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Irrigation suitability evaluation of Zamra irrigation scheme, Abergelle District of Wag-Himra Zone, Amhara Region Ethiopia

Workat Sebnie^{1*} , Enyew Adgo² and Hailu Kendie³

Abstract

Background: Assessment of suitable lands for irrigation is indispensable to plan and implement different programs in a cost-effective approach for sustainable land use planning and efficient utilization of the land. Hence selecting proper land use based on land suitability evaluation will enhance the productivity per unit area and ensures the sustainable use of land resources. Therefore, the research was designed to evaluate the suitability of the soil properties of Zamra irrigation scheme for irrigation purposes.

Method: For this study about 195.16 ha of land were evaluated for irrigation suitability. Four soil profile pits were opened in the representative site of the scheme based on slope, texture, soil color and soil depth. Soil samples were collected from the soil mapping units for analysis of texture, electrical conductivity, and calcium carbonate content, whereas slope, drainage and soil depth were directly measured at the field. The evaluation was carried out using a parametric evaluation method.

Results: The results of the study revealed that four types of soils were identified namely, Rhodic Nitisol (eutric), Haplic Regosol (eutric) Eutric Regosol, Leptic Regosol (eutric, loamic), and Vertic Cambisol (Hypereutric). The soil texture consists of sandy loam and sandy clay loam at the surface and subsurface soil and the soil depth of study area varied from shallow to very deep. The soil of the scheme was free from salinity and the status of calcium carbonate was at a low level. The slope of the study area was ranged from flat (0–3%) to slopping (8–15%). Generally, 80.64 ha (41.32%) of the scheme was moderately suitable whereas 71.68 ha (36.73%) of the land was marginally suitable for irrigation. Due to major limiting factors of soil depth and slope about 42.84 ha of the land (21.95%) were not currently suitable for irrigation.

Conclusion: In the study area, the major limitations were slope and soil depth. Therefore, to increase production and productivity of the scheme, land improvement operations are suggested.

Keywords: Suitability, Irrigation, Capability index, Soil type, Scheme

Introduction

Food security and stability in the world greatly depends on the management of natural resources. Due to the depletion of water resources and an increase in population, the extent of irrigated area per capita is declining

(Hargreaves and Mekley 1998). However, nearly 40% of the world's agricultural production comes from irrigated lands (Albaji et al. 2008). To meet food requirements by 2020, Mudima (2002) estimated that food production from irrigated areas will need to increase from 35% in 1995 to 45% in 2020. It has been proposed as a key solution to address the adverse impacts of rainfall, shortfalls, and variability.

Irrigation in Africa has the potential to boost agricultural productivity by at least 50 percent; food production

*Correspondence: workat85@gmail.com

¹ Sekota Dry-Land Agricultural Research Center, P.O. Box 62, Sekota, Ethiopia

Full list of author information is available at the end of the article

on the continent is almost entirely rain-fed (AGRA 2019). Irrigated agriculture is a priority of the agricultural transformation and food security strategy of the Ethiopian Government. Increased availability of irrigation and less dependency on rain-fed agriculture is taken as a means to increase food production and self-sufficiency of the rapidly increasing population of the country (Loiskandl et al. 2008). It is a reliable method of increasing agricultural production and productivity and has greater impacts on solving food security problems in many parts of the country. Realizing its importance for food production, the country has been allocating huge investments for irrigation infrastructure development over the last two decades (Abate 1994).

In Amhara region irrigated agriculture is expanding since recent years. Currently, more than 6,200 small scale irrigation schemes of which 95% are traditional to exist in the region (Melisew 2012). Interestingly, the irrigation schemes are owned by more than 330,000 households or more than 1.9 million people with an average irrigated land holding of 0.2 ha (Melisew 2012). Furthermore, several new and modern irrigation schemes are under development which will increase the significance of irrigation agriculture in the region. From the new and modern irrigation schemes' constructed in the region Zamra irrigation scheme is the one which is found in Abergelle district of Wag-himra zone. These constructed irrigation schemes' especially in the study area are done without irrigation suitability assessment.

