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Evaluation of Soil Physical and Chemical Indicators as a Basis for Determining Soil Degradation Vulnerability and Conservation in Selected Soils of Sulaimani Province.

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Abstract

The most critical indicators of soil fertility, soil conservation, sustainable and agricultural productivity are Soil physicochemical characteristics. Investigating the variability of these properties across different locations can support sustainable land management practices. This research investigated the physicochemical properties of soils collected from five locations: Jeshana, Samawat, Qaragol, Chawtan, and Saidsadiq. Soil texture, soil water content (Pw), water holding capacity (WHC), electrical conductivity (EC), pH, organic matter (OM), total calcium carbonate ($CaCO_3$), and cation exchange capacity (CEC) were analyzed for soil samples. The outcomes demonstrate substantial difference across locations. Jeshana soil recorded the highest clay content (43.77%), highest WHC (20.07%), and highest CEC (40.14 $Cmol_c\ kg^{-1}$), indicating a higher capacity to retain a water and nutrient. Samawat contained the highest silt content (64.29%) and $CaCO_3$ concentration (41%). The highest organic matter content observed at Chawtan was (4.14%) and EC value (0.6 $dS\ m^{-1}$). Qaragol was obtained by very high silt content (82.13%) and the lowest CEC (19.79 $Cmol_c\ kg^{-1}$). Saidsadiq demonstrated the maximum sand content (51.83%) and the minimum water holding capacity (13.07%). Soil pH values ranging from (7.63 to 7.80), and slightly alkaline across all locations. The results show substantial variability in selected soil properties among the studied soils, with clay-rich soils indicating higher water holding and cation exchange capacities than sandy soils. These differences should be noted when developing soil management for agricultural production.

Keywords: Soil chemical properties, Soil physical properties, Soil degradation, Soil fertility, Soil conservation and Sustainable agriculture.

1. Introduction

Soil is a natural resources act a important role in sustainable life on the earth **(Schoonover and Crim, 2015).** People are becoming more and more dependent on the ecological functions of soil, even if they not realize it. Soil acts key roles in supporting plant growth, agricultural production, and environmental sustainability, air and water regulation, nutrient cycling, and biodiversity conservation, making it indispensable for sustaining both natural and managed ecosystems (Brady et al., 2008). Along with the importance of soil for agriculture, it also has more offer for sustaining living organisms. Soil as an essential part of the terrestrial ecosystem serves various function such as that are fundamental for improving plant growth **(Nwachokor et al., 2009)**.

Soil deterioration refers to the degradation of the biophysicochemical characteristics of soil, leading to a decline in its capability to carry out essential ecosystem functions. Most common forms of soil deterioration include erosion, nutrient depletion, salinization, acidification, compaction and reduction in soil organic matter. These deterioration processes negatively influence water availability, crop productivity, nutrient cycling, and environmental quality **(Lal, 2020)**.

Soil is a crucial part of agriculture. An understanding of physicochemical properties of soil is important for suitable execution of the other soil management practices. Hence, the study of physicochemical properties is very important because both chemical and physical characteristics that influence the soil productivity **(Tale and Ingole, 2015)**, and sustainability of soil health **(Usharani et al., 2019)**. This physicochemical research of soil is depended on different parameters such as: electrical conductivity, pH, moisture, soil organic matter and texture. This information will create awareness across the farmers about economic production (Tale and Ingole, 2015). The physicochemical characteristics of soil govern its capacity to retain water, maintain soil structure, provide nutrients and improve plant growth. Thus, comprehending the spatial differences of these characteristics is crucial for successful soil management, proper land use, and the improvement of site-specific agricultural practices that enhance agricultural productivity while preserving soil resources **(Lehmann et al., 2020, Banwart et al., 2019)**.

