e., 30-70 soil depth). Thus, the soil of the command area is none saline and optimum for all crops growth.

4.2.3 Organic matter (OM)

According to the analytical data the percent organic carbon ranges in the top soil between 2.21 to 3.52 (rated as medium to high values) and 1.54 to 2.65 percent for the sub-soils (rated in medium category). Thus to maintain the organic matter content of the command soils, regular application of crop residues and manure is recommended.

4.2.4 Total nitrogen (T.N %)

The laboratory analyses data show that rating for evaluation of total nitrogen on top soils, it is recorded 0.11 to 0.13 percent, which is found in to high range. For the sub soils, the range is 0 to 0.13 percent which is rated in low to high category. In general proper soil management and regular application of nitrogenous fertilizer may be required based on crops to be grown.

5.2.5 Available phosphorus (Av.P)

The amount of available phosphorus in the command area soil showed 0.04 to 0.09(ppm) on topsoil and 0.05 to 0.07(ppm) which is found in low category and fertilizer response is most likely. A large buildup of available nutrient is needed. Starters and banding will improve the efficiency of the fertilizer used.

4.2.5 Base saturation (BS %)

Base saturation is calculated as the sum of exchangeable bases divided by the CEC of the soil. In most cases the percentage of a base saturation is greater than 80, which indicates that exchange capacity is saturated by bases, while very rare in the exchangeable capacity is hydrogen and aluminium elements. The base saturation present for all the samples ranges between 53 to 72 percent for top and 69 to 75 percent for sub-soils. The fertility levels corresponding to these base saturation values are rated as high for the command area soils.

4.2.6 Cation exchange capacity (C.E.C)

The C.E.C of the project soil is recorded 53.7 to 66.6 meq/100g on the top soils (i.e., 0 to 32 cm soil depth), and 53.4 to 74.1 meq/100g in the sub soil (i.e., 30-70 soil depth which is found within to very high category. The command area soil is good for agriculture development.

4.2.7 Exchangeable magnesium (Mg⁺⁺)

Laboratory results indicate that exchangeable magnesium was recorded very high values (8.88 to 9.33 on top soil and 7.79 to 14.47%) in sub soils which is rated high to very high values.

4.2.8 Exchangeable calcium (Ca⁺⁺)

The overall content of exchangeable calcium of the command area soils are found 28.15 to 46.49 on top soil and 29.54 to 39.18 meq/100g values on sub soils which is found within range of low category. This shows that it is rated in 'very high' ranges and the status is found to be good with the proportion of the rest cations is applied in the soil.

4.2.9 Exchangeable sodium (Na⁺)

The content of exchangeable sodium of the study area recorded 0.10 to 0.15 on top soil rated as low values and 0.35 to 1.74 meq/100g in sub soils which is found within low to high category.

4.2.10 Exchangeable potassium (K⁺)

The content of exchangeable potassium of the study area recorded 0.84 to 1.85 on top soil and 0.32 to 1.63 meq/100g in sub soil rated as medium to very high category. Hence, response to K fertilizer application is unlikely.

4.3 Evaluation of Laboratory Soil Fertility Test Results

The chemical features of the sampled results are evaluated for both, upper and lower horizons of the selected pits within the command area. The rates are evaluated as very low, low, normal, high and very high as specified in the following Table 4-3.

Table 4-3 Result evaluation based on upper and lower horizons of sample soils

No	Properties	Rates achieved									
		Very low		Low/moderate		Normal to medium		High		Very high	
		H1	H2	H1	H2	H1	H2	H1	H2	H1	H2
1	pH			x	x						
2	E.C	x	x								
3	O.M					x	x				
4	T.N						x	x			
5	Av.P	x	x								
6	C.E.C					x	x				
7	Ex.bas.										
	Mg ⁺⁺							x			x
	Ca ⁺⁺							x	x		
	K ⁺						x	x			
	Na ⁺					x			x		

Therefore, the above table indicated that the trend of increasing or decreasing of the evaluated parameters through the soil profiles. (H1) indicates upper horizon and (H2) indicates the lower soil profile or soil horizons. Thus, as it is shown in the above table, the upper horizons/profiles are good for crop production.