Land suitability assessment plays an important role in maintaining and developing land use on a spatial basis (Diallo et al. 2016; Ahmed 2016). However, the evaluation of irrigation suitability for new as well as the existing irrigation schemes is very important. But, in the study area, such studies are not studied. Therefore, the objective of this study was to evaluate the suitability of Zamra irrigation command area soils for irrigation agriculture.

Materials and methods

Description of the study area

The study area Zamra irrigation scheme is located in Abergelle Woreda, Wag-Himra Zone of Amhara Region Ethiopia (Fig. 1). The size of the area is 196.16 ha and the scheme is located 13°01'37.50" latitude and 38°58'36.50" longitude with an altitude of 1270 meter above sea level (m.a.s.l). Zamra river is the major source of irrigation water for the scheme and the river flows throughout the year.

The mean annual rainfall of the study area is 622.37 mm which is an erratic and unevenly distributed over seasons and years (Fig. 2). While the mean minimum and maximum annual air temperatures of the area are 19.19 and 36.08 °C respectively with the mean annual

air temperature of 24.54 °C (<http://gismap.ciat.cgiar.org/MarkSimGCM/#tabs-2>). The farming system is a mixed crop–livestock system in which the livelihood of the people relies on agriculture. Cattle, sheep and goats (Abergelle breed) are the most important livestock reared in the area. The major crops cultivated in the districts are cereals such as sorghum (*Sorghum bicolor*), Pearl millet (*Pennisetum glaucum*), sesame (*Sesamum indicum* L.), teff (*Eragrostis tef*), Wheat (*Triticumae stivum* L.) and Cowpea, and Horticultural crops such as Mango (*Manifera Indica* L), Banana (*Mussa Spp*), Citrus fruits, pepper (*Capsicum Species*), Tomato (*Solanum Lycopersicum* L.), and onion (*Alluim cepa* L.).

Land suitability evaluation procedure for irrigation

Four soil mapping units were identified based on surface soil color, slope, texture (by feel method) and soil depth and delineated using ArcGIS 9.1.2 (Fig. 3). Four soil profiles were dug in the representative sites as shown (Fig. 4) of the scheme and described according to FAO (2006) guidelines. The effective soil depth, drainage, and slope were measured directly at the field. The physico-chemical property of the soil were analysed in laboratory following the laboratory procedure. The irrigation suitability evaluation was done based on topography (slope) and soil characteristics (soil texture, depth, salinity, drainage and calcium carbonate content) factors. Parametric evaluation system was used to evaluate the land suitability for irrigation using Sys et al. (1991) guideline. The method is based on topography and soil characteristics which are an important environmental factors that influence the irrigation suitability. In this method, the land is evaluated according to numerical indexes (Table 1). This approach allows calculating the suitability index for irrigation considering the factors that influence the soil suitability. Six parameters such as soil texture, soil depth, calcium carbonates status, electrical conductivity of soil solution, drainage properties, and slope were considered. The capability index for irrigation (Ci) was developed as shown in the equation below:

$$Ci = A \times \frac{B}{100} \times \frac{C}{100} \times \frac{D}{100} \times \frac{E}{100} \times \frac{F}{100}$$

where Ci: Capability index for irrigation, A: rating of soil texture, B: the rating of soil depth, C: the rating of CaCO₃ status, D: electrical conductivity rating, E: drainage rating, and F: slope rating. After laboratory analysis and directly measured the value at the field for each land mapping unit, the parameters were rated by using Sys et al. (1991) rating as per the related tables. Irrigation suitability maps of the study area were produced depending on the rating values (Fig. 4).

