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Soil Characteristics, Water Quality Assessment and Mapping of Agricultural Land Use in Raya Azebo, Tigray, Ethiopia

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Soil survey assessment was conducted to characterize and map the distribution of the physico-chemical characteristics of irrigated and rain-fed agriculture and water quality evaluation from irrigated areas in Raya Azebo, Tigray, Ethiopia. A total of 76 Auger samples have been taken from a depth of 0-20cm. Three Pits, 1m x1m and 40cm depth also were opened, and soil samples were taken from two soil depths 0-20 and 20-40cm. Assessment of the groundwater quality of the study area was done to determine its suitability for agricultural purposes and water for this purpose

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requires meeting certain safety standards. Water samples were also collected from the main source hand-dug wells and the furrow irrigation for analysis. Accordingly, major soil properties and water quality parameters were analyzed and mapped. The selected parameters for rain-fed were pH, electrical conductivity, total nitrogen, available phosphorus, organic matter, cat ion exchange capacity, available potassium, exchangeable calcium and magnesium. Important constituents like TDS (243.2 to 448 mg/l), pH (7.08 to 7.95), and EC (0.95 to 1.75 dS/m) were assessed from the water sample and compared with standard limits of irrigation water quality. In general, the soils of both rain-fed and irrigated areas and the irrigation water quality laid under safe and salt-free, but some soil nutrients like organic matter, nitrogen, potassium, calcium and magnesium status showed low to medium rank. Hence, the soil requires attention regarding integrated nutrient management approaches.

Keywords: Soil fertility; groundwater; soil mapping; soil characterization; water quality.

1. INTRODUCTION

Soil fertility is one of the key factors for agricultural productivity in Tigray, Ethiopia. Low essential soil nutrients due to limited replenishment of removed nutrients, and high erosion rates in mountainous areas caused soil fertility decline to threaten current and future food production [1,2]. Due to long history of agriculture, population growth and unwise utilization of natural resources, Tigray has faced challenges related to land degradation for a long period and agricultural productivity has decreased dramatically. Soil characterization, soil classification, and soil mapping provides information that could benefit farmers, especially in the area of food security and environmental sustainability. Soil characterization provides information to understand the physical, chemical, mineralogical, and microbiological properties of the soils we depend on to grow crops, sustain forests and grasslands as well as to support homes and society structures [3]. Soil characterization study, therefore, is beneficial to understand the soil, classifying it, and to understand the environment [4].

Determining the suitability of land for irrigation requires a thorough evaluation of the soil properties, the topography of the land in the field and the quality of water to be used for irrigation [5]. One of the special purposes of a soil survey is the type of soil survey that is implemented to establish soil fertility, soil chemical and physical properties, and mapping of fertilizer recommendations. For such type of soil survey, the acceptable international standard scale ranges from 1:25,000 to 1:50,000 based on the variability of soils where the observation density varies in the range of 1:10 to 50 ha [6].

In our region, some areas have high potential for crop production. For example, Raya Azebo district has a big flat land that can be used for irrigation. This area is intensively used for irrigation and rain-fed production by investors and farmers of the area. Some or limited studies were conducted in the area, according to [7] soils of the area are generally potential for agriculture, and more than 80% of the area is being cultivated, mainly for teff and sorghum. However, regarding the soil properties, detail sampling has not been taken and was not well-studied yet. Due to climate challenges, there is an erratic rainfall distribution in the area but the area has underground water potential. Therefore, the challenge can be addressed with the expansion of irrigated agriculture. Even though, intensive farming and surface irrigation have been practiced in the soils of the cultivated area, soil physico-chemical properties of the irrigated and non-irrigated areas in Raya Azebo district were unknown. Therefore, the objective of the study was to characterize the soil physico-chemical properties and water quality of irrigated and non-irrigated parts of the study area.

Spatiotemporal analysis, monitoring, and change detection in soil and water quality and their amendment would help researchers, policy makers, industrial players and farmers to take remedies to improve soil fertility, soil health, and water quality to enhance nutrient and water use efficiency and to sustain the agricultural land in general.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The study area is Raya Azebo district in Tigray Region (Fig. 1B), Northern Ethiopia. It is located between latitude 12^0 5'N and 39^0 10'E longitude. The administrative center of this district is Mehoni. The district represents rain-fed based farming systems of lowlands and Vertisol is the dominant soil types, which cover over 70% of the study area [8]. The main activities carried out in the study area are mixed farming or sedentary (i.e. crop production and animal husbandry). The main crops grown in the area include teff, sorghum, maize, and barley production followed by pulses. Cropping season is almost once a year because the study area has unimodal rainfall distribution except in some rural kebelles which obtain rain in summer and spring. Therefore, for this study, we selected two kebelles using purposive sampling techniques, Kara Adishaho and Tsigea Wargiba with an elevation of 1669m and 1895m, respectively. These selected areas used both rain-fed and irrigation-based cropping systems.

2.2 Soil Sampling and Georeferenced Information

Boundaries and soil sampling location points were determined from other maps such as geology, land use, or any other administrative maps. To validate the map, ground truthing or google earth checking was done to determine the soil sampling area. After stratifying the area of interest, sampling locations have been randomly distributed over the agricultural land with highly skewed to the currently cultivated land. It is especially important to view the map scale from the point of view of the soil survey consumer. Therefore, the scale was detailed (1:10,000) (Fig. 1C).

2.3 Sampling Design and Field Survey

The soil survey was conducted in two steps- auger and pit-based analysis. All observation points were accurately geo-referenced by hand-held, Global Positioning System (GPS) and at every auger point site, other information was described. During an auger observation, a mostly free survey technique (random sampling) was used.

The type of sampling employed was composite soil sampling taken from locations having similar soil types, topography and history of similar land utilization types (LUT). A total of 76 soil samples of both kebelles have been taken from a depth of 0-20cm. Three Pit also opened 1x1m and 40 cm depth, and soil samples were taken from two soil depth 0-20 and 20-40 cm. Water samples also collected from the irrigation sites of the two kebelles and have been taken 4 water samples from the main source hand dug wells and 4 samples from the furrow which comes from each hand dug wells in both kebelles for analysis.