5. DESCRIPTION OF SOIL MAPPING UNITS

Soils are natural bodies on the earth surface and occur on different types of landforms. They are not discrete bodies, but continuous entities, which merge into each other across the terrain. Therefore, soils form an integral part of the SOTER unit. To map and classify the soil units of the command areadivision of the major landforms has been made at 2 units of generalization.

The structure of the division shows their inter-relationships as well as the characteristics by which they differ. On this basis homogenous terrain units are distinguished at each level of generalization. A particular combination of land form and lithology can be then hierarchically further sub-divided and delineated on the basis of soil characteristics. Lithology gives the petrographic nature of hard rock or origin of soft cover formations from which the soils have been developed.

In distinguishing criteria for mapping units balanced approach is set to maintain detailed information, that can be identified as soil mapping units and be mapped with an acceptable degree of accuracy that the project requires. A soil inventory is required before a land classifier can rate land as to its suitability for irrigation. This soil information may be obtained from an existing soil survey map or by performing a soil survey. Soil map units of the command area can be described as follows:

5.1 Soil map unit-1

Observation Number	(Pit-1&3)
Total Area (ha)	53.33
Soil Classification (FAO):	Vertisol
Parent Material:	Piedmont alluvium derived from basic volcanic rocks.
Elevation:	2055/1934masl
Slope:	1-2%
Land use/vegetation:	Fallow, -farmed teff
Climate:	Sub humid warm tropical
Moisture Condition:	Moist throughout
Groundwater Level	None
Runoff:	None
Drainage Class:	Imperfect
Permeability:	Very slow

Internal Drainage:	Very slow
Flooding:	None
Rockiness:	None
Stoniness:	2%
Erosion:	Slight sheet an rill
Surface Cracking:	80 cm deep

Profile Description:

0-30/0-25cm; Very dark gray (10YR3/1)(moist) clay-loam; extremely hard (dry), extremely firm (moist), sticky, and plastic (wet); strong medium and coarse angular blocky structure; many fine tubular pores; 2-5% slightly rounded basalt gravel and stones; many medium and coarse roots; non calcareous; pH=7.4/7.1 and EC=0.2/0.25ds/m.; clear and smooth on:

30-70/25-70cm; Black (2.5Y2/0)(moist) clay; extremely firm (moist), sticky and plastic (wet); strong coarse and very coarse angular blocky structure; few very fine tubular pores; 2-5% slightly rounded basalt gravel and stones; few very fine and fine roots; common moderately developed non intersecting slickenside; non calcareous; pH=7.5/8.3; and EC=0.14/0.3ds/m gradual and wavy on:

70-100/70-104cm; Very dark gray (10YR3/1)(moist) clay-loam; clay firm (moist) ; moderate to strong medium angular blocky structure; few fine tubular pores; 2-54 slightly rounded basalt gravel; no roots; many moderately developed intersecting slickenside; slightly calcareous and few lime mycelia; pH=7.3/8.5 and EC=0.11/0.4ds/m; diffuse and irregular on:

104-200 cm; Very dark grayish brown (10YR3/2-3)(moist) clay; friable (moist); moderate medium angular blocky structure; very few tubular pores; 2-57. Slightly rounded basalt gravel; calcareous and few lime mycelia; pH=8.8 and EC=1.16ds/m.

5.2 Soil map unit 2

Observation Number	pit-2
Total Area (ha)	26.66
Soil Classification (FAO):	Cambisol
Parent Material:	Alluvium derived from basic volcanic rocks.
· Elevation:	2032 m asl
· Slope:	5%
· Land use/vegetation:	Dry-farmed sorghum and maize
· Climate:	Sub humid warm tropical
· Moisture Condition:	Slightly moist throughout
· Groundwater Level	None
· Runoff:	Medium
· Drainage Class:	Mod. well,
· Permeability:	Slow
· Flooding:	None
· Internal Drainage:	Medium
· Rockiness:	None
· Stoniness:	5-10 %
· Erosion:	Moderate sheet and gully formation
· Surface Cracking:	None