Assessment of soil degradation requires reliable indicators that reflect changes in soil quality **(Hazelton and Murphy, 2016)**. Soil physical characteristics such as texture and water-holding capacity, affect infiltration, water retention, aeration, and root growth. In addition, regulating ion exchange processes, nutrient availability and soil fertility affected by chemical properties such as soil pH, electrical conductivity (EC), calcium carbonate ($CaCO_3$), organic matter (OM) and cation exchange capacity (CEC) **(Schoonover and Crim, 2015, Hazelton and Murphy, 2016)**.

The interaction between the chemical and physical properties of soil determines its overall quality and susceptibility to degradation. Aggregate stability, which avoids erosion, is basically affected by the interaction of clay content and soil organic matter playing as natural binding agents (Bronick and Lal, 2005). This structural arrangement directly affects hydraulic parameters, particularly water holding capacity (WHC) and available water content (Pw). Furthermore, chemical properties such as $CaCO_3$ and EC crucially alter these physical arrangements; proper $CaCO_3$ levels support flocculation, while high EC values often threaten structural integrity **(Qadir et al., 2006)**. Consequently, understanding how these chemical indicators affect physical conditions is therefore a prerequisite for mapping soil vulnerability and implementing effective conservation strategies **(Blanco-Canqui and Lal, 2008)**.

Despite the importance of soil characterization, information regarding the spatial difference of soil physicochemical characteristics remains inadequate in many agricultural regions, especially where comprehensive soil surveys and monitoring programs are lacking **(Bunemann et al., 2018)**. Detailed assessment of these characteristics is therefore significant for establishing baseline information for soil quality evaluation, supporting sustainable agricultural improvement, and guiding environmental management and land-use planning **(Lehmann et al., 2020)**.

Therefore, the aim of this research to evaluate selected soil physicochemical indicators to determine soil deterioration vulnerability among different agricultural sites. The outcomes are expected to provide a scientific basis for identifying vulnerable soils and recommending appropriate conservation strategies that enhance soil quality, improve sustainable agriculture, and support long-term environmental conservation.

Materials and Methods

The Study Area Description

This research was carried out on five different soil locations around the Sulaimani city; the sampling sites were presented in Qaragol, Saidsadiq, Chawtan, Samawat and Jeshana (Table 1, Figure 1).

Table 1: The coordinates of the studied sites identified by (GPS).

Location	Latitude	Longitude
Qaragol	35° 20' 46" N	45° 38' 11" E
Saidsadiq	35° 21' 30" N	45° 53' 24" E
Chawtan	35° 31' 17" N	45° 52' 17" E
Samawat	35° 26' 36" N	45° 27' 00" E
Jeshana	35° 29' 45" N	45° 21' 20" E