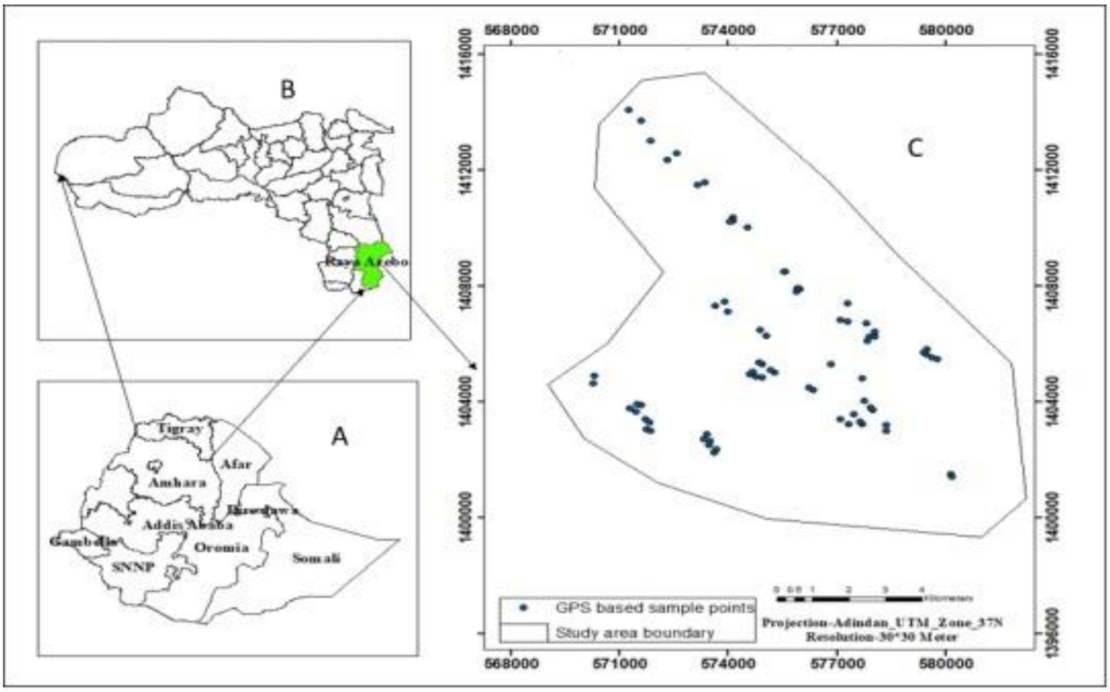

Fig. 1. Geographical location of the study area (Ethiopian Regions (A), Tigray Districts (B), and Study boundary with sample points (C))

Interview was conducted using informal discussion to capture data pertaining to farmer's perception on soil fertility and 30 sample farmers were randomly selected from the provided area.

2.4 Soil and Water Sample Analysis

Soil and water samples were analyzed at Mekelle Soil Research Center laboratory. Soil samples were air dried and passed through a 2-mm sieve. For determination of organic carbon (OC) and total nitrogen (TN), 0.5 mm sieve was used. Soil pH was measured using meter equipped with combined glass electrode from pH 1:2.5 soil/solution in water. The electrical conductivity (EC) of the 1:2.5 soil/solution in water suspension was recorded with the help of an electrical conductivity meter. Organic carbon by modified Walkley and Black method [9]; cation exchange capacity (CEC) by replacing exchangeable cations with ammonium acetate (NH_4OAc) [10]; available phosphorous [11] and total nitrogen [12] were used for estimation. Soil texture was determined by hydrometer determination [13]. Moreover, available potassium (av. K), exchangeable calcium (Ca) and magnesium (Mg) were measured for soil analysis. Also, pH, EC, Bicarbonates (HCO_3), Total Dissolved Solids (TDS), Ca, Mg, Chlorine (Cl) & Sodium (Na) were determined for water quality.

2.5 Data Analysis

Descriptive statistics such as minimum, maximum, mean and percentages were used to analyze soil property data. Different standard rate and guidelines for interpretations of results of soil physico-chemical characterization and water quality for irrigation has been used. The generated raster layers of each soil parameter were further reclassified in spatial analyst tools of the ArcGIS 10.2 software using different rating classes and maps of major properties generated [14,15,16].

3. RESULTS

3.1 Assessment of Soil Physico-chemical Properties of Rain-fed Area

Texture: A total of 76 soil samples of both kebelles have been collected and analyzed for soil texture. 80 % of the total samples were categorized as clay and 20% as clay loam hence the study area had a dominantly clay texture and was classified as vertisol [7].

Soil reaction (pH 1:2.5): pH ranged from 7.1 to 7.9. According to the soil alkalinity rating fixed by [16] (Supplementary Table 1), it was observed that nearly 96% of samples were categorized as moderately alkaline, and 4% of samples were categorized under neutral soil pH. Similar to our study, [7] also reported the soil pH of the area as moderate to strong alkaline.

Salt concentration (EC_e): The electrical conductivity (EC) of the soil samples analyzed ranged from 0.05 to 1.22 mmohs/cm. The total samples were classified under normal or non-saline ranges according to the previously described limit set by [15] (Supplementary Table S1). The geospatial interpolation result depicted that the study area is characterized as almost free of salinity.

Cation exchange capacity (CEC): The cation exchange capacity ranged from 34.4 to 70 cmol/kg. The majority of the sampled area falls under very high status and only a few samples ranged in high cat ion exchange capacity. According to the rating of CEC set by [17] (Supplementary Table S1), 97% of the total sample is classified under high status, and 3% of the total sample also classified under low status. Hence, the soil can hold the cations with a good soil management practice.

Organic matter (OM %): The organic matter analyzed in all sampled clayey soils exhibited in the range of 1.09 to 3.87%. The distribution of soil samples concerning OM content indicates that the soil is low to medium range. The OM content classification of our results was based on the limit or rating set by [16] (Supplementary Table S 1), 59% of the total samples had low organic matter, and 41% of the total sample was also laid on medium organic matter content (Fig 2).

Total nitrogen (TN %): The total N content of the clayey soil ranged from 0.04 to 0.2%. The majority of the sampled area falls under medium status and the rest is in low total Nitrogen (Fig. 3). According to the rating on soil total nitrogen set by [16] (Supplementary Table S1), 81% of the total samples of the area had the medium status of total nitrogen and 19% of the total sample also had a low status of total nitrogen.