Profile Description:

0-32cm; Very dark grayish brown (10YR3/2)(moist) clay and dark grayish brown (10YR4/2)(dry) loam; hard (dry), non-sticky and non-plastic (wet); moderate coarse sub angular blocky and crumb structure, partly massive; many very fine to medium tubular pores; 2-57. slightly rounded basalt gravel; many very fine to medium roots; non calcareous; pH=7.3 and EC=0.3ds/m; ; abrupt and smooth on:

32-70cm; Very dark grayish brown (10YR3/2)(moist) clay-loam friable (moist); moderate coarse sub angular blocky structure; many very fine and fine tubular pores; 2-5% slightly rounded basalt gravel; many very fine roots; non calcareous; pH=7.7 and EC=0.2ds/m; diffuse and smooth on:

70-105cm; Very dark grayish brown (10YR3/2) (moist) loam; friable (moist); moderate medium and coarse sub angular (blocky structure; many very fine and fine tubular pores; 2-5% slightly rounded basalt gravel; few very fine roots; non calcareous; pH=8 and EC=0.2ds/ m; clear and smooth on:

105-200cm, grayish brown (10YR3/2)(moist) moist) loam; friable (moist); moderate medium and coarse sub angular (blocky structure; many very fine and fine tubular pores containing slightly rounded basalt gravel and stones.

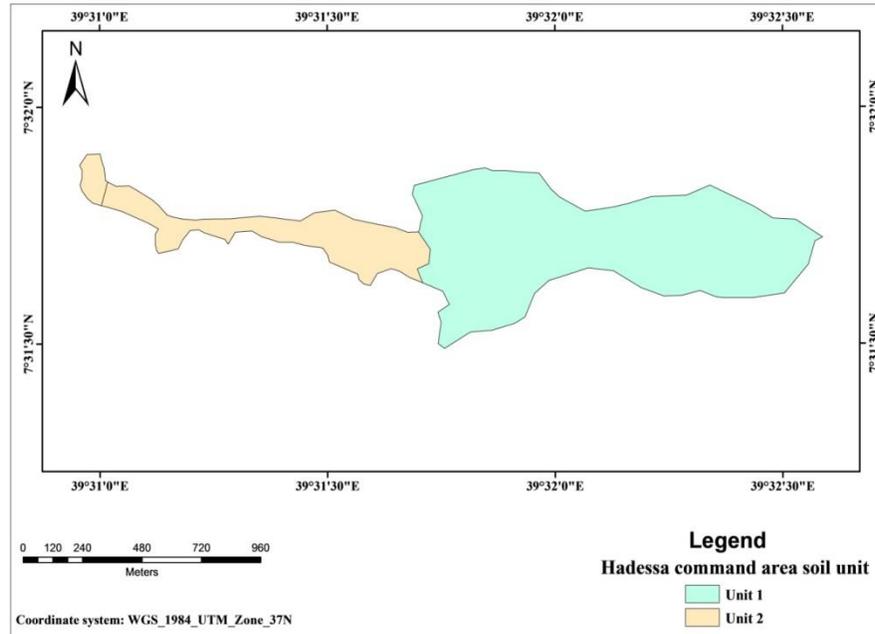


Figure 5-1: Soil map of study area

6. LAND EVALUATION

A fuller use of land and water resources by the development of irrigation facilities could lead to substantial increases in food production in many parts of the world. The process whereby the suitability of land for specific uses such as irrigated agriculture is assessed is called land evaluation. Land evaluation provides information and recommendations for deciding 'Which crops to grow where' and related questions. Land evaluation is the selection of suitable land, and suitable cropping, irrigation and management alternatives that are physically and financially practicable and economically viable. The main product of land evaluation investigations is a land classification that indicates the suitability of various kinds of land for specific land uses, usually depicted on maps with accompanying reports.

The land evaluation study has been conducted based on the FAO Framework for land evaluation scheme. The methodology outlined in the FAO Soil Bulletin No.55, Guideline for Land Evaluation for Irrigated Agriculture (FAO, 1985) and Soil Bulletin No 32, A Framework for Land Evaluation has been followed.