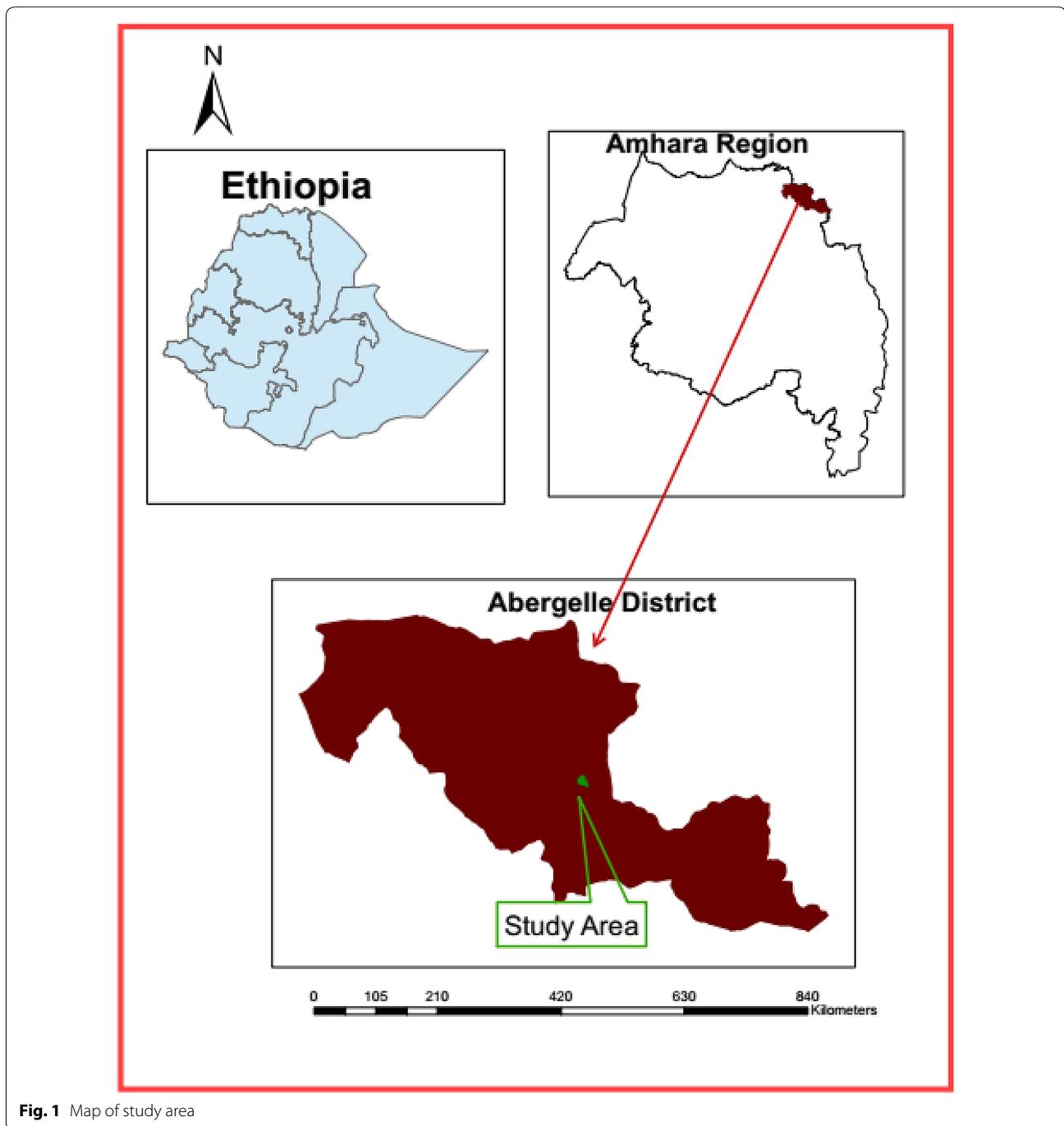


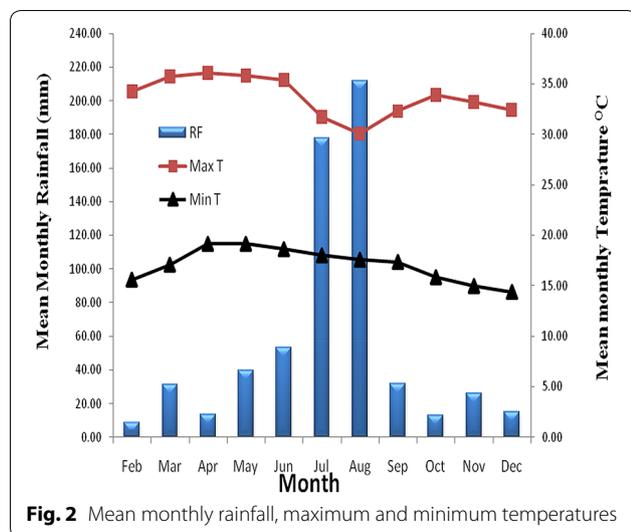
Fig. 1 Map of study area

A procedure used for irrigation suitability map.