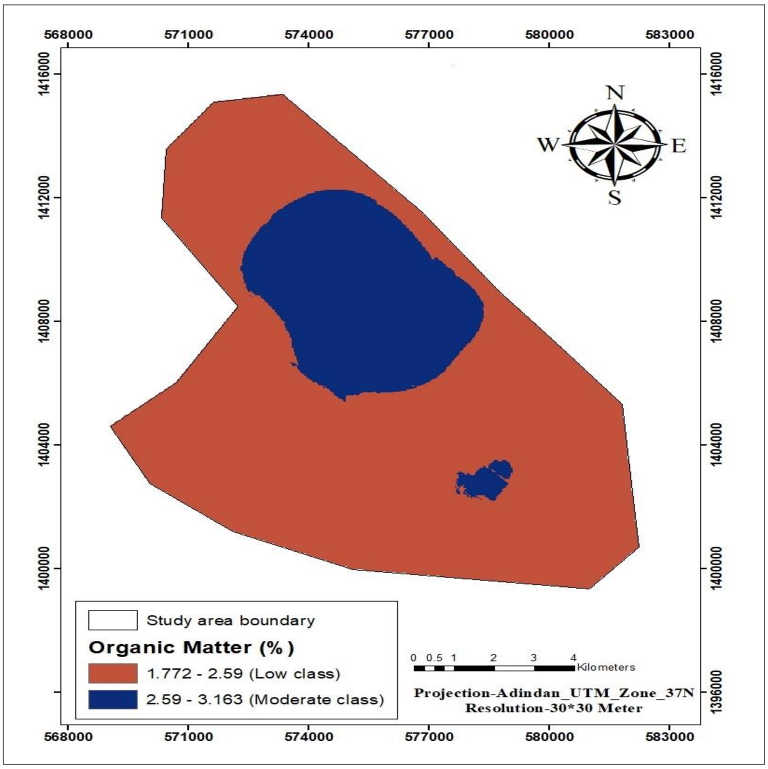

Fig. 2. Spatial distribution of soil organic matter

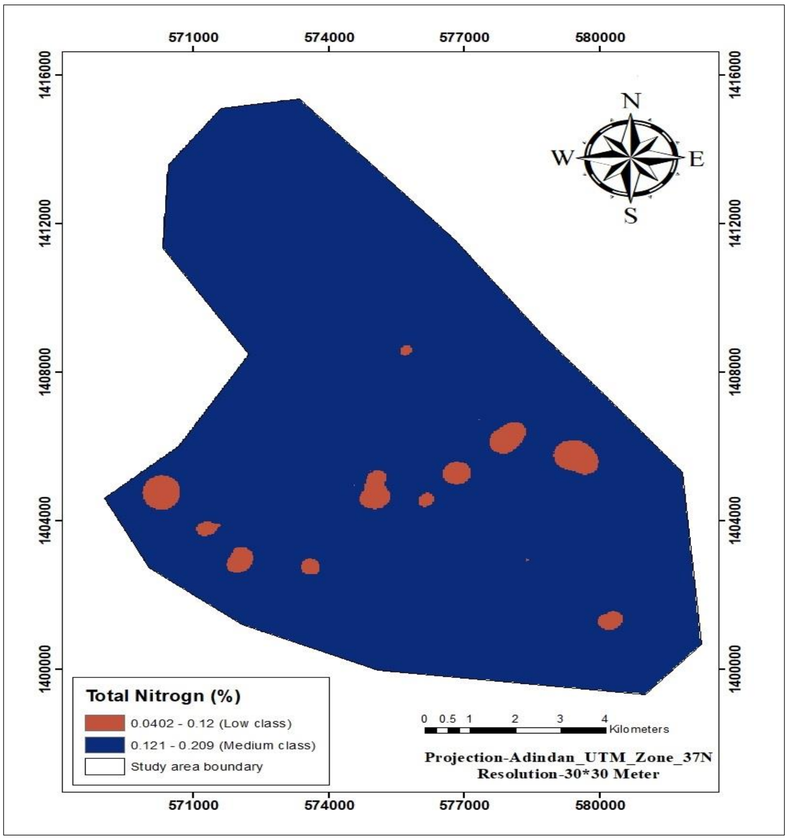

Fig. 3. Spatial distribution of soil total nitrogen

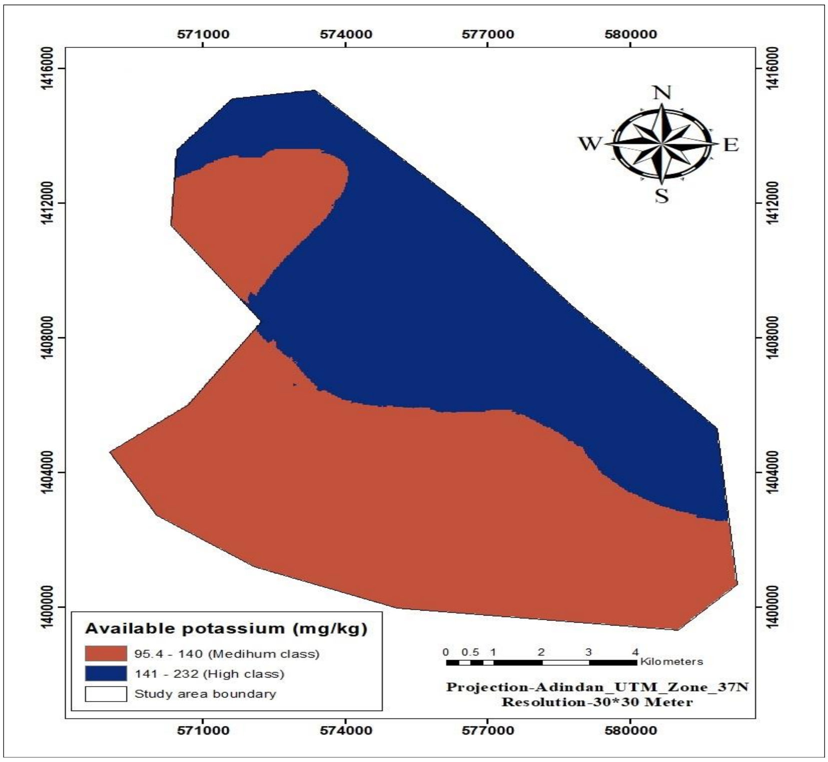

Fig. 4. Spatial distribution of soil available potassium

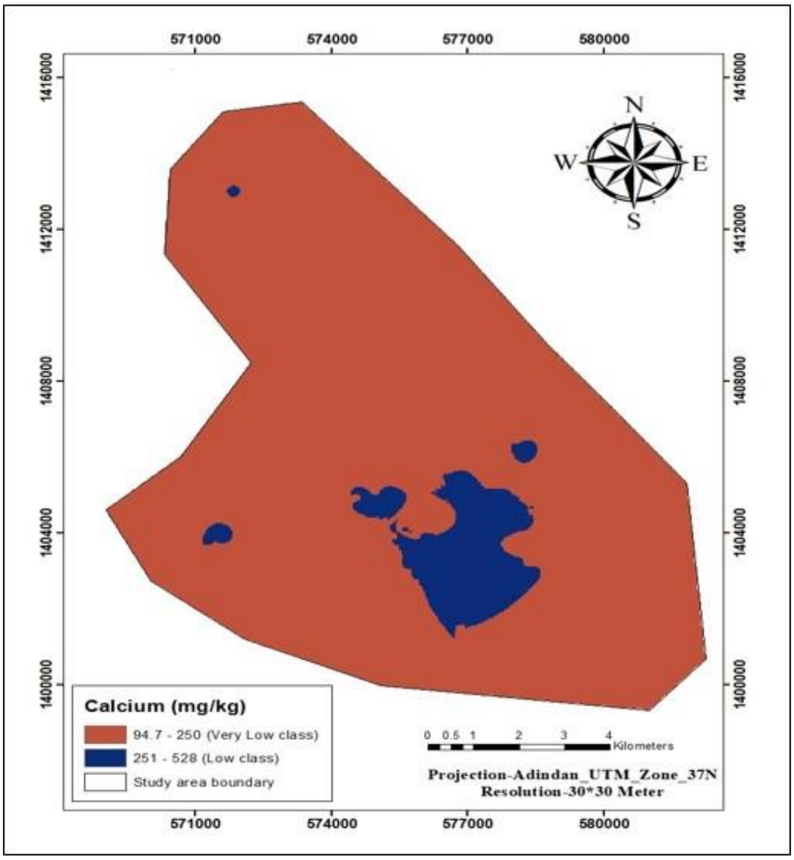

Fig. 5. Spatial distribution of soil calcium

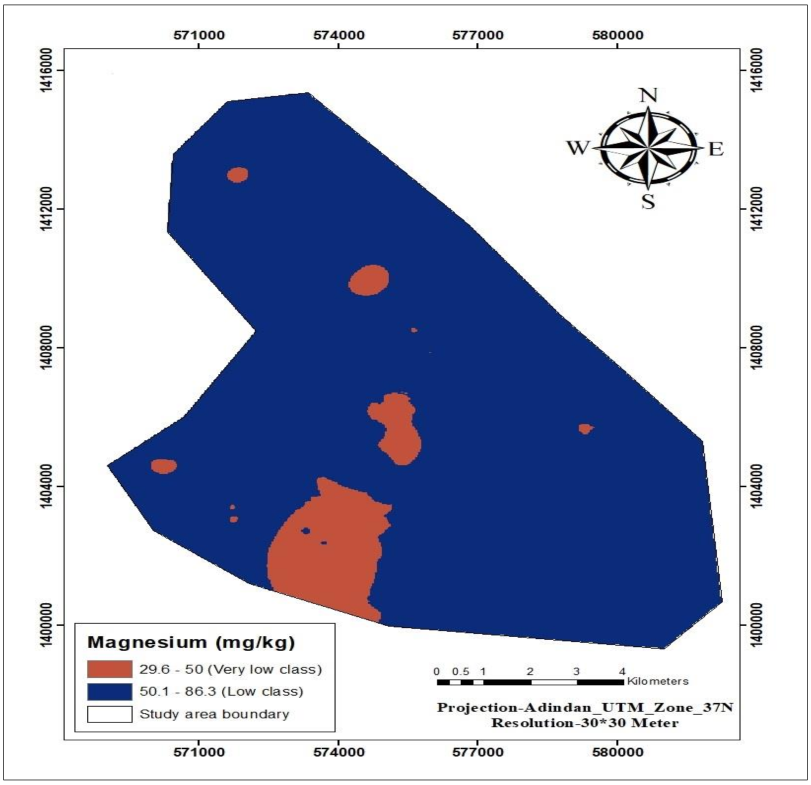

Fig. 6. Spatial distribution of soil magnesium

Available phosphorus (av. P): The available Phosphorus varied from 6.74 to 42.2 mg/kg. The study indicated that the majority of the sampled area exhibited high and few also as a medium of Phosphorus content. This is based on the rating set by [18] (Supplementary Table S1), 84% of the sampled area exhibited as high and 16% also as a medium of P content.

Available potassium (av. K): The results showed that the available K content ranged from 87.1 to 257 mg/kg (Fig. 4). The data reveals that 45% of soil samples tested were in medium level of available K, 29% as high and 26% of samples were indicated as a very high range. The K availability rating was depending on [19] (Supplementary Table S1).

Calcium (Ca): The Calcium content of the sampled area ranged from 92 to 312 mg/kg. The result indicates that the highest of the sampled area exhibited very low (Fig. 5). According to [19] (Supplementary Table S1), the result indicates that about 75% of the total sampled area exhibited very low and 25% also under low calcium content.

Magnesium (Mg): The results showed that the magnesium content varied from 28.8 to 86.4 mg/kg. The result has shown that about 79% of soil samples tested were low (Fig. 6). The result has shown that about 79% of soil samples tested were low and 21% had very low soil magnesium content in the sampled area. This rating is according to [19] (Supplementary Table S1).

3.2 Pit Soil and Ground Water Quality for Irrigation Purpose

3.2.1 Physico-chemical properties of soil in the irrigated area

As indicated in Table 1, this study compares the soils of the irrigated area in soil property and fertility status with two depths of 0-20 and 20-40cm. In both depths, the soil was in the same range of moderately alkaline in reaction and showed a pH range of 7.85 to 8.0. The salt concentration of the two depths was laid on salt-free, which ranged from 0.25 to 0.55 mmohs/cm. The organic matter content and total nitrogen were found to be in the low and medium range, respectively in both depths, however, the upper depth (0-20cm) contained more organic matter and total nitrogen than the bottom depth (20-40cm). A similar study in this area by [7] reported that the organic matter content of the soils is rated as low to medium, and declines with depth.