The land suitability of a land unit for irrigated agriculture based on the different Land Utilization Type (LUTs) considered are determined by comparing the land use requirements for surface and/or overhead irrigated agricultural development with the land qualities and/or characteristics (actual environmental conditions) of the land unit. The values of each land quality/characteristic are checked against the class limits of land use requirements for irrigated agricultural development (for each LUTs separately). Thus suitability assessments of the land unit are made for each land use requirements separately.

The overall suitability of the land unit are then determined on the basis of the suitability ratings, referred to as partial suitability of the individual land use requirements for the LUTs under consideration separately. The most commonly used method is to assign the suitability class according to the suitability rating of the most limiting condition. For instance, a land unit, which is moderately suitable (S2m) for the production of the LUTs in terms of moisture availability (m), and marginally suitable (S3r) in terms of soil depth (r), is classified as marginally suitable (S3r).

6.1 Land Suitability Classes

Land A fuller use of land and water resources by the development of irrigation facilities could lead to substantial increases in food production in many parts of the world. The process whereby the suitability of land for specific uses such as irrigated agriculture is assessed is called land evaluation. Land evaluation provides information and recommendations for deciding 'Which crops to grow where' and related questions. Land evaluation is the selection of suitable land, and suitable cropping, irrigation and management alternatives that are physically and financially practicable and economically viable. The main product of land evaluation investigations is a land classification that indicates the suitability of various kinds of land for specific land uses, usually depicted on maps with accompanying reports.

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6.2 Land Suitability Classes

Land suitability is a measure of how well the qualities and/or characteristics of a land unit match with the requirements of a particular form of LUTs. The suitability of the land for specific use has been defined by rating the land qualities of land units, which are relevant to specific land utilization types

The suitability of land for irrigated agriculture has been determined by rating land quality of each soil-mapping unit, which is relevant to the land utilization type. In this way the limitation of each land unit has been identified for the land use under consideration.

The FAO Framework encompasses the following four levels of land suitability classes. At highest level there are two suitability orders, Suitable (S) and Not Suitable (N). **Suitable** land is land on which sustained use of the kind under consideration is expected to yield benefits, which "justify the inputs and development costs, without unacceptable risk of damage to land resources. **Not Suitable** indicates that the land has qualities that appear to preclude sustained use of the kind under consideration. At second level the suitability orders are divided into three classes.

These are: Class S1, Highly Suitable; Class-S2, Moderately Suitable; Class-S3, Marginally Suitable; Class-N1, Marginally Not Suitable; and class N2, Permanently Not Suitable. Table 12 gives the definition and application of these classes.

6.3 Limitations land suitability sub-classes

At third level there are a number of classes which reflect the kind of limitations that restrict the suitability of land for specific land use. Sub-classes reflecting a requirement or limitation are denoted by a letter suffix, these are s, t or d indicating a soil, topographic or drainage deficiency respectively. The sub-class codes are defined specifically for the six LUTs under consideration based on surface and overhead systems of irrigated agricultural development with medium to high input level. Table 12 gives the definitions and applications of these sub-classes.

Table 6-1: Land Suitability Classification Levels

Order	Class	Name	Definition
S		Suitable	The land can support the land use. Benefits justify inputs without unacceptable risk of damage to land resources.
	S1	Highly Suitable	Land without significant limitations. The potential yield level expected is 85% or more of optimum yield.
	S2	Moderately Suitable	Land having limitations that either reduce productivity or increase the inputs needed to sustain productivity levels compared with those needed on S1 land. The potential yield level expected is 60-85% of the optimum yield.
	S3	Marginally suitable	Land with limitations so severe that benefits are seriously reduced and/or the inputs required to sustain productivity are such that this cost is only marginally justified. The potential yield level expected is 40-60% of the unsuitable optimum yield.
N		Unsuitable	Land that cannot support the land use sustainable, or land on which benefits do not justify inputs
	N1	Currently unsuitable	Land with limitations to sustained use that cannot be overcome at currently acceptable cost
	N2	Permanently unsuitable	Land with limitations to sustained use that cannot be overcome

This type of land suitability classification levels represents those used by the FAO but some modifications and updating have been made by different authors based on research results on some definition about yield level, factor ratings, etc based on, however, on FAO system.