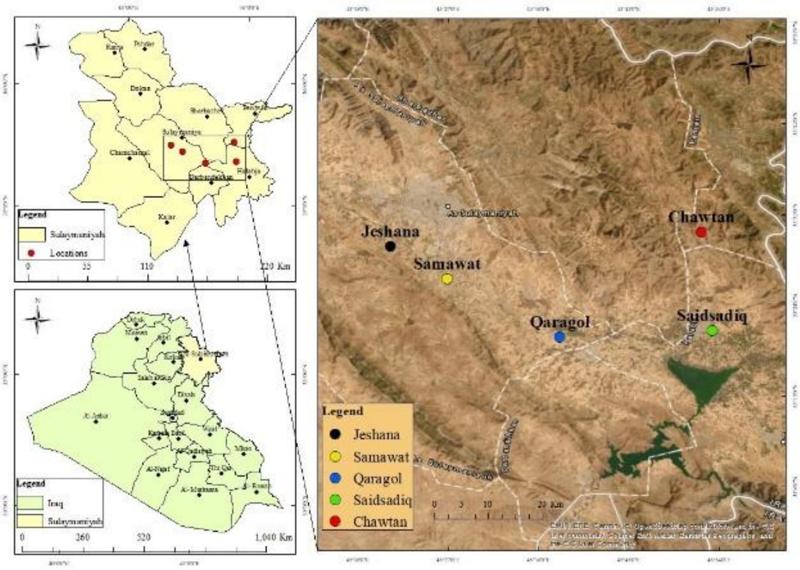

Figure 1: Locations map showing the study sites

Soil Analysis

Preparation of Samples

Soil samples were taken from five different sites at a depth of 30 cm in the topsoil. Soil samples were air-dried in the laboratory, and then sieved in 2 mm. The physiochemical properties of soil samples were determined. Soil pH measured by pH meter in 1:5 soil-water suspensions according to **(Ryan et al., 2001)**. Electrical conductivity EC was measured in 1:5 soil-water dilution according to (Rhoades, 1996), by using an EC meter, and model WTW 82362 Weinheim, Germany, after being adjusted to 25°C. Soil organic matter (SOM) was measured by utilizing the **(Walkley and Black, 1934)** method, as described by **(Ryan et al., 2001)**. Total calcium carbonate was measured with 1M HCl, and the excess of HCl was titrated with 1M NaOH by utilizing phenolphthalein indicator as described by **(Loeppert and Suarez, 1996)**. Texture was determined according to international pipette method with removing carbonate as described by **(Black, 1965)**. Cation Exchange Capacity (CEC) was determined according to equation provided by **(Fattah and Karim, 2021)**. Soil Water holding capacity (WHC) was determined using the gravimetric method and calculated as: WHC (%) = [(weight of saturated drained soil − weight of oven-dried soil) / weight of oven-dried soil] × 100 **(Klute, 1986, Thapa et al., 2024)**. Soil moisture content was measured by gravimetric method according to **(Gardner, 1986).**

Results and Discussions:

Selected Physical Properties of Studied Soils.

Table 2 presents some physical properties of studied soils. The range of sand, silt, and clay were (6.47 and 51.83), (25.85 and 82.13), and (11.40 and 43.77) % soil for Jeshana, Samawat, Chawtan, Qaragol and Saidsadiq, respectively. Soil texture class ranged from loam to silty clay and sandy clay loam, indicating considerable variation in particle size distribution and surface area. **Figure (2)** shows the particle size distribution in study locations. Considerable variation was appeared in the proportions of sand, silt, and clay the study locations, this indicates heterogeneity in soil texture. Particle size distribution is noticeably determined by weathering processes and parent material, so it is considered one of the most stable soil properties and plays an essential role in controlling nutrient availability, aeration, infiltration, soil water retention, and susceptibility to degradation **(Weil and Brady, 2017, Hillel, 2003)**.

The highest clay content appeared in Jeshana (43.77%) compared to the other studied sites, but Qaragol had the lowest clay content among all other studied sites. Clay particles has a high surface charge and large specific surface area, enabling them to retain greater exchangeable nutrients and quantities of water than coarser particles. Clay-rich soils such as Jeshana are generally less susceptible to drought because of their greater water storage but may suffer from poor drainage, structural degradation, and compaction if improperly managed. Therefore, Jeshana soil is anticipated to show relatively high nutrient retention, water-holding capacity, and cation exchange capacity, also the opposite is true for soils with low clay content **(Weil and Brady, 2017, Hillel, 2003).** However, excessive clay may also increase susceptibility to compaction and decrease soil permeability, especially when the soil is worked under wet conditions or under concentrate cultivation. These characteristics suggest that although Jeshana soil has high fertility, but careful management is necessary to avoid physical degradation and preserve soil structure.

Nonetheless, Saidsadiq contained the maximum sand content (51.83%), but the minimum sand content appeared in Qaragol (6.47%). Soil with a high value sand content have a larger pore spaces that assist excellent rapid water infiltration and soil aeration. Furthermore, coarse-textured soils generally have lower capacities for nutrient and water retention because sand particles have a small specific surface area and relatively limited adsorption sites **(Weil and Brady, 2017)**. Whereas, the high silt value recorded in Qaragol (82.13%), but the lowest value observed in Saidsadiq (25.85%), silt particles are structurally less stable than clay aggregates, but provide moderate water storage. A result, Qaragol soil may be more susceptible to compaction, crust formation, and water erosion, especially under intensive improper tillage or rainfall. Although its high silt content can support good moisture availability, conservation practices are required to maintain aggregate stability and reduce erosion risk.