Soil sample preparation and Soil analysis

The collected soil samples were first air-dried, grounded and passed through 2 mm sieve to undertake the physical and chemical analysis. The particle size distribution of the soils was analyzed by the Bouyoucos

hydrometer method (Day 1965). The electrical conductivity was measured by conductivity meter in the soil-water extract (Okalebo et al. 2002). Calcium carbonate content was determined following the acid neutralization method in which the soil carbonate was decomposed by excess standard HCl solution and back titrated with standard NaOH after filtering it (Jackson 1970).



Result and discussion

Land and soil characteristics of the scheme

The result of the study areas (Table 2) showed that the soil depths varied from 39 to 178 cm. Except for soil mapping unit 4 Leptic Regosol (eutric, loamic) which is 39 cm depth, and the other soil mapping units had deep soil > 100 cm which is good for root growth of the crops. Thus, all soil mapping units except SMU4 Leptic Regosol (eutric, loamic) (the soil depth were rated as 100% for irrigation suitability. The effective depth of mapping units 1 Rehodic Nitisol (eutric) and SMU2 Vertic Cambisol (Hypereutric) were > 150 cm which represents very deep soil whereas mapping unit 3 Haplic Regosol (eutric) had deep soil which ranged from 100 to 150 cm. Deep soils are very important to anchor plants nutrient, provide an adequate condition for water, air movement, and growth of roots. Soil depth determines the potential of rooting depth and affects agricultural production.

The textural class of the mapping units of the soil was ranged from sandy clay loam to sandy loam. Soil mapping units 1 Rehodic Nitisol (eutric) and SMU2 Vertic Cambisol (Hypereutric) had a surface textural class of sandy clay loam whereas soil mapping units 3 Haplic Regosol (eutric) & 4 Leptic Regosol (eutric, loamic) had sandy loam textural class. Soil mapping units 1 Rehodic Nitisol (eutric) and SMU2 Vertic Cambisol (Hypereutric) were rated as 95% suitable whereas land mapping units 3 and 4 as 75% suitable for irrigation (Table 2). The slope of a given area plays an important role in agricultural production and productivity. The slope of the study area ranged from flat (0–3%) to sloping (8–15%). The soil mapping unit 2 Vertic Cambisol (Hypereutric) had a flat (0–3%) slope which is suitable for agriculture production whereas soil mapping unit 1 Rehodic Nitisol

(eutric) (3–5%) and soil mapping unit 3 Haplic Regosol (eutric) (5–8%) where the indicated slope is less suitable for agriculture than mapping unit 2 Vertic Cambisol (Hypereutric). According to Sys et al. (1991) landscapes with 1–3% slope are rated 95% suitable, 3–5% slope as 90% suitable, 5–8% rated 80% suitable, and 8–16% slope rated as 70% suitable for none terraced slopes. According to Sys et al. (1991), soil drainage of a specified area can be divided into five classes. These are well-drained, moderately drained, imperfectly drained, poorly drained and very poorly drained. The study area soils had a well-drained and moderately drain in all mapping units. Soil mapping units 1 Rehodic Nitisol (eutric) and SMU2 Vertic Cambisol (Hypereutric) were moderately drained whereas soil mapping units 3 Haplic Regosol (eutric) and SMU4 Leptic Regosol (eutric, loamic) were well drained and rated for irrigation as 90% and 95% suitable, respectively. The calcium carbonate status influences the soil–water relationship of the soil and its available nutrient for plant growth (Sys et al. 1991). The calcium carbonate content of the soil in the study site ranges from 0.3–10% which had an irrigation rating value of 95%. The salt content of the soil was considered as suitable for irrigation and rated 100 for all mapping units.

Land suitability evaluation of the irrigation scheme

The result revealed that soil mapping unit 1 Rehodic Nitisol (eutric) and Vertic Cambisol (Hypereutric) soil mapping unit 2 had above 60% of capability index which is moderately suitable (S2), whereas soil mapping unit 3 Haplic Regosol (eutric) was slightly suitability (S3) with 47.38% of capability index and soil mapping unit 4 Leptic Regosol (eutric, loamic) had 32.49% capability index which is currently not suitable (N1) for irrigation (Table 3). As shown in Table 3, there is no an area classified as highly suitable (S1) or permanently non-suitable for irrigation (N2) (Fig. 5).