Table 6-2 Land Suitability Limitations

Sub-class	Description
C	Climate (Temperature regime): Land units having either very low or very high temperatures below or above the critical temperatures, which may cease the plant growth and may have adverse effect on rate of plant growth, depending on the type of plants and varieties to be grown. Thus adaptable crops should be carefully selected for evaluation.
M	Moisture availability: Land units having soil moisture deficiencies, there is a need for an increased amount and frequency of irrigation and/or selection of draught-resistant crop varieties. Overhead irrigation may be more cost effective.
D	Oxygen availability: Land units having soil drainage deficiencies, ascribed to poor soil drainage that may be due to high ground water table, flooding, slow infiltration, slow permeability, slow surface drainage (low physiographic position) or some combination of these. Sub-soiling, diversion ditches and under drainage may be required. Selection of more tolerant crops like rice can be another solution.
N	Nutrient retention: Land units having poor capacity of soil to retain added nutrients as against loses caused by leaching, ascribed to low CEC, and these by organic matter. Thus, additional input is required to conserve organic matter and improve soil structure and require fertilizer application.
Z	Nutrient availability: Land having poor capacity to supply crop with nutrients, ascribed to pH, nutrient availability is 7.0 to 7.9 which is moderately alkaline by fixation.
R	Rooting condition: Land units with limited effective soil depth (effective depth is a depth to a limiting horizon having high amount of gravels, hard pan or toxic layers) and restrictive root penetration having massive, columnar or coarse sized structure coupled with very firm consistence and high amount of stones or gravels. Land having restrictive effective soil depth and/or penetrability, which impairs germination and hinders mechanical cultivation.
W	Workability: Land units with poor workability, ascribed to massive clays, poor organic matter content, very firm consistence and occurrence of high amount of stones and gravels in the surface layers.
K	Potential for mechanization: Land units having unfavorable slope steepness, rock hindrances, presence of large amount of surface stones and plastic heavy clays, which affects mechanized agricultural operations by any kind of implements.
T	Land preparation and clearance: Land having topographic limitations ascribed to unfavorable slope angel, micro-relief coupled with excess rock out crops and denser vegetation covers, which needs a higher initial land development cost, requiring land leveling (or short channel lengths and drop structures), grading, terracing, clearances of rock hindrances and vegetation clearances
E	Erosion hazard: Land having an increased water erosion risk under irrigation. Conservation practices and surface drainage control are required.

7. CONCLUSION AND RECOMMENDATION

- ❑ The soil of the command area is well drained and has got good moisture retention capacity, moderately deep to very deep effective soil depth which is suitable for most of the crop varieties and fertilizer requirements need to be reworked through research based experiments.
- ❑ The EC and cation and anion value has no indication of inducing salinity and sodicity problem to develop the land for irrigated agriculture. pH of soil is recorded moderately alkaline values and When the pH level is found in between 7 and 8.5 the availability of phosphorous and micronutrients with the exception of Mb. Therefore, phosphorus application rate necessary to correct the deficiencies and banded phosphorus applications are more effective than broadcast applications.
- ❑ A total area of 80 ha is commendable by gravity irrigation within the study area, assuming that a weir will be built at the planned weir site. Out of these 80 ha, a total area of 51 ha is classified as highly suitable (S1) when drainage or slopes are not limiting factors and an area of 9 ha is classified as moderately suitable for irrigation development (**S2**). In total gross command area 20ha are classified as currently unsuitable for irrigation agriculture (N1).
- ❑ A total area of 51ha is classified as highly suitable for irrigation development (S1). This area includes the low lying alluvial lands along the Hadhessa river (land units 1&2). These lands are highly suitable for irrigation development under the assumption that investments will be carried out:
- ❑ Topsoil amelioration and bunding will be carried out wherever necessary. Crops which rate as highly suitable under irrigated conditions are: onion, carrot, potato and cabbage for dry season and barley and wheat are selected for the wet season
- ❑ The land and soils of this unit pose almost no limitations to irrigated agriculture, if the above mentioned land improvements are carried out. Only crops which are sensitive to water stress may suffer limited yield decline.
- ❑ Presently, an area of about 20ha from the gross command area characterized by limiting factors such as topography, steep slope, dissection and erosion. This is judged to be under-utilization of the land. It is recommended to give opportunities to move to grazing activities to land with a lower suitability for irrigation development.

