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Mappig of Some Properties of the Solhan Plain Soils by Using Ordinary Kriging Method

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Abstract

This study aimed to show the spetial variability and distribution of certain soil properties of the Solhan Plain in Bingöl using data derived from soil quality parameters such as organic matter, cation exchange capacity, and available water content. Soil samples were collected from 85 different coordinates at a depth of 0-30 cm, with sampling points arranged in a 300 m x 300 m grid using ArcGIS 10.8 software. Laboratory analyses were conducted to determine the available water content (AWC), cation exchange capacity (CEC), and organic matter content (OM) of the soil samples. The results revealed that the AWC of the Solhan Plain ranged between 1.06% and 25.27%, with an average of 10.15%. The CEC varied from 35.38 to 85.28 cmol.kg^{-1}, averaging 60.53 cmol.kg^{-1}. The organic matter content ranged from 0.84% to 4.76%, with an average of 2.50%. For the soils in the study area to perform their desired functions, their physical, chemical, and biological quality must meet the required standards. In areas where soil quality is low, practices such as crop rotation and manure application can positively impact the physical, chemical, and biological properties of the soil in a short time. Conversely, poor land management practices can further degrade already weak soil properties. This study emphasizes the importance of providing farmers, land managers, and decision-makers with the necessary information to make informed and effective decisions regarding sustainable land use and soil health improvement practices. This study emphasizes the critical role of soil quality in ensuring sustainable agricultural production and environmental health. By understanding the spatial variability of soil properties like AWC, CEC, and OM, stakeholders can make informed decisions to improve soil functionality and resilience. The findings underscore the need for integrated soil management practices that balance productivity with conservation, ensuring the long-term sustainability of the Solhan Plain and similar regions.

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Solhan Ovası Topraklarının Bazı Özelliklerinin Ordinary Kriging Yöntemi Kullanılarak Haritalanması

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Öz

Bu çalışma, organik madde, katyon değişim kapasitesi ve kullanılabilir su içeriği gibi toprak kalitesi parametrelerinden elde edilen verileri kullanarak Bingöl'deki Solhan Ovası'nın belirli toprak özelliklerinin alansal değişkenliğini ve dağılımını göstermeyi amaçlamıştır. Toprak örnekleri 85 farklı koordinattan 0-30 cm derinlikte toplanmış ve örnekleme noktaları ArcGIS 10.8 yazılımı kullanılarak 300 m x 300 m'lik bir gridde düzenlenmiştir. Toprak örneklerinin yarayışlı su içeriğini (YSİ), katyon değişim kapasitesini (KDK) ve organik madde içeriğini (OM) belirlemek için laboratuvar analizleri yapılmıştır. Sonuçlar, Solhan Ovası'nın YSİ'sinin %1,06 ile %25,27 arasında değiştiğini ve ortalama %10,15 olduğunu ortaya koymuştur. KDK 35.38 ila 85.28 cmol.kg^{-1} arasında değişmekte olup, ortalaması 60.53 cmol.kg^{-1}'dir. Organik madde içeriği %0,84 ile %4,76 arasında değişmekte olup ortalaması %2,50'dir. Çalışma alanındaki toprakların istenen işlevleri yerine getirebilmesi için fiziksel, kimyasal ve biyolojik kalitelerinin gerekli standartları karşılaması gerekmektedir. Toprak kalitesinin düşük olduğu bölgelerde, ürün rotasyonu ve gübre uygulaması gibi uygulamalar toprağın fiziksel, kimyasal ve biyolojik özelliklerini kısa sürede olumlu yönde etkileyebilir. Tersine, kötü arazi yönetimi uygulamaları zaten zayıf olan toprak özelliklerini daha da bozabilir. Bu çalışma, çiftçilere, arazi yöneticilerine ve karar vericilere sürdürülebilir arazi kullanımı ve toprak sağlığını iyileştirme uygulamalarına ilişkin bilinçli ve etkili kararlar almaları için gerekli bilgilerin sağlanmasının önemini vurgulamaktadır. Bu çalışma, sürdürülebilir tarımsal üretim ve çevre sağlığının sağlanmasında toprak kalitesinin kritik rolünü vurgulamaktadır. YSİ, KDK ve OM gibi toprak özelliklerinin mekansal değişkenliğini anlayarak, paydaşlar toprak işlevselliğini ve direncini geliştirmek için bilinçli kararlar alabilirler. Bulgular, Solhan Ovası ve benzer bölgelerin uzun vadeli sürdürülebilirliğini sağlamak için üretkenliği koruma ile dengeleyen entegre toprak yönetimi uygulamalarına duyulan ihtiyacın altını çizmektedir.