The largest area of the scheme (80.64 ha) is considered as being moderately suitable land for irrigation due to the limitation of a moderate slope, texture, and drainage. Soil texture affects permeability, water holding capacity, and infiltration of soil. There was no any permanently non-suitable land for irrigation in the study area. The largest portion of the scheme were moderately suitable for irrigation this might be due to the moderate slope, texture, and drainage limitations. The current study is similar with Sulieman et al. (2015) who reported that the largest area of their study was found moderately suitable for irrigation due to limitation of texture and drainage. Similarly Kebede and Ademe (2016) reported that the largest portion of the land was moderately suitable for surface irrigation due to slope factor. The marginally suitable land was covered by about 71.68 ha which was due to limiting

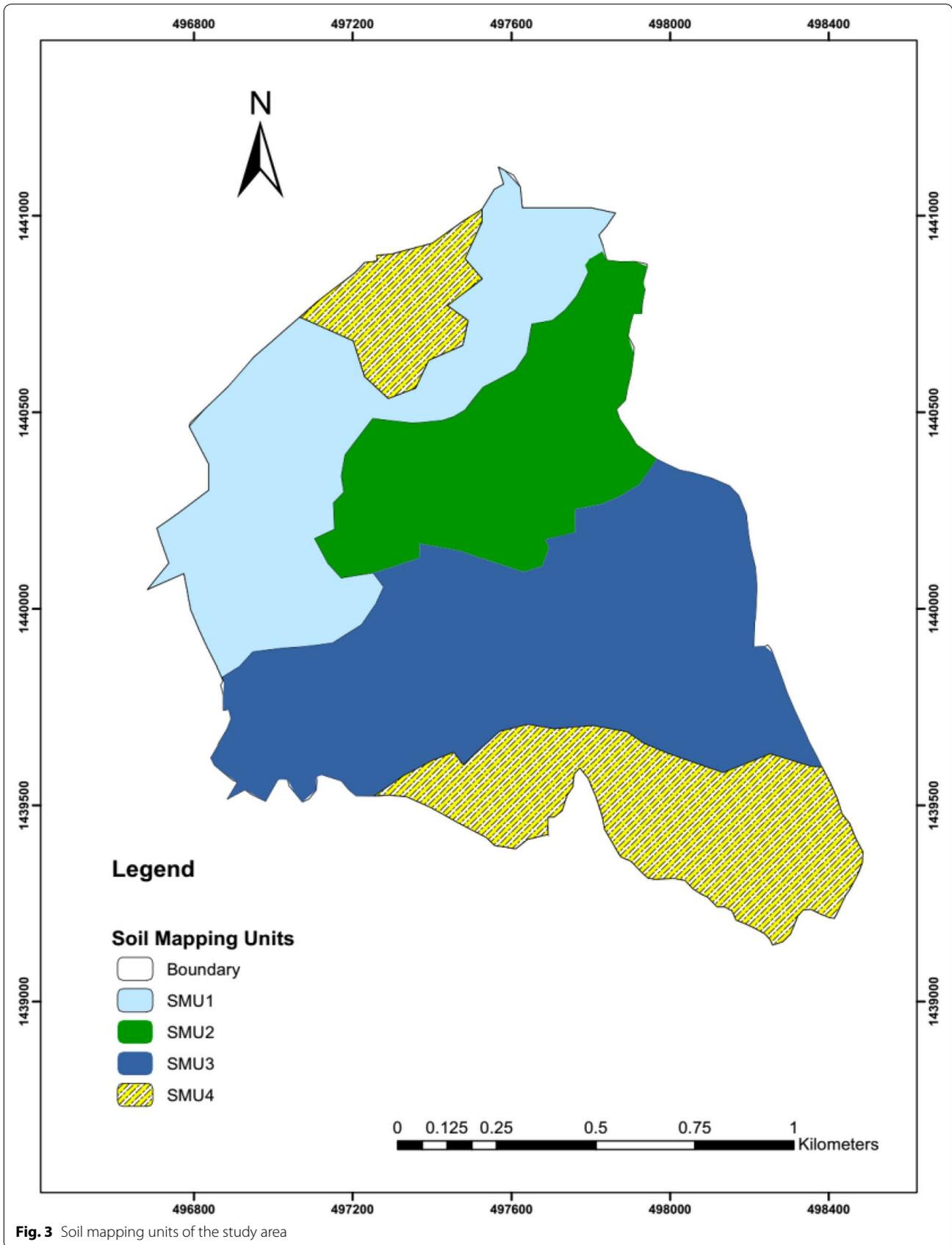


Fig. 3 Soil mapping units of the study area

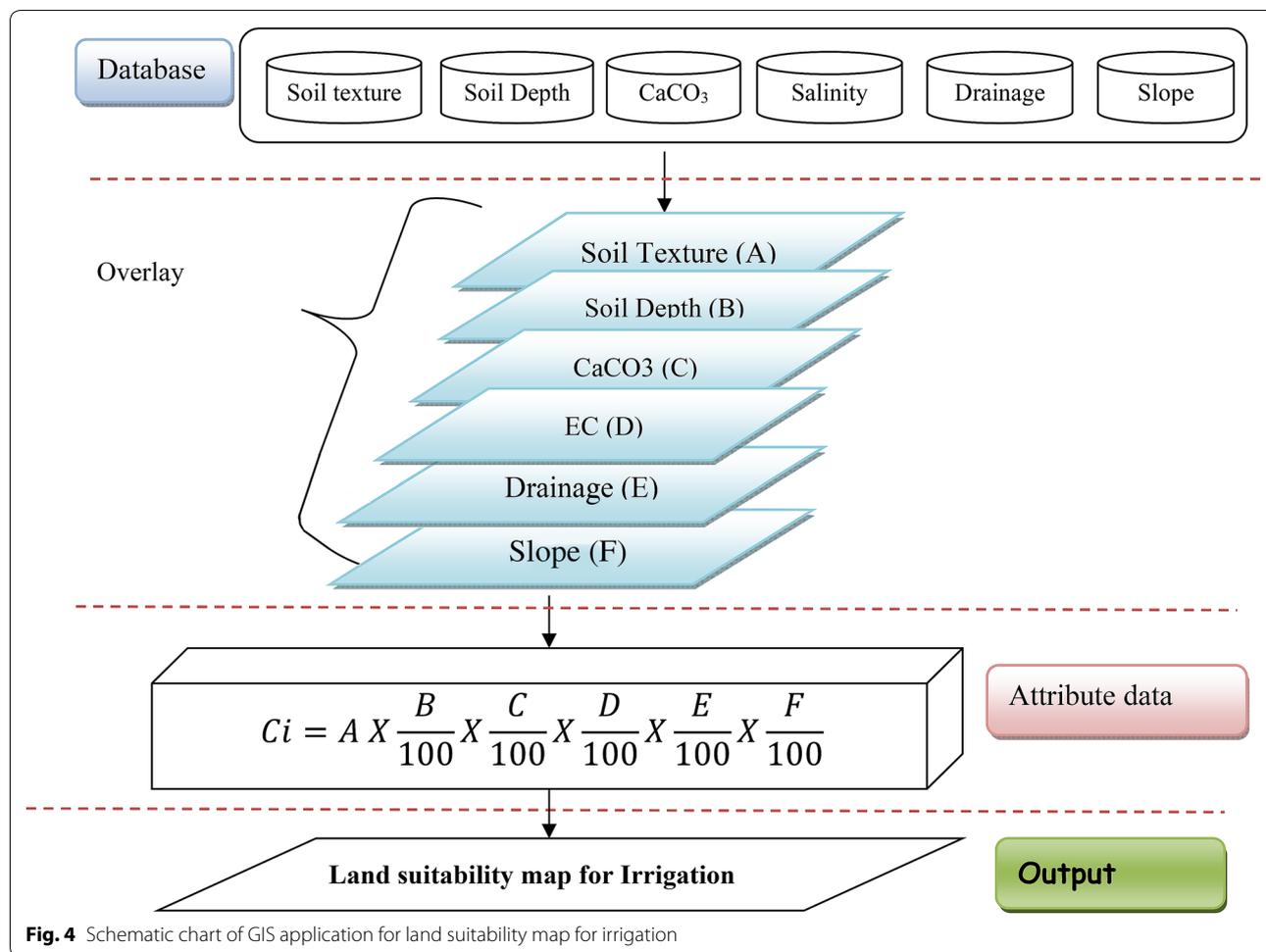


Table 1 Suitability classes for the irrigation capability indices (Ci)