Table 1. Some physico-chemical properties of the irrigated soil

Soil depths (cm)	Properties									
	Textural class	**pH**	**OM%**	**ECe** mmohs/cm	**TN %**	**Av.P** mg/kg	**CEC** cmol/kg	**Av. K** mg/kg	**Ca** mg/kg	**Mg** mg/kg
Profile 1										
0-20	Clay	7.92	2.55	0.3	0.14	10.6	69.6	195	100	67.2
20-40	Clay	7.85	2.21	0.33	0.11	7.58	67.4	152	128	57.6
Profile 2										
0-20	Clay	7.86	2.14	0.55	0.12	11.24	69.8	138	92	52.8
20-40	Clay	7.93	2.32	0.43	0.10	6.7	70.2	104	76	43.2
Profile 3										
0-20	Clay loam	8.2	1.67	0.48	0.11	30.9	52.2	108	68	45.6
20-40	Clay loam	7.93	1.33	0.25	0.08	6.38	36.8	59.5	60	31.2

OM = Organic Matter, ECe = Electrical Conductivity, TN = Total Nitrogen, Av.P = Available Phosphorus, CEC = Cat ion Exchange Capacity, Av.K = Available Potassium, Ca = Calcium, Mg = Magnesium, mmohs/cm = millimhos per centimeter, mg/kg = milligram per kilogram, cm = centimeter, cmol/kg = centimol per killogram,

Table 2. Different parameter indices for rating groundwater quality and their mean results

Source of WS[a]	Parameters							
	pH	**ECe in dS/m**	**Ca^{2+}** mg/l	**Mg^{2+}** mg/l	**TDS** mg/l	**Na^{+}** me/l	**Cl^{-}** me/l	**HCO_3^{-}** me/l
Irrigated area 1								
main source 1	7.4	1.7	132	43.2	435.2	1.83	2.81	3.8
furrow water 1	7.4	1.45	252	48	371.2	2.7	2.05	4.8
Irrigated area 2								
main source 2	7.5	1.45	136	50.4	371.2	1.9	2.42	4.4
furrow water 2	7.5	1.38	248	48	352	2.95	1.65	5
Irrigated area 3								
main source 3	7.4	1.75	160	50.4	448	1.9	2.03	4.4
furrow water 3	7.4	1.73	224	48	441.6	3.97	2.48	4.6
Irrigated area 4								
main source 4	7.9	0.95	196	55.2	243.2	2.19	1.63	3.8
furrow water 4	7.1	1.2	228	50.4	307.2	3.11	1.25	3.6

SW[a] = Water Sample, mg/l = milligram per litter, me/l= milliequivalent per litter, dS/m = deciSiemens per meter, Na^{+}= Sodium, Cl^{-}=Chloride, HCO_3^{-}= Bicarbonate

Soil available phosphorus, available potassium, cat ion exchange capacity, calcium and magnesium content was found to be higher in the upper depth (0-20cm) than that of lower depth (20-40cm).

3.2.2 Ground water quality for irrigation

The source of water for irrigation in this study was ground water and two types of water samples has been taken (from main source and canal/furrow) to compare the quality of water with the soil of the irrigation area. Each parameter of the water quality area is indicted below (Table 2) and the rating of the water quality status is according to (Supplementary Table S2).

Hydrogen ion concentration (pH): The concentration of hydrogen ion (pH) from both the main source and the furrow source ranges from 7.08 to 7.95 (Table 2). All the water samples analyzed from both sources have similar concentrations within the moderately safe limit of 6.5 to 8.4 standard set by [20] (Supplementary Table S2).

Bicarbonate (HCO_3-): Substantial bicarbonate levels in irrigation water can increase soil pH, and in combination with carbonate, they may affect soil permeability. The concentration of bicarbonate in both sources of a water sample is found to be in a slight to moderate hazard range of (3.6-5.0 me/l) (Table 2), related to the rating in (Supplementary Table S2).

Magnesium (Mg^{2+}): Magnesium is an important contributor to water hardness. In the study area, magnesium concentration ranged between 43.2 to 55.2 mg/l in the main and furrow sources of water, which is a very low to low-rate concentration (Table 2).

Calcium (Ca^{2+}): Calcium contributes to the hardness of water and it is the fifth most common element found in most natural waters. The calcium concentration in the sampled groundwater and furrow in the study area is verylow132 to 252 mg/l. which is a very low to low rate of Ca concentration (Table 2).

Total dissolved solids (TDS): Salts of calcium, magnesium, sodium, and potassium present in the irrigation water may prove to be injurious to plants. When present in excessive quantities, they reduce the osmotic activities of the plants and may prevent adequate aeration. The TDS value of the study area ranges from 243.2 to 448 mg/l. They are generally classified as excellent to good irrigation water (Table 2).

Electrical conductivity (EC ds/m): Conductivity is measure of the ability of water to conduct an electric current. It is used to estimate the number of dissolved solids. It increases as the amount of dissolved mineral (ions) increases. In the study area, the value of conductivity ranged between 0.95 to 1.75ds/m. Which is non-saline level of EC (Table 2).

Chloride (Cl^-): Chloride is a common ion in irrigation waters. Although chloride is essential to plants in very low amounts, it can cause toxicity to sensitive crops at high concentrations. According to [20] guideline for rating of water quality the concentration of chloride is low or with no problem and ranged between 1.25 to 2.81 me/l (Table 2).

Sodium (Na^+): Sodium content is another important factor in irrigation water quality evaluation. Plant roots absorb sodium and transport it to leaves where it can accumulate and cause injure. In this study the sodium content is found to be in a range 1.83-3.97 me/l (Table 2), which is 75 % of the total sample is in a safe or none hazard, whereas 25 % of the samples showed slight to moderate hazard.

3.3 Farmers Perception on Soil Fertility Status

Farmers' response in the study area and their best practice is that they strongly believe that returning sorghum residue in to the field can increase soil fertility status through decomposition. Farmers of the area had less demand on chemical fertilizer due burning of their crops in having of a rainfall shortage. About this [21] reported that because of low amounts and poor distribution of rainfall, farmers have less interest in chemical fertilizer use alone.

Moisture stress is a frequent occurrence in the study area. Soil moisture is a main concern which needs proper soil moisture conservation practices that are acceptable by the communities in terms of cost, accessibility and ease to use. Farmers in the study sites offered practices like crop and soil fertility management, agricultural water management, and soil and water conservation aspects. There is also a huge potential for livestock and irrigation crops commodity value chain development. [7] also reported that with the absence of enough moisture, the use of chemical fertilizer is not an appropriate solution in the study district. Preferably, the use of organic fertilizer as organic amendment is suitable for the area. This practice can increase the organic content of the soil as well as provide nutrients such as nitrogen and phosphorus while increasing CEC values of the soil. In addition, the organic amendment is useful to reduce soil pH to neutral level. Application of sulfur containing fertilizer is also beneficiary to reduce higher soil pH.

