Soil physicochemical properties and their significance for sustainable sugarcane production in Kesem Allaideghe plains irrigation project area, Eastern Ethiopia

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ABSTRACT

A feasibility study was carried out to assess the suitability of Allaideghe plains, located in middle awash valley, for the cultivation of sugarcane plantation. The project area, covering 38000 ha, lies between 9° 07' to 9° 26' N latitude and 40° 30' to 40° 50' E longitude. A detailed soil survey was carried out on 500 m x 500 m grid consisting 1520 auger holes and 76 soil profile observations. The soils of the entire project area were very deep (>200 cm). The textural classes included silty clay loam, clay and heavy clay which revealed that texture varied from fine to very fine with high clay content. Soil reaction (pH), electrical conductivity of saturated extract (ECe), exchangeable sodium percentage (ESP), cation exchange capacity (CEC), organic carbon (OC), $CaCO_3$ ranged between 7.7 to 8.2, 0.9 to 8.0 dS m^{-1}, 9.9 to 42.7%, 40.6 to 61.7 cmol $(_+)$ kg^{-1}, 0.3 to 1.2 g kg^{-1}, and 8.3 to 18.3 %, respectively. Soluble cation contents of Na, Mg, Ca and K varied from 8.5 to 20.2, 0.2 to 2.6, 4.7 to 12.6, and 0.1 to 0.2 meq l^{-1}, respectively. Major hydraulic properties influencing water availability and irrigation scheduling for sugarcane included infiltration rate and hydraulic conductivity. Basic infiltration rate varied from 0.2 to 6.2 cm h^{-1} and in-situ hydraulic conductivity varied from 0.07 to 0.60 m d^{-1}. Low hydraulic conductivity may cause waterlogging in the project area. In order to improve soil structure and water availability, addition of gypsum, plant residues and organic matter are recommended.

Key words: Soil survey, physical and chemical soil properties, infiltration rate, hydraulic conductivity
DOI: http://dx.doi.org/10.4314/ejst.v11i1.2

INTRODUCTION

Ethiopia has 12 river basins with an annual runoff volume of 122 billion m^3 of water and an estimated 2.6-6.5 billion m^3 of groundwater potential, which makes an average of 1575 m^3 of physically available water per person $year^{-1}$ (Seleshi Bekele *et al.,* 2007). However, the total irrigated area is only about 250,000 ha (Seleshi Bekele *et al.,* 2005). The expansion of irrigated agriculture for achieving food self sufficiency is currently the most promising option (Mekuria Tafesse, 2003; Dessale Kidane *et al.,* 2014; Gebremedhin Gebrehawarya, 2015). The study was conducted in one of the basins of Awash River that starts in the central highlands of Ethiopia and ends at Lake Abe in Afar Region.

The Food and Agriculture Organization of the United Nations (1965) surveyed the Awash River Basin as a whole on reconnaissance scale and classified the soils as marginally irrigable land. Halcrow (1989) also reported that soils of the Awash Basin are classified as fine textured and concluded that there are good prospects for irrigation of Awash River Basin. The latter study was also carried out on limited scale. The above studies indicated the potential to utilize Awash

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plains for commercial cultivation. However, there is paucity of data on detailed scale. In order to classify the soils for their suitability for sugarcane cultivation in Allaideghe plains, a detailed soil survey on 1:50,000 scale was carried out studying 1520 augur holes and 76 soil profiles, with detailed analysis in the laboratory.

Climatically, the Allaideghe plain is well suited for cultivating sugarcane. The upper Awash valley already has two sugarcane plantations at Wonji Shoa and Metehara. Tendaho, located at downstream, has also started sugar production. The middle Awash valley where these plains are located is still unexploited for commercial cultivation. The government of Ethiopia, keeping in view the infrastructure that has already been developed in surrounding areas for sugarcane plantation, is planning to establish a sugar factory at Kesem Allaideghe plain area too. In order to become self-sufficient in sugar production and to be able to export as well, there is immediate need to expand sugar production in the country.