Symbol	Definition	Capability index
S1	Highly suitable	> 80
S2	Moderately suitable	60–80
S3	Marginally suitable	45–60
N1	Currently not suitable	30–45
N2	Permanently not suitable	< 30

Table 3 Ci values and suitability classes of each mapping units for irrigation

Land mapping unit	Area		Capability index	Suitability class
	ha	%		
SMU1	45.69	23.41	73.10	Moderately suitable
SMU2	34.95	17.91	77.27	Moderately Suitable
SMU3	71.68	36.73	47.38	Marginally suitable
SMU4	42.84	21.95	32.49	Currently not suitably

SMU soil mapping unit

Table 2 Land and soil characteristics rating for irrigation of the land units

Land mapping unit	A		B		C		D	E		F	
	Texture		Depth		CaCO ₃			EC		Slope	
	Rating	Class	Rating	Cm	Rating	%		Rating	dsm ⁻¹	Rating	%
SMU1	95	SCL	100	178	95	0.5	90	100	0.11	90	(3–5)
SMU2	95	SCL	100	167	95	2	90	100	0.12	95	(0–3)
SMU3	75	SL	100	134	95	0.6	95	100	0.10	70	(5–8)
SMU4	75	SL	60	39	95	3	95	100	0.06	80	(8–15)