The farmers rarely practiced crop rotation but the cultivated area has a potential to grow not only sorghum but also teff, wheat, barley and chick pea. They raised a problem that when we grow teff lately, most of the time it is damaged by flies and sorghum also has disease in its foot and around head. Therefore, according to farmer's response, the area has high potential in crop productivity through good farm management. This is strongly agreed with [21] study that these potentials have been limited due to drought, deforestation, and shortage of fuel wood. Recently, farmers are exposed to irrigation crops development without full understanding of the skill and science of irrigated agriculture.

4. DISCUSSION

The study investigates the physico-chemical properties of soil and water quality in irrigated and rainfed agricultural lands. With a focus on understanding the suitability of these resources for agricultural purposes, the research employs various sampling techniques and analyzes key parameters to assess the conditions of the soil and water.

The scientific relevance of this study lies in its contribution to understanding the environmental factors influencing agricultural productivity in the specific area of Raya Azebo. By characterizing soil properties such as pH [22], electrical conductivity [23], nutrient content (nitrogen, phosphorus, potassium [24,25], organic matter [26], and exchangeable cations (calcium, magnesium [27,28], the study provides valuable insights into the fertility and health status of the soil in both rainfed and irrigated areas [29,30]. Furthermore, the evaluation of water quality parameters such as total dissolved solids (TDS), pH, and electrical conductivity (EC) [31] from various sources adds depth to the assessment, particularly regarding the suitability of water for irrigation purposes [32,33].

Comparison with existing studies on soil quality and agro-environmental factors in tropical agricultural territories of Latin America may reveal similarities or differences in soil and water characteristics, as well as agricultural practices and management strategies [34,35]. Such comparative analysis can enhance the understanding of regional variations in soil fertility [36,37,38], nutrient management practices [39,40], and water quality concerns, thereby informing the development of context-specific agricultural interventions and policies [41,42,43].

In terms of findings, the study indicates that while the soils in both rainfed and irrigated areas are generally safe and free from salinity issues, they exhibit deficiencies in key nutrients such as nitrogen, potassium, calcium, and magnesium, as well as low to medium levels of organic matter. This suggests the need for integrated nutrient management approaches to improve soil fertility and health [44,45,46]. Moreover, the evaluation of water quality parameters against standard limits underscores the importance of ensuring the suitability of water for irrigation to maximize agricultural productivity and sustainability [47].

The study's emphasis on spatiotemporal analysis, monitoring, and change detection in soil and water quality further highlights its scientific significance. By employing such approaches, policymakers and farmers can identify trends, patterns, and potential areas of concern, enabling them to implement targeted remedial measures to enhance soil fertility, soil health, and water quality [48,49]. Ultimately, these efforts contribute to improving nutrient and water use efficiency and ensuring the long-term sustainability of agricultural lands in the region [50,51,52].

5. CONCLUSION

Poor soil fertility status is a key production constraint in agriculture. Hence, soil characterization and irrigation water quality assessment provides information for our understanding of the physical, chemical, mineralogical, and microbiological properties of the soils and water. The properties of soil and water in the study area were categorized as;

- Moderately alkaline in soil pH, and soluble salt content comes under safe or non-saline condition.
- The soil of the irrigated area was also in the same range of moderately alkaline in soil pH and the ECe of the two depths also on salt free.
- The OM, TN, av.P, av.K, CEC, Ca and Mg were found to be in low and medium range, but these parameters shows soil nutrients decreasing as soil depth increasing.
- The ground and canal water quality of the study area was assessed and found; non-saline, slight to moderate bicarbonate, with no problem in chloride and low in calcium, magnesium and sodium.

Farmers in the area, believed that returning crop residue in to the field would improve soil fertility and soil health but rarely practiced crop rotation regardless of potential of the area for crop diversification due to competing interest of the residue for livestock feed and fuel wood. In general the soil and water quality were found to be safe and salt free. Thus, the soil requires attention regarding integrated nutrients management approaches. Spatiotemporal analysis, monitoring, and change detection in soil and water quality and their amendment could help researchers, industrial players, policy makers and farmers to take remedies to improve soil fertility, soil health, and water quality.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Gachimbi LN, van Keulen H, Thuranira EG, Karuku AM, Jager Ad, Nguluu S, Ikombo BM, Kinama JM, Itabari JK,