Thus, the principal objective of investigating the soils of Allaideghe plains located in the middle Awash Valley was to assess the possibility of introducing sugarcane plantation. The study area, in general, can be characterized by its almost homogenous topography. The plain is predominantly flat. Presently, this area is subjected to intensive grazing throughout the year, especially, during the dry seasons when grass cover is scanty. The water requirement to irrigate Allaideghe plain is intended to be met by abstracting water mainly from Kesem River and supplementing from Awash River. Frequent dry spells and droughts exacerbate the incidence of crop failure and hence food insecurity and poverty. To meet the ever increasing demand for food, sugar, fiber and other agricultural products, there is a need for increasing the land area under production and for intensifying agricultural productivity mainly through expanding new irrigation schemes. The sugarcane plantation will be utilized as input for the new sugar factories to be established in middle Awash plains by the Ethiopian Sugar Corporation (WIC, 2012).

In view of the above premises, the present feasibility study was carried out at middle Awash. The study was intensive and multidisciplinary covering wide ranges of natural and socio-economic issues of the project area. In this paper, it is attempted to briefly present characteristics of soils of Kesem Allaideghe plains with respect to its potentiality for sugarcane cultivation.

MATERIALS AND METHODS

Description of the Study Area

The project area is located at the right bank of Awash River in the middle of Awash basin in Afar National Regional State, between 9^{o} 07’ to 9^{o} 26’ N latitude and 40^{o}30’ to 40^{o}50’ E longitude and bordered by the main road from Awash Arba to Tendaho (Figure 1). The area is subjected to intensive grazing and comprised of old alluvium and colluvium deposits. The slope of the command area is gentle ranging from 0.01 to 0.05 m km^{-1}; i.e., almost flat topography. The maximum and minimum mean monthly temperatures of the project area are 38^{o}C in June and about 15^{o}C in December. The annual pan evaporation rate is 2400 mm (NMA, 2005). The land use of the entire area is virgin grazing land which has never been cultivated.

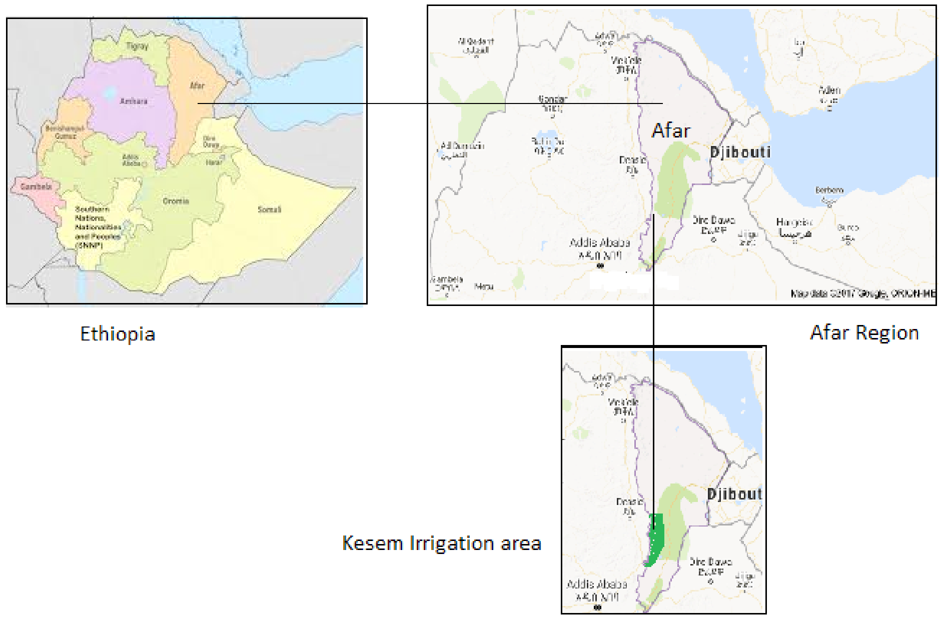

Figure 1. Location map of the study area

Field Investigations

In order to characterize the project area with respect to physicochemical and hydro-dynamic soil properties, a detailed soil survey (FAO, 1979; FAO, 1985; Landon, 1991) on 500m x 500m grid was carried out. Prior to field investigation, land satellite images (EMA, 2005) on 1:50000 scale were collected and interpreted. Topographical maps at a scale of 1:50,000 depicting slopes and other relevant features were also studied. Auger-hole studies were made to distinguish soil variation in lateral directions using a grid of 500m x 500m; i.e. one auger-hole observation for every 25 ha area with a total number of 1520 auger holes covering 38,000 ha area.