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Introduction

The rapid increase in the world population is making access to basic food resources increasingly difficult and deepening the global hunger problem. According to 2024 data, the number of people suffering from hunger has reached 733 million, with one third of this group being children under the age of five. In addition, 130 million people are struggling with chronic hunger by 2023 (Anonymous, 2024a). This situation necessitates the adoption of sustainable environmental policies and effective management of natural resources. In this context, the examination of the Solhan Plain soils is of great importance. One of the most important factors that increase productivity in crop production is the organic matter content of soils. In addition to improving the physical properties of the soil, organic matter contributes significantly to crop production by providing plant nutrients and energy source for microorganisms. Improvement of physical, chemical and biological properties of soil can directly affect crop yield.

Studies have shown that some organic materials positively affect the physical properties of soil (Alagöz et al., 2006; Özyazıcı et al., 2011; Madakbaş et al., 2014; Demir and Doğan Demir, 2019). In addition, it has been reported that the water holding capacity of the soil contributes significantly to plant growth (Süleyman et al., 2019; Söylemez et al., 2020). The stabilisation of organic matter in soil is directly related to the specific surface area determined by soil texture and mineralogy. This process occurs through organo-mineral interactions and ensures the preservation of organic matter in forms resistant to biological activity (Sagar et al., 1996; Baldock and Skjemstad, 2000). This increases the long-term retention of nutrients in the soil and their availability to plants (Oades, 1998; Anderson and Paul, 1984). Therefore, many researchers have studied the accumulation of organic matter in different fractions and its effects on soil properties (Anderson et al., 1981; Tiessen et al., 1983; Dalal and Mayer, 1986; Caravaca et al., 1999; Zhao et al., 2006).

Like nitrogen, carbon is also affected by factors such as soil texture, clay type and land use and is related to the amount of clay and silt (Hassink, 1994; Hassink, 1997; Parfitt et al., 1997). In this study, the quality parameters such as organic matter, cation exchange capacity and the amount of water available were investigated by laboratory analyses in the soils of Solhan Plain, which is located 6 km away from Solhan District centre. The spatial variability of the obtained soil properties was modelled and mapped by ordinary kriging method using ArcGIS 10.8 software. These analyses provide important data for understanding the regional distribution of some soil quality parameters and developing strategies for sustainable agricultural practices.

Material and Method

Basic Characteristics of the Research Area

This research was carried out in a specific region in Solhan district of Bingöl province. The study area is located in the south of Bingöl-Muş highway and is located between 4564904,46 - 4567004,46 north latitudes and 4711938,672 - 4714938,672 east longitudes according to WGS 1984 UTM Zone 37N coordinate system. The climate characteristics of Solhan district are arid and hot in summer and cold and harsh in winter. The average annual temperature of the district was measured as 11,4 °C (Anonymous, 2024).
According to the climate classification, the climate pattern of the region is Mesic. It is rainy in summer and dry and harsh in winter. Therefore, the humidity regime of the region is defined as Xeric. These climatic characteristics have significant effects on soil structure, vegetation and agricultural activities. These climatic and geographical characteristics of the study area are important factors to be taken into consideration when evaluating the results of the research.