Table (2) selected some physical properties in the studied soils.

Locations	Piratical size distribution			Texture Class	W.H.C %	Pw %
	Sand %	Silt %	Clay %			
Jeshana	7.84	48.39	43.77	SiC	20.07	4.93
Samawat	8.64	64.29	27.07	SiCL	18.61	4.95
Chawtan	40.37	43.40	16.23	L	19.04	3.73
Qaragol	6.47	82.13	11.40	SiL	15.28	3.53
Saidsadiq	51.83	25.85	22.32	SCL	13.07	4.39

Note: SiC (Silty Clay), SiCL (Silty Clay Loam), L (Loam), SiL (Silty Loam), SCL (Sandy Clay Loam), WHC (Water Holding Capacity).

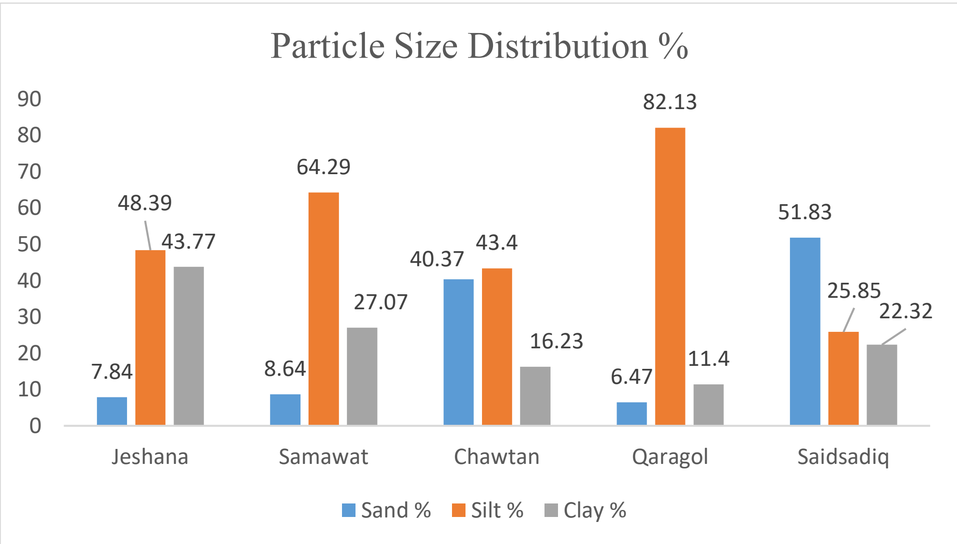

Figure 2: Particle size distribution (%) of soils collected from the five study locations.

In Table (2) the results of water holding capacity and soil water content ranged between (20.07 and 13.07) %, and (4.95 to 3.53) %, respectively. Figure 3 illustrates the variation in water-holding capacity (WHC %) and soil water content (Pw %) among the five study locations. In both parameters considerable differences were observed, reflecting the influence of pore-size distribution and soil texture on soil water retention. Water-holding capacity represents the amount of water that soil can retain after excess gravitational water has drained **(Hillel, 2003, Weil and Brady, 2017)**.