Each auger-hole observation point was recorded by hand-held GPS. The salient soil characteristics including horizon-wise color using Munsell color chart, texture, consistence, structure (feel method), presence of $CaCO_3$ through HCl reaction; EC (1:2.5) and pH (1:2.5) soil-water using portable digital EC and pH meter, respectively, were observed at each auger-hole site.

In order to characterize the soil, particularly for irrigation purpose, soil profile pits were excavated to a depth of 2 m with 1 m width and 2 m length. The number of soil profile pits observations at representative sites covering entire command area were 76 (one profile per 500 ha of area). The chemical analysis using standard techniques was carried out for pertinent soil properties in soil laboratories of the Ministry of Water Resources, Addis Ababa, and of Wonji Sugar Factory. The major physical and chemical properties analysis of model profiles included dominant textural classes, soil reaction (pH), ECe, ESP, CEC, organic carbon, soluble cations and $CaCO_3$.

Infiltration Rate

The infiltration rate is exceedingly important for selection of suitable irrigation methods, design of irrigation system and water management techniques. In the present study, infiltration rate was measured in situ using double ring infiltrometer at 28 representative sites each in triplicate. The UTM coordinates, north and east for each location, was recorded using hand-held GPS. The infiltration rates were computed for three quantities as cumulative intake (cm), average infiltration rate (cm h^{-1}) and basic infiltration rate (cm h^{-1}).

In-situ Hydraulic Conductivity

In the absence of groundwater table, inverse auger-hole method (Kessler and Oosterbaan, 1974) was used to determine hydraulic conductivity in field at twenty one representative locations replicated three times for active rooting zone depth of 1m. The procedure in brief included: drilling of hole of 8 cm diameter using post-hole auger to a depth of 1 meter. Care was taken to drill the hole as straight as possible. The hole was saturated over night. Water was poured in wetted hole and about 2/3 of depth of hole was filled with water. The rate of falling of water in hole was measured using a specially designed water level indicator assembly consisting of two electrode terminals, flexible wire, and an attached multimeter. The readings of fall of water level against time were recorded till steady state rate was achieved. Generally, the last three consecutive readings showed stable rate. Hydraulic conductivity (k) was computed using following relation:

$k=1.15r \tan \alpha$, cm sec^{-1} (Kessler and Oosterbaan, 1974)

where k = hydraulic conductivity, cm sec^{-1}

r = radius of hole i .e 4 cm

α =slope of straight line by plotting water falling depth against time on a semi-logarithmic paper.

The units of hydraulic conductivity were changed to m d^{-1} by multiplying with a suitable factor. UTM reading was recorded for each location of hydraulic conductivity test in the field.

Laboratory Studies

For mechanical and chemical analysis, the soil samples were dried, ground and passed through a 2 mm standard sieve. Mechanical analysis (particle size distribution) was carried out by the modified hydrometer method (Sahlemedihin Sertsu and Taye Bekele, 2000). Soil pH and electrical conductivity (EC) of saturated paste extract were determined by pH and EC meter, respectively (Schoffied and Taylor, 1955); organic carbon by wet digestion method (Nelson and Sommers (1982); cation exchange capacity using ammonium saturation method; exchangeable sodium percentage (ESP) using analytical procedure as described in diagnosis and improvement of saline and alkali soils (Richards, 1969; FAO, 1988).

RESULTS AND DISCUSSION

Infiltration Rate

Infiltration is one of the most important parameters which is considered in designing the optimum stream-size of furrow irrigation for sugarcane crop. In order to characterize the intake behavior of project lands, infiltration was measured in triplicates at twenty eight representative locations using double ring infiltrometer. Infiltration characteristics are expressed in three quantities as cumulative infiltration, average infiltration rate and basic infiltration rate (Table 1). The cumulative and average infiltration rates plotted on log-log scale are expressed by equations as $Y_{cum} = ax^n$ and $Y_{ave} = ax^{-n}$, respectively. The basic infiltration rate is a stable rate arrived after 4 to 5 hours, the wetting front reaching a depth of 35 to 50 cm. Thus, infiltration rate has practical significance in recharging soil root zone depth. The basic infiltration rate of soils of the project area generally varied from 0.2 to 6.2 cm h^{-1}, i.e. slow to moderate (Landon, 1991). This could be due to high clay content and relatively high organic matter attributed to the no tillage operations, which restricted the oxidation of organic matter. Similar results for fine-textured soils of Rift Valley were also reported by Tadele Amdemariam *et al*. (2011).