SMU soil mapping unit, SCL sand caly loam, sand loam

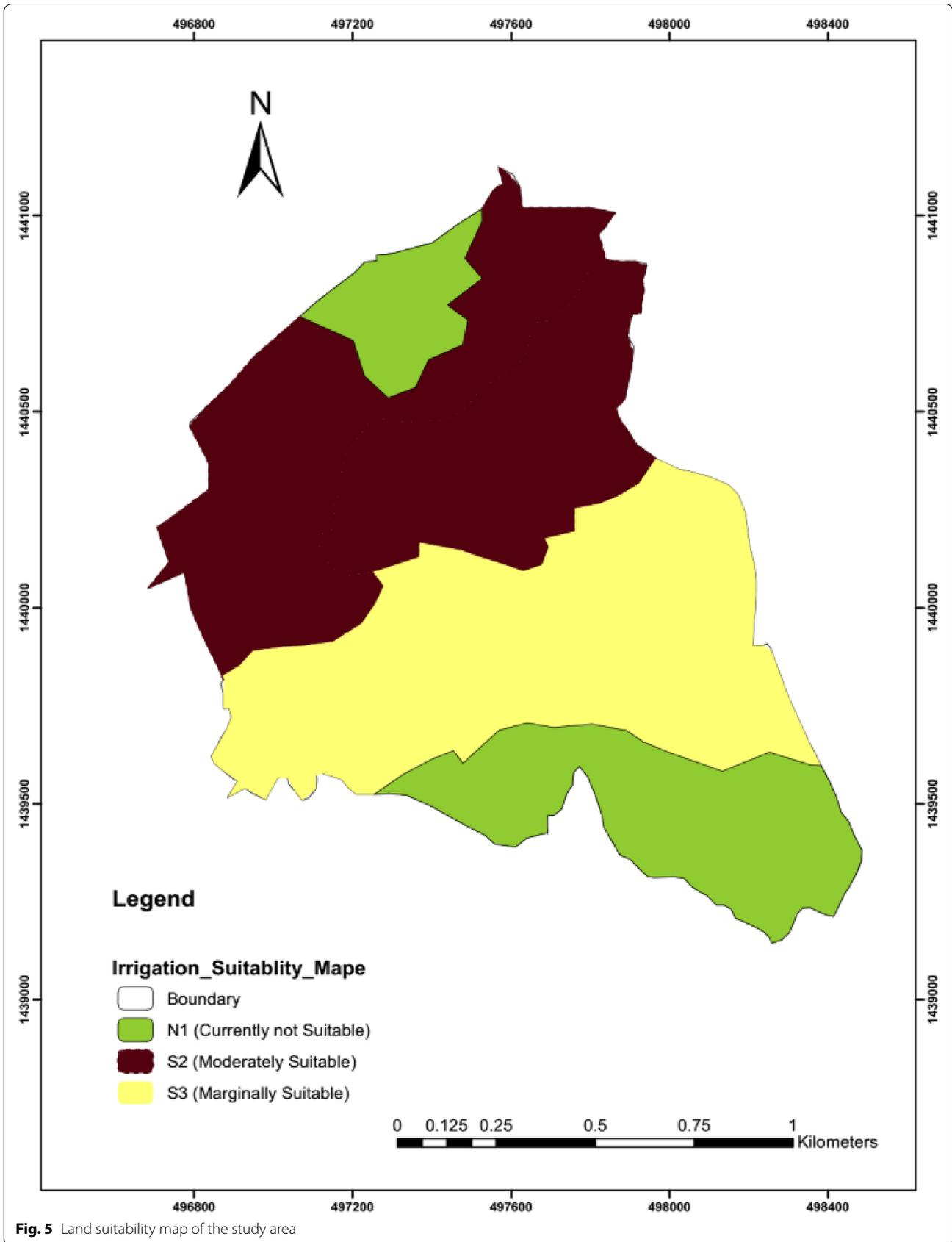


Fig. 5 Land suitability map of the study area

factors of texture, slope, and drainage. Due to slope, texture, depth and drainage land characteristics factor about 114.52 ha of land is marginally and currently non suitable for irrigation in the scheme. Different researches conducted in irrigation suitability evaluation confirmed that major limiting factor for irrigation suitability are slope, depth, texture and drainage. Research conducted by Yitbarek et al. (2016), in western Ethiopia showed that due to limiting factors of soil depth and texture the land was marginally suitable for irrigation. Similarly, research conducted in Dejen areas of Ethiopia by Mehari and Alebachew (2013) confirmed that about 341 ha of land were marginally and currently non suitable for irrigation due to limiting factors of slope, soil depth, and texture.

Depth do not influence the suitability of soil mapping unit 1 Rehodic Nitisol (eutric) and SMU2 Vertic Cambisol (Hypereutric) whatsoever. Currently non-suitable land was observed in the scheme due to the physical limitations of soil depth rated (60%), texture rated (75%), and slope rated (80%). It covers about 42.84 ha of land. There was no permanently non-suitable land in the irrigation command area. Salinity was not considered as a limiting factor in the study area. There was no highly suitable land for irrigation in the study area. Similar result was reported by Mehari and Alebachew (2013) and Suliman et al. (2015) who confirmed that they did not found highly suitable land for irrigation.

Conclusion and recommendation

Irrigation suitability evaluation using the parametric method is very important to identify the irrigable and non-irrigable lands. The method is based on the topography, physical, and chemical properties of the soil without considering the social and economic constraints. Result obtained from the study confirmed that the soils are moderately suitable, marginally suitable, and currently not suitable for irrigation. Vertic Cambisol (Hypereutric) and Rehodic Nitisol (eutric) are moderately suitable for irrigation while Haplic Regosol (eutric) is marginally suitable and Leptic Regosol (eutric, loamic) is not currently suitable for irrigation due to major limiting factors of depth and slope. Generally, about 80.64 ha or 41.32% of irrigated land is moderately suitable, about 71.68 ha or 36.73% of the land is marginally suitable and about 42.84 ha or 21.95% of the scheme is currently not suitable for irrigation. It could be recommended that, further, studies should be carried out on water quality, water requirements, irrigation interval, suitability evaluation for different horticultural crops to maximize the water productivity and production of the study area.

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Authors' contributions

WS did the experimental work, processed the data and wrote the first draft of the manuscript. EA and HK supervised and revised the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The data used to support the findings of this study are available from the corresponding author upon request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that there are no conflicts of interest regarding this article.

Author details

¹ Sekota Dry-Land Agricultural Research Center, P.O. Box 62, Sekota, Ethiopia. ² College of Agriculture and Environmental Sciences, Bahir Dar University, P.O. Box 1289, Bahir Dar, Ethiopia. ³ Amhara Agricultural Research Institute, P.O. Box 527, Bahir Dar, Ethiopia.

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