- ❑ A total area of 9 ha is classified as moderately suitable for irrigation development. This area includes part of the higher piedmont slopes (land unit 2). These lands are moderately suitable for irrigation development under the assumption, that wherever necessary' topsoil amelioration will be effectuated and (minor) flood protection works will be constructed.
- ❑ In the present study it is assumed that irrigation water is not a limiting factor, both in a quantitative and a qualitative sense. No barriers seem to exist for the construction of primary irrigation channels. Basic soil infiltration rates, estimated soil perm abilities and available soil water holding capacities are suitable for irrigation development. Furrow irrigation is recommended as irrigation application technique.
- ❑ It is possible that two cropping pattern under irrigation and rain fed agriculture that will be practiced and that adequate crop rotations will be adopted. Fertilizers, pesticides etc. are assumed to be available. The three growing seasons cover the following periods of the Year
 - ❑ From mid February to mid-May - rain fed crops
 - ❑ From June September- irrigation crops
 - ✓ The rainfall distribution is such that in many years supplementary irrigation at the end of growing periods or between two short growing periods will be sufficient to create two growing seasons per year of adequate length.
- ❑ One major land improvement, i.e. the construction of drainage system is assumed to be part of the irrigation and drainage package. Without a drainage system, the land suitability of the best land will be reduced due to the buildup of water logging problems.
- ❑ There is one, possibly overruling, constraint to irrigation development which must be considered carefully. The Hadhesa river is a river which carries a large sediment load during peak flows. The rate at which a weir and other structures would lose efficiency by filling up with sediments is high. Careful study of water shade management plan and application of effective soil and water conservation measures is unquestionable. In the present study the simple (and in the light of the above argumentation possibly realistic) assumption is made, that irrigation water can be commanded from the diversion weir without limitation

- In the command area soil usually stays without cover after the harvest. Plant residue decomposition in soil is critical in replenishing organic matter and enhancing nutrient availability in soil. It contributes enormously in soil regeneration and formation. Crop residues should be left on soil surface to prevent erosion and enhance biomass decomposition on soil to improve soil quality and ensure food quantity.

8. REFERENCES

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Annex 1: Hadessa Soil Laboratory Test Result

	Company Name: OROMIA WATER WORKS DESIGN AND SUPERVISION ENTERPRISE		Doc. No. DSESWL /133 & 138/10
	Doc. Title: Soil Analysis Laboratory Result		Page No.: 4 of 4

Name of Customer : **BBG Engineering PLC**

Project : **Hadessa Small Scale irrigation** Location - **Shirka Woreda, Arsi Zone, Oromia Region**

LAB NO	Field Code	Depth Cm	p ^H -Water 1:2.5	E.C ds/m	M.Content %	Particle Size Distribution			TEXTURAL CLASS
						Sand %	SILT %	CLAY %	
1853 /18	Pit - 1	0-30	7.4	0.200		23	18	59	clay
1854 /18		30-70	7.5	0.147		29	24	47	clay
1855 /18		70-100	7.3	0.113		41	26	33	Clay loam
1856 /18	Pit - 2	0-32	7.3	0.305		27	24	49	clay
1857 /18		32-70	7.7	0.235		31	36	33	Clay loam
1858 /18		70-105	8.0	0.228		41	32	27	Loam
1859 /18		105-200	8.0	0.218		47	32	21	Loam
1860 /18	Pit - 3	0-25	8.1	0.257		41	36	23	Loam
1861 /18		25-70	8.3	0.391		31	26	43	clay
1862 /18		70-104	8.5	0.427		21	20	59	clay
1863 /18		104-200	8.2	0.306		25	22	53	clay