Table1: Infiltration Characteristics (respective average of three replicates) at representative sites of project area

Site no.	UTM coordinate of site		Cumulative infiltration rate (cm)	Average infiltrate rate (cm h^{-1})	Basic infiltration rate (cm h^{-1})	Suitability class
	North	East				
1	1014637	0628146	$Y=0.187X^{0.460}$	$Y=3.850X^{-0.311}$	0.7	Moderately slow
2	1012000	0633000	$Y=0.226X^{0.772}$	$Y=15.986X^{-0.228}$	4.6	Moderate
3	1011500	0632000	$Y=0.194X^{0.776}$	$Y=11.620X^{-0.224}$	3.3	Moderate
4	1015000	0634500	$Y=0.097X^{0.495}$	$Y=5.793X^{-0.505}$	0.4	Slow
5	1017500	0635000	$Y=0.109X^{0.529}$	$Y=6.569X^{-0.471}$	0.4	Slow
6	1019500	0635090	$Y=0.473X^{0.641}$	$Y=28.404X^{-0.359}$	3.4	Moderate
7	1024750	0636752	$Y=0.227X^{0.802}$	$Y=14.158X^{-0.148}$	6.2	Moderate
8	1021250	0637250	$Y=0.327X^{0.773}$	$Y=19.634X^{-0.227}$	5.8	Moderate
9	1027750	0639250	$Y=0.040X^{0.572}$	$Y=2.401X^{-0.428}$	0.2	Slow
10	1019250	0638250	$Y=0.108X^{0.930}$	$Y=6.466X^{-0.070}$	4.1	Moderate
11	1017850	0639250	$Y=0.343X^{0.754}$	$Y=20.589X^{-0.246}$	4.8	Moderate
12	1019400	0639785	$Y=0.751X^{0.481}$	$Y=45.052X^{-0.519}$	2.6	Moderate
13	1018750	0637250	$Y=0.116X^{0.850}$	$Y=6.970X^{-0.150}$	2.9	Moderate
14	1015280	0637740	$Y=0.433X^{0.670}$	$Y=25.983X^{-0.330}$	3.8	Moderate
15	1016282	0647295	$Y=0.205X^{0.741}$	$Y=12.303X^{-0.260}$	3.0	Moderate
16	1015687	0643169	$Y=0.456X^{0.670}$	$Y=27.379X^{-0.330}$	4.2	Moderate
17	1020750	0647250	$Y=0.126X^{0.828}$	$Y=7.592X^{-0.172}$	2.7	Moderate
18	1023261	0646763	$Y=0.592X^{0.504}$	$Y=35.526X^{-0.496}$	2.1	Moderate
19	1021246	0642769	$Y=0.438X^{0.686}$	$Y=26.269X^{-0.314}$	4.3	Moderate
20	1035250	0648750	$Y=0.405X^{0.645}$	$Y=24.334X^{-0.355}$	3.0	Moderate
21	1033750	0652250	$Y=0.271X^{0.764}$	$Y=16.253X^{-0.236}$	4.2	Moderate
22	1030750	0645750	$Y=1.045X^{0.348}$	$Y=62.687X^{-0.652}$	1.5	Moderately slow
23	1036750	0641771	$Y=0.299X^{0.749}$	$Y=17.972X^{-0.251}$	4.4	Moderate
24	1038250	0650750	$Y=0.499X^{0.641}$	$Y=29.981X^{-0.359}$	3.9	Moderate
25	1032250	0647750	$Y=0.549X^{0.627}$	$Y=32.937X^{-0.373}$	4.0	Moderate
26	1018750	0644250	$Y=0.240X^{0.623}$	$Y=14.396X^{-0.376}$	1.7	Moderately slow
27	1028750	0643750	$Y=0.611X^{0.477}$	$Y=36.682X^{-0.523}$	1.7	Moderately slow
28	1021680	0635257	$Y=0.219X^{0.731}$	$Y=13.158X^{-0.269}$	3.4	Moderate