Nandwa SM. Nutrient balances at farm level in Machakos (Kenya), using a participatory nutrient monitoring (NUTMON) approach. Land Use Policy. 2005;22(1):13–22
2. AGRA. Africa agriculture status report: Climate change and smallholder agriculture in sub-Saharan Africa. Nairobi, Kenya. Alliance for a Green Revolution in Africa; 2014.
3. Ogunkunle AO. Soil survey and sustainable land management. Invited paper at the 29th annual conf. of SSSN held at University of Nigeria, Abeokuta, from 6th to 10th Dec. 2004; 2005.
4. Esu IE. Soil characterization and mapping for food security. A Keynote Address at the 29th annual conf. of SSSN held at University of Nigeria, Abeokuta, from 6th to 10th Dec.2004; 2005.
5. Thomas FS, David F, Larry C, Soil, water and plant characteristics important to Irrigation. North Dakota State University, Fargo, North Dakota; 2017.
6. Dent d, Young A. Soil survey and land evaluation. George Allen & Unwin, London; 1981.
7. Amanuel Z, Girmay G, Atkilt G. Characterization of agricultural soils in cascape intervention woredas in southern tigray, Ethiopia; 2015.
8. Getachew Znabu. The effectiveness and challenges of soil and water conservation practices in Raya Azebo woreda of Tigray, Ethiopia; 2014.
9. Jackson ML. Soil chemical analysis, Prentice Hall of India, New Delhi; 1967.
10. Chapman HD. Cation exchange capacity. pp. 891-901. In: black, C. A. (ed), Methods of Soil Analysis Part II. American Society of Agronomy, Madison, WI; 1965.
11. Olsen SR, Cole CV, Watanabe FS, Deal LA. Estimation of available phosphorus in soil by extraction with sodium bicarbonate, pp 1—19, Government Printing Office, Washington, DC. USDA Circular. 1954;939.
12. Bremner JM, Mulvaney CS. Total nitrogen. In: Page, A.L. Miller, R.H. and Keeney, D.R. (eds). Methods of Soil Analysis, Part 2. Argon. Mongr. 9. 2 eds. Agronomy Society of America and Soil Science Society of America, Madison, WI., USA; 1982.
13. Day PR. Particle fractionation and particle-size analysis. In: Method of Soil Analysis Part I, Black, C.A. (ed.), pp 545—567, American Society of Agronomy, Madison, WI; 1965.
14. Horneck DA, Ellsworth JW, Hopkins BG, Sullivan DM, Stevens RG. Managing salt-affected soils for crop production. Oregon State University. PNW 601-E; 2007.
15. Marx ES, Hart J, Stevens RG. Soil test interpretation guide. Oregon State University, (Reprinted August 1999). EC 1478; 1996.
16. Tekalign T, Haque I, Aduayi E. Soil, plant, water, fertilizer, animal manure and compost analysis. Plant Science Division, Working Document. No.B13, ILCA, Ethiopia; 1991.
17. Hazelton P, Murphy B. Interpreting soil test results: What do all the numbers mean? 2nd Edition. CSIRO Publishing. 2007;152.
18. Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soils by extraction with sodium carbonate. USDA Circular. 1954;939:1-19.
19. Jones JB. Agronomic handbook: Management of crops, soils, and their fertility. CRC Press LLC, Boca Raton, FL, USA. 2003;482p.
20. FAO. Appendix 3 FAO irrigation water quality guidelines. Adopted from ayers and west cot (1985). Reproduced by permission of the Food and Agriculture Organization of the United Nations; 2006.
21. Abeba T, Mekin M. Participatory integrated watershed management research for sustainable resource use and livelihood improvement in site selection and interventions in southern zone of tigray, Ethiopia. International Journal of Agriculture and Biosciences; 2017. P-ISSN: 2305-6622; E-ISSN: 2306-3599.
22. Araya-Alman M, Olivares B, Acevedo-Opazo C, et al. Relationship between soil properties and banana productivity in the two main cultivation areas in venezuela. J Soil Sci Plant Nutr. 2020;20(3):2512-2524. Available:https://doi.org/10.1007/s42729-020-00317-8
23. Campos BO. Banana production in venezuela: Novel solutions to productivity and plant health. Springer Nature; 2023. Available:https://doi.org/10.1007/978-3-031-34475-6
24. Calero J, Olivares BO, Rey JC, Lobo D, Landa BB, Gómez JA. Correlation of banana productivity levels and soil morphological properties using regularized optimal scaling regression. Catena. 2022;208:105718.

Available:https://doi.org/10.1016/j.catena.2021.105718

25. Olivares BO, Vega A, Calderón MAR, Rey JC, Lobo D, Gómez JA, Landa BB. Identification of soil properties associated with the incidence of banana wilt using supervised methods. Plants. 2022;11:2070. Available:https://doi.org/10.3390/plants11152070
26. Rey JC, Olivares BO, Perichi G, Lobo D. Relationship of microbial activity with soil properties in banana plantations in venezuela. Sustainability. 2022;14:13531. Available:https://doi.org/10.3390/su142013531
27. Olivares B. Machine learning and the new sustainable agriculture: Applications in banana production systems of Venezuela. Agricultural Research Updates. 2022;42:133-157.
28. Rodríguez-Yzquierdo G, Olivares BO, Silva-Escobar O, González-Ulloa A, Soto-Suarez M, Betancourt-Vásquez M. Mapping of the susceptibility of colombian musaceae lands to a deadly disease: Fusarium oxysporum f. sp. cubense Tropical Race 4. Horticulturae. 2023;9:757. Available:https://doi.org/10.3390/horticulturae9070757
29. Hernández R, Olivares B. Application of multivariate techniques in the agricultural land's aptitude in Carabobo, Venezuela. Tropical and Subtropical Agroecosystems. 2020;23(2):1-12. Available:https://n9.cl/zeedh
30. Hernández R. Olivares B. Ecoterritorial sectorization for the sustainable agricultural production of potato (*Solanum tuberosum* L.) in Carabobo, Venezuela. Agricultural Science and Technology. 2019;20(2):339-354. Available:https://doi.org/10.21930/rcta.vol20_num2_art:1462
31. Hernandez R, Olivares B, Arias A, Molina JC, Pereira Y. Eco-territorial adaptability of tomato crops for sustainable agricultural production in Carabobo, Venezuela. Idesia. 2020;38(2):95-102. Available:http://dx.doi.org/10.4067/S071834292020000200095
32. Hernández R, Olivares B. Arias A, Molina JC, Pereira Y. Agroclimatic zoning of corn crop for sustainable agricultural production in Carabobo, Venezuela. Revista Universitaria de Geografía. 2018a; 27(2):139-159. Available:https://n9.cl/l2m83
33. Hernández R, Pereira Y, Molina JC, Coelho R, Olivares B, Rodríguez K. Calendario de siembra para las zonas agrícolas del estado Carabobo en la República Bolivariana de Venezuela. Sevilla, Spain, Editorial Universidad Internacional de Andalucía. 2017;247. Available:https://n9.cl/sjbvk
34. Hernández R, Olivares B, Arias A, Molina JC, Pereira Y. Identification of potential agroclimatic zones for the production of onion (*Allium cepa* L.) in Carabobo, Venezuela. Journal of the Selva Andina Biosphere. 2018b;6(2):70-82. Available:http://www.scielo.org.bo/pdf/jsab/v6n2/v6n2_a03.pdf
35. Hernández R, Olivares B, Coelho R, Molina JC, Pereira Y. Analysis of climate types: Main strategies for sustainable decisions in agricultural areas of Carabobo, Venezuela. Scientia Agropecuaria. 2018c;9(3):359–369. DOI: 10.17268/sci.agropecu.2018.03.07
36. Lobo D, Olivares B, Cortez A, Rodríguez MF. y Rey JC. Socio-economic characteristics and methods of agricultural production of indigenous community Kashaama, Anzoategui, Venezuela. Rev. Fac. Agron. (LUZ). 2017;34(2):187-215. Available:https://n9.cl/p2gc5
37. López M, Olivares B. Normalized difference vegetation index (NDVI) applied to the agricultural indigenous territory of Kashaama, Venezuela. UNED Research Journal. 2019;11(2):112-121. Available:https://doi.org/10.22458/urj.v11i2.2299
38. López-Beltrán M, Olivares B, Lobo-Luján D. Changes in land use and vegetation in the agrarian community Kashaama, Anzoátegui, Venezuela: 2001-2013. Revista Geográfica De América Central. 2019;2(63):269-291. DOI: https://doi.org/10.15359/rgac.63-2.10
39. Montenegro E, Pitti J, Olivares B. Adaptation to climate change in indigenous food systems of the Teribe in Panama: A training based on CRISTAL 2.0. Luna Azul. 2021;51-2:182-197. Available:https://n9.cl/qwvwz.
40. Montenegro E, Pitti J, Olivares B. Identificación de los principales cultivos de subsistencia del Teribe: Un estudio de caso basado en técnicas multivariadas. Idesia. 2021;39 – 3:83 - 94.