LAB NO	Na	K	Ca	Mg	SUM	CEC	BS	EX. Acidity	Ex. Al ³⁺
Cmol(+)Kg ⁻¹									
1853 /18	0.15	1.80	37.08	9.33	48.36	66.9	72		
1854 /18	0.35	1.50	33.35	8.75	43.95	63.6	69		
1855 /18	0.55	1.70	26.75	7.23	36.24	51.2	71		
1856 /18	0.12	1.85	28.15	8.88	39.01	53.7	73		
1857 /18	0.39	1.63	29.54	7.79	39.35	53.4	74		
1858 /18	1.02	1.81	28.87	6.74	38.43	53.3	72		
1859 /18	0.54	1.75	29.93	8.17	40.39	45.5	89		
1860 /18	0.10	0.84	46.49	8.88	56.31	66.6	85		
1861 /18	1.74	0.32	39.18	14.47	55.71	74.1	75		
1862 /18	3.41	0.48	36.70	15.20	55.79	63.6	88		
1863 /18	3.85	0.76	33.09	12.11	49.82	52.4	95		

LAB NO	T.N	O.C	O.M	C/N	Av.K	Av.P	P ₂ O ₅	F.C	P.W.P
%									
1853 /18	0.12	1.28	2.21	11		0.07	0.16		
1854 /18	0.13	1.54	2.66	12		0.07	0.16		
1855 /18	0.09	0.88	1.52	10		0.03	0.07		
1856 /18	0.11	1.41	2.43	13		0.04	0.09		
1857 /18	0.09	1.07	1.84	12		0.06	0.14		
1858 /18	0.07	0.81	1.40	12		0.01	0.02		
1859 /18	0.07	0.75	1.29	11		0.01	0.02		
1860 /18	0.15	2.04	3.52	14		0.09	0.21		
1861 /18	0.10	1.28	2.21	13		0.07	0.16		
1862 /18	0.11	1.04	1.79	9		0.05	0.11		
1863 /18	0.07	0.67	1.16	10		0.01	0.02		

Remark: _____

Checked By Fikru Asrat Signature [Signature] Date 24/02/18

Approved By Haesen Ahmed Muma Signature [Signature] Date 24/02/18
Laboratory Service Process Manager



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Annex 2: Representative physical properties of soil

Soil Texture	Infiltration 1/and Permeability cm/hpf	Total pore space% N	Apparent specific gravity A_s	Field capacity %FC	Permanent Wilting %PWP	Total Available Moisture		
						Weight% $P_w=FC_PW$	Volume $P_v = P_w A_s$	cm/m $d=P_w/100A_sD$
Sand	5 (2.5-25)	38(32-42)	1.65(1.551.80)	9 (6-12)	4 (2-6)	5 (4-6)	8 (6-10)	8 (6-10)
Sandy-loam	2.5 (1.3-7.6)	43(40-47)	1.50(1.401.60)	14 (10-18)	6 (4-8)	8 (6-10)	12 (9-15)	12 (9-15)
Loam	1.3 (0.8-2.0)	47(43-49)	1.4(1.5-1.50)	22 (18-26)	10 (8-12)	12 (10-14)	17 (14-20)	17 (14-20)
Clay-loam	0.8 (0.25-1.5)	49(47-51)	1.35(1.301.40)	27 (23-31)	13 (11-15)	14 (12-16)	19 (16-22)	19 (16-22)
Silty-clay	0.25 (0.03-0.5)	51(49-53)	1.3(1.10-1.40)	31 (27-35)	15 (13-11)	16 (14-18)	21 (18-23)	21 (18-23)
Clay	0.5 (0.01-1.0)	53(51-55)	1.25(1.201.20)	35 (31-39)	17 (15-19)	18 (16-20)	23 (20-25)	23 (20-25)

Note:- Normal ranges are shown in parentheses.

Source: - Israelson and Hanson (1962), publishers J. Wiley and Sons, New York.