Among the studied locations, Jeshana displayed the highest water-holding capacity (20.07%), while the lowest value appeared in Saidsadiq (13.07%), The high WHC observed in Jeshana is consistent with its high clay content (43.77%), and high organic matter (3.59%) because soil OM content influences the ability of soils to retain moisture, also, clay particles have a large specific surface area and abundant micropores capable of retaining significant quantities of water. The combination of silt fractions and high clay therefore improves the soil's ability to store moisture for plant use. This result strongly aligns with the conceptual observations documented by **(Adamu and Aliyu, 2012)**, namely that [fine texture and high amount of soil organic matter enhance soil WHC], further substantiating the validity of our results. Saidsadiq illustrated the lowest WHC, which is consistent with its high sand content (51.83%). A greater proportion of large pores contain in sandy soils simplify rapid drainage and decrease the capacity to retain water opposite gravitational forces. These findings corroborate the textual assertions by **(Herawati et al., 2021)**, they argued that (sandy soils have low WHC, high runoff, and high infiltration). Accordingly, fine-textured soils commonly provide a bigger reservoir of plant-available water than coarse-textured soils **(Weil and Brady, 2017)**.

On the other hand, soil water content (Pw) ranged from maximum 4.95% to minimum 3.53% in Samawat and Qaragol, respectively. When a soil displays a high gravimetric water content, its pore spaces become mostly occupied by water, which decreases the effective stress and inter-particle friction, thereby decreasing the soil's shear strength **(Weil and Brady, 2016)**. This behavior is frequently observed in fine-grained or clayey soils due to their high water-holding capacity and specific surface area **(Hillel, 2003)**. Otherwise, retains water only as thin films around soil particles if soil has a low gravimetric water content, leaving the macro-pores filled with air. While this condition can temporarily increase structural stability via matric suction, it severely limits biological activity, nutrient mobility, and solute transport within the soil profile **(Dane and Topp, 2020)**.

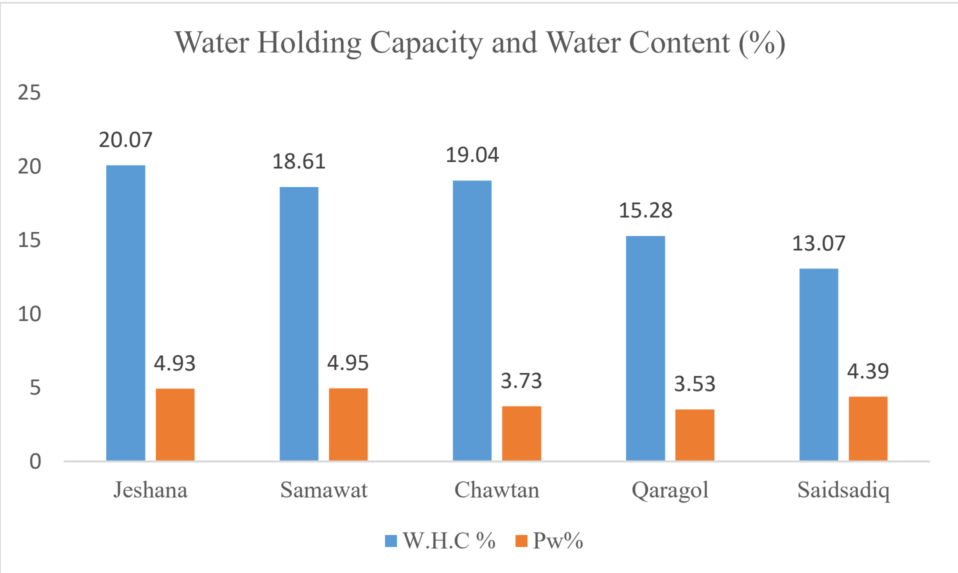

Figure 3: water holding capacity and water content among five different soils.