Available:http://dx.doi.org/10.4067/S0718-34292021000300083

41. Rodríguez M, Olivares B, Cortez A, Parra R, Lobo D. y Rey JC. Análisis temporal de la sequía meteorológica en localidades semiáridas de Venezuela. UGCiencia. 2016b;22(1):11-24.
Disponible en DOI: https://doi.org/10.18634/ugcj.22v.1i.481
42. Rodríguez MF, Olivares B, Cortez A, Rey JC. y Lobo D. Desarrollo del sistema de información de la red de pluviómetros alternativos en medios rurales. Caso: Anzoátegui, Venezuela. Acta Universitaria. 2016a;26 (4):65-76.
DOI: 10.15174/au.2016.961
43. Rodríguez MF, Cortez A, Olivares B, Rey JC, Parra R. y Lobo D. Análisis espacio temporal de la precipitación del estado Anzoátegui y sus alrededores. Agronomía Tropical. 2013;63(1-2): 57-65.
Available:https://n9.cl/14iow
44. Cortez A, Olivares B, Parra R, Lobo D, Rodríguez MF. y Rey JC. Description of meteorological drought events in localities of the central mountain range, Venezuela. Ciencia, Ingenierías y Aplicaciones. 2018;I(1):22-44.
DOI: http://dx.doi.org/10.22206/cyap.2018.vlil.pp23-45.
45. Olivares B, Verbist K, Lobo D, Vargas R. y Silva O. Evaluation of the USLE model to estimate water erosion in an Alfisol. Journal of Soil Science and Plant Nutrition of Chile. 2011;11(2):71-84.
Available:http://dx.doi.org/10.4067/S0718-95162011000200007
46. Olivares B, Lobo D. y Verbist K. Application of the USLE model in erosion plots under soil and water conservation practices in San Pedro de Melipilla, Chile. Revista Ciencia e Ingeniería. 2015b;36(1):3-10.
47. Olivares B. Description of soil management in agricultural production systems in the Hamaca de Anzoátegui sector, Venezuela. La Granja: Revista de Ciencias de la Vida. 2016;23(1):14–24.
Available:https://n9.cl/ycp08
48. Cortez A, Olivares B, Muñetones A. y Casana S. Strategic elements of organizational knowledge management for innovation. Case: Agrometeorology Network. Revista Digital de Investigación en Docencia Universitaria. 2016a ;10(1):68-81.
Available:http://dx.doi.org/10.19083/ridu.10.446
49. Olivares B, Lobo D, Cortez A, Rodríguez MF. y Rey JC. Socio-economic characteristics and methods of agricultural production of indigenous community Kashaama, Anzoategui, Venezuela. Rev. Fac. Agron. (LUZ). 2017b;34(2):187-215.
Available:https://n9.cl/p2gc5
50. Olivares B, Pitti J, Montenegro E. Socioeconomic characterization of Bocas del Toro in Panama: An application of multivariate techniques. Revista Brasileira de Gestao e Desenvolvimento Regional. 2020;16(3):59-71.
Available:https://n9.cl/1dj6
51. Olivares B, Rodríguez MF, Cortez A, Rey JC, Lobo D. Physical natural characterization of indigenous community kashaama for sustainable land management. Acta Nova. 2015;7(2):143-164.
Available:https://n9.cl/6gezo
52. Olivares B, Zingaretti ML, Demey Zambrano JA, Demey JR. Typification of agricultural production systems and the perception of climatic variability in Anzoátegui, Venezuela. RevistaFAVE-CienciasAgrarias. 2016; 15 (2):39-50.
Available:https://doi.org/10.14409/fa.v15i2.6587

SUPPLEMENTARY TABLES

Table S1. Limits for the soil test values used for rating the soil properties in the study area

Parameters	Rating or class						References
Soil pH	strongly acidic	moderately acidic	slightly acidic	neutral	moderately alkaline	strongly alkaline	Tekalign (1991)
	4.5-5.2	5.3-5.9	6 - 6.6	6.7-7.3	7.4-8.0	>8.0	
OM (%)	Low 0.86-2.59			Moderate 2.59-5.17	High > 5.17		Tekalign (1991)
ECe (mmohs/cm)	< 1			1-2	> 2		Marx et al (1996)
TN (%)	Very low <0.05			low 0.05-0.12	Medium 0.12-0.25		Tekalign (19991)
Av.P (mg/kg)	Low <5			medium 5-10	High >10		Olsen et al 1954
Av.K (mg/kg)	Medium 91-140			High 141-300	v.high >300		Jones (2003)
CEC (cmol/kg)	High 25-40			v.high >40			Hazelton and Murphy(2007)
Ca (mg/kg)	V.Low 1-250			Low 251-1000			Jones (2003)
Mg (mg/kg)	V.Low 1-50			Low 51-150			Jones (2003)

Table S2. FAO Guidelines for interpretations of water quality for irrigation

Sr. No	Parameters	Unit	FAO Guidelines for irrigation Degree of restriction on Use		
			None	Slight to moderate	Sever
1	pH	-	Normal range 6.5 – 8.4		
2	TDS	mg/l	<450	450-2000	>2000
3	Electrical Conductivity	ds/m	<0.7	0.7-3.0	>3
4	Sodium	me/l	<3	3-9	>9
5	Chloride	me/l	<4	4-10	>10
6	Bicarbonate	me/l	<1.5	1.5-8.5	>8.5

TDS = Total Dissolved Solids, FAO = Food and Agriculture Organization

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