Hydraulic Conductivity

Results of hydraulic conductivity tests conducted at representative locations in the project are presented in Table 2. Hydraulic conductivity varied from 0.07 to 0.6 m d^{-1}; i.e. slow to moderately slow for very fine and fine textured soils based on the ratings of Landon (1991). The low value of hydraulic conductivity is attributed to high ESP which causes dispersion of soil particles reducing considerably the size of the pore spaces and thus increasing flow path tortuosity in the soil. Abayneh Esayas (2001) reported that high Na^+ and residual sodium carbonate (RSC) causing high ESP in some parts of the Rift Valley. It is further mentioned that sodic soils have low hydraulic conductivity indicating risk of water logging and very low water transmission to roots from the soil. Soils having larger quantity of fine clays generally have lower hydraulic conductivity (Kenney *et al.*, 1992; Benson *et al.*, 1994; Benson and Trast, 1995). Owing to the low hydraulic conductivity, soils are less permeable, and such soils are thus classified as poorly to imperfectly drained. This is one of the most important parameters, which downgrades the suitability of these soils for irrigated sugarcane cultivation.

Table 2: Results of hydraulic inductivity tests (respective average of three replicates) conducted at representative locations in the project area.

Sr. No	UTM coordinates of test location		Hydraulic conductivity (m d^{-1})	Conductivity classes
	North	East		
1	1021246	0642769	0.18	Slow
2	1038250	0650750	0.12	Slow
3	1030750	0645750	0.21	Slow
4	1035250	0648750	0.17	Slow
5	1033758	0652234	0.21	Slow
6	1023250	0646750	0.42	Moderately slow
7	1020750	0647250	0.30	Moderately slow
8	1015650	0643169	0.60	Moderately slow
9	1016282	0647295	0.38	Moderately slow
10	1032250	0637750	0.07	Slow
11	1014637	0628146	0.25	Slow
12	1012000	0633000	0.28	Slow
13	1015000	0634500	0.07	Slow
14	1017500	0635000	0.13	Slow
15	1019500	0635090	0.23	Slow
16	1021250	0637250	0.27	Slow
17	1021680	0635257	0.07	Slow
18	1019400	0639785	0.19	Slow
19	1018750	0637250	0.09	Slow
20	1015280	0637740	0.29	Slow
21	1028750	0643764	0.12	Slow

Soil Physico-Chemical Properties

Pertinent physico-chemical properties of soils of the project area are presented in Table 3. In the study area, soil texture varied from fine to very fine with high clay content. Three dominant textural classes were observed as silty clay loam, clay and heavy clay. Invariably, the pH value of the project lands are generally high ranging from 7.7 to 8.2 and with minimum variation. Similar soil reaction values were also reported by Eylachew Zewdie (2004) for soils of the Rift Valley.

In most of the soils of the study area, ECe and ESP indicate the occurrence of higher level of sodicity as they ranged between 0.9 to 8.0 dS m^{-1} and 9.9 to 42.7%, respectively. Results indicated that ESP values above 15% cover large area of the project that revealed the occurrence of high sodicity in soil. As a matter of fact sugarcane is not tolerant to sodicity where there is considerable risk of yield reduction and crop cultivation is not commercially viable. In addition to the effect of the salt on yield, soils having high sodicity have poor soil structure that affect crop performance (Mass and Gratton, 1999; FAO-UNESCO, 1973; FAO, 1979a). Such soils that are developed on ancient alluvium and colluvium remain virgin without cultivation and soil manipulation. As a result, there is no appreciable change in the salt, water and nutrient dynamics. Consequently, ESP remains high. Hailay Tsige *et al*. (2000) and Abayneh Esayas (2001) found similar results for soils of Awash valley. It is worth mentioning that the project lands have high clay content coupled with sodicity and that rooting system of grass and other vegetation is restricted to upper soil layer. Hence, roots in the subsoil are unable to survive due to these problems and lack of appreciable water movement/availability.