Selected Chemical Properties

From **Table 3** the results indicate that the pH ranged from 7.63 to 7.80, meaning all soils are slightly alkaline. This narrow alkaline range suggests the soils are influenced by calcareous parent materials, which is supported by the presence of $CaCO_3$ and certain cations. Electrical conductivity (Ec) ranged from 0.30 to 0.60 dS m^{-1}. These findings demonstrated that all soil samples were non-saline soils due to Ec values below 2 dS m^{-1} the limits recommended by **(Schoeneberger et al., 2012)**. Organic matter contents vary between the studied soil samples ranged from (1.52 and 4.14) %. The result shows that the highest value of OM was recorded from Chawtan Higher organic matter improves Cation exchange capacity (CEC), Water retention, Nutrient holding capacity and Aggregate stability. Therefore, Chawtan soil may exhibit better nutrient retention than other soils **(Schoonover and Crim, 2015)**. Total calcium carbonate (T-$CaCO_3$) ranged between (4 and 41) %. This result indicates that all soils are considered to be calcareous soils except Saidsadiq **(Sakin and Yanardağ, 2024)**. This variation may have been caused by the diverse parent material, leaching processes, and creation of each soil, especially those that are connected to weathering processes and levels of soil development. Jeshana recorded the highest value of cation exchange capacity was 40.14 $Cmol_c$ kg^{-1}, while Qaragol recorded the lowest value was 19.79 $Cmol_c$ kg^{-1}.

In Figure 4 the results show that the pH values among all locations were very similar. The highest value was 7.80 recorded in Qaragol, while the lowest value was 7.63 observed from Jeshana. This point out that the soils are slightly alkaline, which is a common characteristic of calcareous soils. calcareous soils are identified by the presence of calcium carbonate ($CaCO_3$) in the parent material and lime deposition. These soils are generally known to have a pH 7 and above **(Sakin and Yanardağ, 2024)**. This slight difference in pH indicates that the soils were developed from identical parent materials and under comparable environmental condition. Although, most crop can grow in this pH range, slightly alkaline soils can reduce the availability of certain micronutrients **(Sakin and Yanardağ, 2024)**.

The electrical conductivity (EC) shown in Figure 4. Chawtan recorded the maximum value was (0.60 dS m^{-1}), while Samawat had the minimum value was (0.30 dS m^{-1}). Despite these differences, the electrical conductivity values for all soil samples remained below 2 dS m^{-1} as recommended by **(Schoeneberger et al., 2012)** classifying the soils as non-saline. This condition is favorable for crop production because low salinity allows crops to absorb water and nutrients without stress from excess soluble salts **(Shabala and Munns, 2017)**.

Also, organic matter content in soil presents in Figure 4. Compared to pH and EC the outcome showed much greater difference among the sampling locations. The highest value organic matter content was observed in Chawtan (4.14%), followed by Jeshana (3.59%). But, Samawat had the lowest organic matter content (1.52%), while Qaragol (2.07%) and Saidsadiq (2.41%) had exhibited moderate values. These variations may be related to differences in vegetation cover, land utilize, residue management and farming practices. SOM improve crop production, enhancing the beneficial physical, chemical and biological properties of soils. Furthermore, it raising the level of organic carbon added and reducing the rate of organic matter loss. SOM also significantly improving the growth of healthy crops and providing populations of beneficial organisms. Creative SOM management will combine a number of practices that work together on individual farms **(Magdoff and Weil, 2004)**.

Overall, the findings demonstrate that the studied soils are suitable for agricultural production. Among five locations, Chawtan seems to have the most favorable chemical characteristics, mainly because of its higher organic matter content, while Samawat may benefit from improved soil management practices aimed at increasing organic matter.

Table (3) selected some chemical properties in the studied soils.

Locations	EC ds.m^{-1}	pH	OM %	$CaCO_3$ %	CEC Cmol$_c$kg^{-1}
Jeshana	0.33	7.63	3.59	28.5	40.14
Samawat	0.30	7.76	1.52	41	27.89
Chawtan	0.60	7.78	4.14	17.5	25.32
Qaragol	0.35	7.80	2.07	30	19.79
Saidsadiq	0.32	7.65	2.41	4	26.42

Note: EC (Electrical Conductivity), pH (Soil Reaction), OM (Organic Matter), CEC (Cation Exchange Capacity)

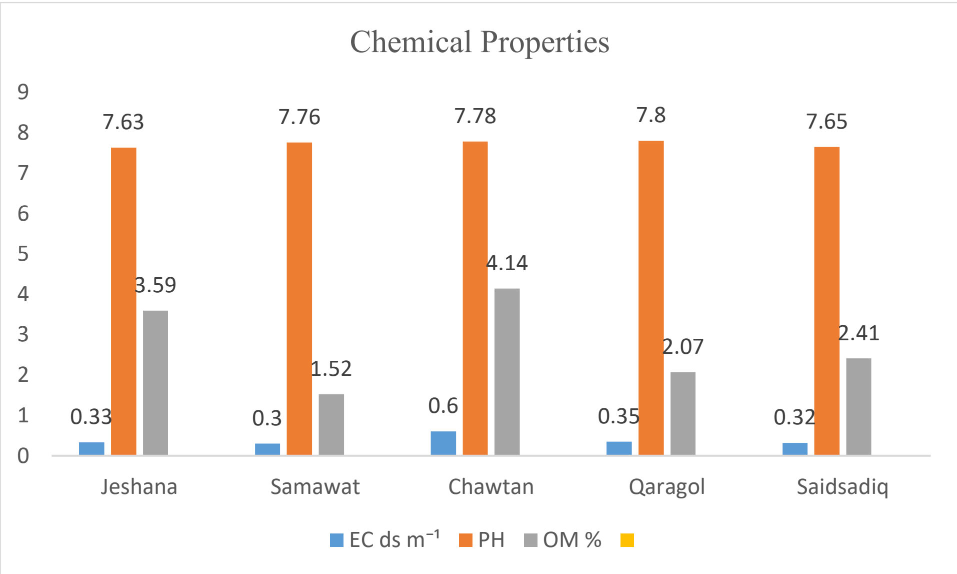

Figure 4: Result of chemical properties among five different soil sites.

The result of total calcium carbonate ($CaCO_3$) and cation exchange capacity (CEC) showed in Figure 5. These two chemical properties Like EC, pH and OM are important because their effect on soil fertility and nutrient availability. The results show that the $CaCO_3$ content different among the studied soils. Samawat recorded the highest value was (41.0%), after that Qaragol (30.0%) and Jeshana (28.5%), whereas Chawtan (17.5%) had a moderate amount of calcium carbonate. These outcomes indicate that most of the studied soils are calcareous according to **(Sakin and Yanardağ, 2024)**, who conducted that calcareous soils are defined by the presence of calcium carbonate ($CaCO_3$) in the parent material and lime deposition. These soils are generally known to have a pH 7 and above. High levels of calcium carbonate help maintain a stable soil pH, but they can also decrease the nutrients availability such as iron, phosphorus, manganese and zinc **(Sakin and Yanardağ, 2024)**. Consequently, in highly calcareous soils crops grown may require careful fertilizer management to prevent nutrient deficiencies. The CEC values showed clear variations in the nutrient-holding capacity of the studied soils. Jeshana had the maximum CEC (40.14 cmolc kg^{-1}), followed by Samawat (27.89 cmolc kg^{-1}), Saidsadiq (26.42 cmolc kg^{-1}), and Chawtan (25.32 cmolc kg^{-1}). The minimum value was observed in Qaragol (19.79 cmolc kg^{-1}). The relatively high value of CEC may be because of high clay content in Jeshana. Similar result finded by **(Räty et al., 2021)**, who said that high clay content in soil cause to high CEC, and high level of CEC cause to high level of water holding capacity (Bell et al., 2015). Cation exchange capacity is a measuer of soil's ability to retain positively charged ions. Cations are crucial for plant growth as they are contributed in many of the biological and chemical processes in the soil **(Sakin and Yanardağ, 2024)**. Generally, soils with higher CEC can be retained in higher amount of essencial elements including calcium, potassium, ammonium and magnesium enhansing their availability for plant uptake and reducing leaching losses.