Table 3: Major physicochemical properties of soils of the project area

UTM coordinates of model soil profile sites		Dominant textural class	pHe	ECe (dS m^{-1})	ESP (%)	CEC (Cmol (+) kg^{-1})	Soluble cations (meq l^{-1})				Organic carbon (g kg^{-1})	$CaCO_3$ (%)
North	East						Na	Mg	Ca	K		
1012100	0628303	C	7.9	6.9	9.9	45.9	8.5	1.2	7.6	0.2	0.9	13.1
1015550	0632371	C	7.7	4.8	14.0	42.2	10.0	1.1	6.3	0.1	0.5	10.5
1015280	0637450	HC	7.9	3.8	14.5	50.6	12.7	1.3	10.1	0.1	0.7	15.5
1011965	0633991	SiCL	8.0	4.3	17.3	50.9	11.7	1.6	11.4	0.1	1.0	12.8
1019403	0639785	C	7.9	6.7	19.2	40.6	11.1	1.1	7.7	0.1	0.6	8.3
1027756	0639247	C	8.2	4.9	42.7	49.8	10.2	0.5	4.7	0.1	0.5	11.7
1021250	0637250	HC	8.0	5.4	23.2	47.3	13.0	1.3	9.0	0.1	0.7	9.7
1021066	0633957	C	8.0	4.7	28.1	51.8	13.5	1.5	11.4	0.1	1.2	14.1
1017210	0645215	HC	8.0	6.9	27.7	51.4	13.5	0.2	7.9	0.1	0.7	16.0
1016282	0647295	CL	8.2	1.2	22.2	45.4	13.2	0.6	5.2	0.2	0.9	-
1038780	0648805	C	8.0	0.9	14.1	54.9	15.5	1.4	10.8	0.1	0.7	10.8
1025668	0642350	HC	7.8	4.8	13.7	45.0	12.5	0.7	7.6	0.1	0.6	-
1026702	0647641	Si	7.8	5.0	16.9	43.3	10.2	2.6	6.0	0.1	0.5	13.1
1023250	0646750	C	7.9	6.2	19.7	47.9	16.2	2.6	7.9	0.1	0.7	18.1
1032250	0647750	CL	8.0	7.6	25.9	42.6	11.3	1.4	6.4	0.2	0.3	14.3
1035250	0645250	HC	8.1	8.0	27.2	49.5	20.2	2.3	12.6	0.1	0.7	18.3
1037255	0648748	HC	8.0	6.6	22.3	61.7	19.5	1.3	6.5	0.1	0.7	14.8
1038250	0650750	HC	8.0	7.6	26.5	41.8	10.9	1.0	6.8	0.1	0.6	11.0
1030600	0645400	HC	8.1	5.3	20.8	54.1	13.20	1.1	4.7	0.1	0.7	15.5

Note: HC-heavy clay; C-clay; SiCL-silty clay loam; CL- Clay loom; Si- Silt

The soils of the project area also have high CEC with minimum variation ranging from 40.6 to 61.7 $Cmol_c$ kg^{-1}. High CEC values ranging from 22.0 to 33.6 $Cmol_c$ kg^{-1} were also reported for Andisols of the study area (Eylachew Zewdie, 2004). Soluble cations of Na, Mg, Ca and K varied from 2.5 to 20.2, 0.2 to 2.6, 4.7 to 12.6 and 0.1 to 0.2 meq l^{-1}, respectively. The variations in carbon contents are also minimum (0.30 to 1.2 g kg^{-1}) throughout the project area. This indicates that the area is not under cultivation attributing to minimum variability. The soils are generally calcareous in nature which ranges from 8.3 to 18.3 per cent.

CONCLUSIONS

From the results of the study it is concluded that soils of the project area are very deep, fine textured with restricted drainage, and dispersed with occurrence of sodicity causing increased possibility of prolonged water logging upon introduction of irrigation. Low hydraulic conductivity may restrict the water availability to plant roots for sugarcane crop. There is a possible risk of considerable yield reduction which may affect the project's economic viability. In view of this, it is suggested that these soils be reclaimed before introducing cultivation. Low nutrient availability can be improved by green manuring and by applying organic as well as chemical fertilizers that are recommended for sugarcane production. To improve soil structure and hydraulic conductivity and to facilitate water availability to roots, ploughing back of crop residues as sugarcane leaves and stubbles, frequent green manuring, growing leguminous crops and adding sufficient organic manure are recommended. As some soils exhibit sodicity problems, addition of suitable amount of gypsum and appropriate leaching are also recommended for sustainable sugarcane production.

ACKNOWLEDGEMENTS

Authors are extremely grateful to the Federal Democratic Republic of Ethiopia Ministry of Water Resources for providing the funds and facilitating this study. The present study was part of consultancy services conducted by Water and Power Consultancy Services (India) Ltd in association with Water Works Design and Supervision Enterprise, Ethiopia.

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