The findings also demonstrate that a high $CaCO_3$ content does not always lead to a high CEC. For instance, Samawat recorded the maximum $CaCO_3$ content but not the maximum CEC, while Jeshana recorded the highest CEC but not the highest $CaCO_3$ content. This may be due to the other soil characteristics, especially clay content and organic matter, have a high effect on CEC **(Schoonover and Crim, 2015)**. In Fig 4, Jeshana also illustrated relatively high level of organic matter content, which may have contributed to its higher capacity to maintain nutrients.

Overall, the outcomes show that the chemical characteristics of the studied soils differ from one sites to another. Jeshana looks to have the best nutrient-retention capacity because of its high CEC. While, Samawat has a very high $CaCO_3$ content that may decrease the availability of certain minerals despite its moderate CEC. On the other hand, Saidsadiq, recorded the lowest $CaCO_3$ level while maintaining a satisfactory CEC, suggesting that nutrient retention is also significantly affected by other factors than calcium carbonate, like soil organic matter and clay minerals.

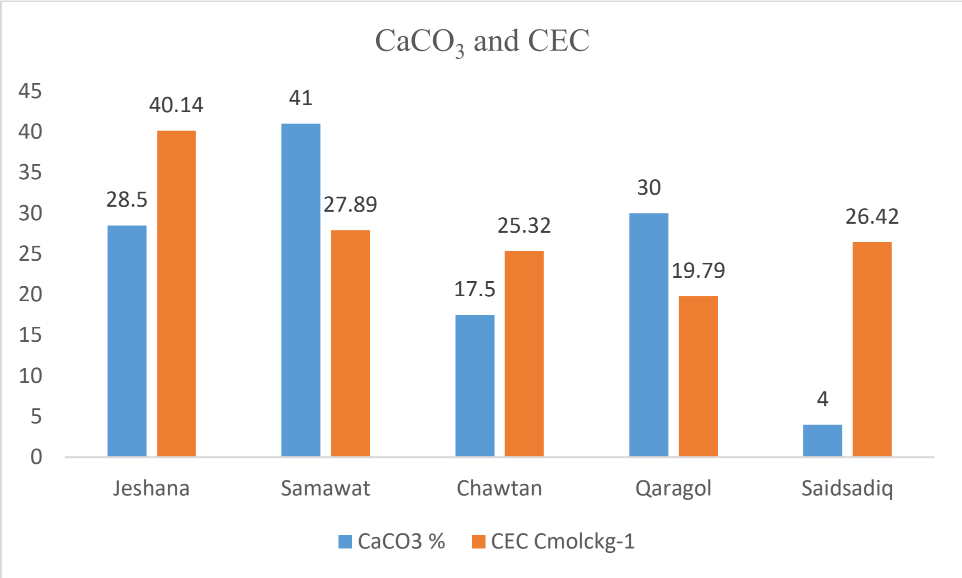

Figure 5: Calcium Carbonate and CEC of five different soil locations.

Conclusion

The results of this study displayed obvious differences in the chemical and physical properties of study locations. On the other hand, we found that a strong relationship exists between soil texture, OM, and WHC. It was appeared that soil with high clay content and organic matter cause to high water holding capacity, while soil that high sand content leads to low water holding capacity, and making it relatively more susceptible to nutrient leaching and drought stress, because coarse textured soils have less ability to retain moisture than fine texture. Hence it is clear that the soil with high clay, CEC, $CaCO_3$, and WHC, then this soil will have very stable aggregate. In this situation the risk of erosion is greatly reduced and the ability to conserve water and nutrients is very high so less conservation is required to prevent erosion and vice versa, but still requires management to prevent waterlogging. The findings indicate that soil properties vary considerably from one location to another, which can affect soil productivity and management requirements. Understanding these variations is important for improving soil use and supporting sustainable agricultural practices in the study area to prevent soil erosion and retain soil physiochemical properties in good condition.

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