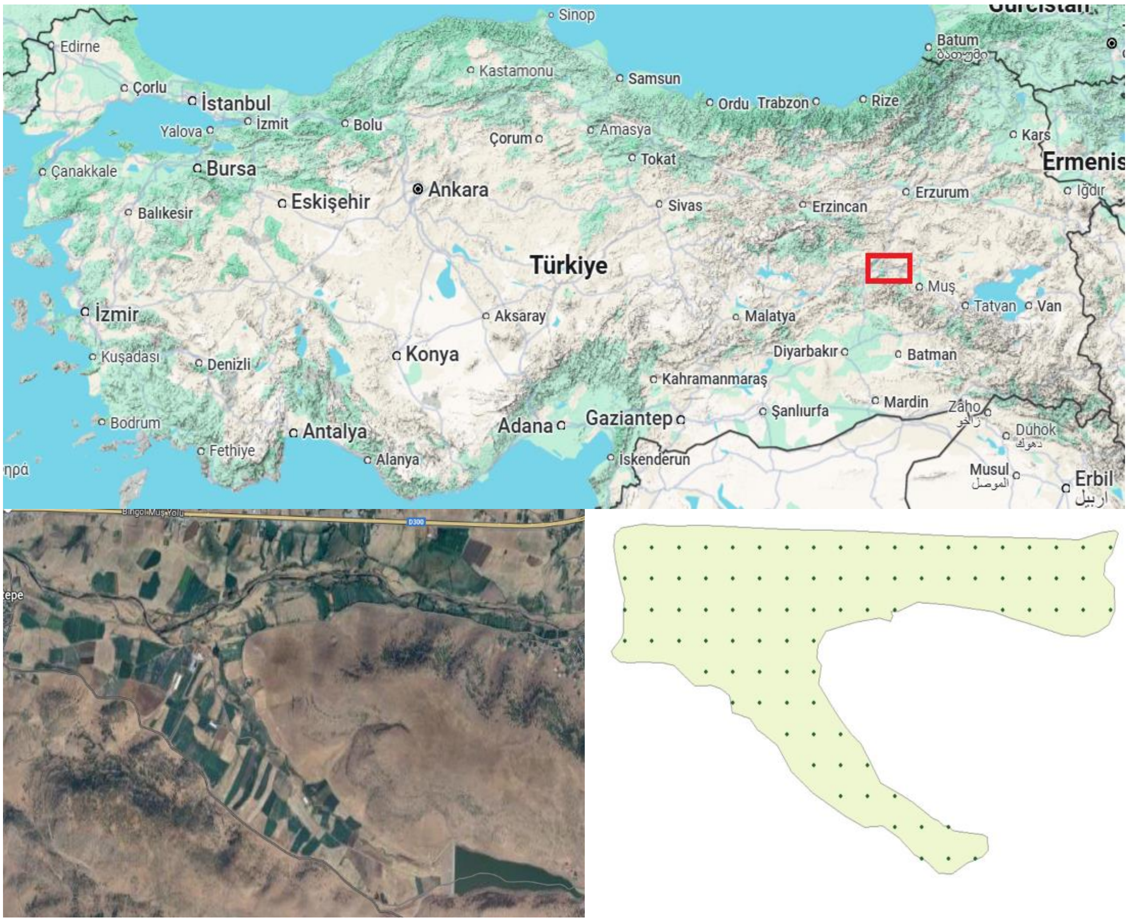

Figure 1. Working area

Soil Sampling and Analyses

In this study carried out in Solhan Plain of Bingöl Province, the boundaries of the research area (Figure 1) were determined on the basemap map using ArcGIS 10.8 software and the area was divided into grids with 300x300 m intervals. Approximately 85 soil samples were collected from the intersection points of these grids from the soil layer up to 30 cm depth. The soil samples were dried at room temperature and then sieved through a 2 mm sieve to prepare them for analysis.
In the field and laboratory analyses, basic soil quality parameters such as useful water content (Klute, 1986), cation exchange capacity (Summer, 1996) and organic matter content (Nelson and Sommers, 1982) were measured. Different models were used to determine soil quality indices (Şeker et al., 2017; Şenol et al., 2020).

In the process of soil quality assessment, since collecting all soil data can be challenging in terms of time and cost, a minimum data set was created and basic parameters reflecting the general soil quality were used (Andrews et al., 2004a; Veum et al., 2017; Budak et al., 2018). This approach both facilitated the data collection process and enabled an effective assessment of soil quality. The findings obtained provide important information about the soil quality of the region and contribute to the development of strategies for sustainable agricultural practices.

Results and Discussion

Table 1. Descriptive statistics of soils in the study area

VARİABLES	Mean	SE	SD	CV	Kurtosis	Skewness	Range	Min	Max
OM	2,50	0,11	0,97	0,94	-0,39	0,77	3,92	0,84	4,76
FC	26,91	0,62	5,74	32,93	-0,26	0,19	26,63	15,19	41,82
PWP	16,76	0,55	5,08	25,84	-0,20	-0,01	23,99	3,94	27,93
AWC	10,15	0,58	5,31	28,15	-0,53	0,39	24,21	1,06	25,27
CEC	60,53	1,31	12,11	146,62	-0,66	-0,14	49,90	35,38	85,28

OM: Organic matter (%), CEC: Cation Exchange Capacity(cmol.kg^{-1}), AWC: Available water content.

Investigation of some basic properties of the soils in the study area revealed that the organic matter content varied between 0.84% and 4.76% and the average was 2.5%. Organic matter content is an important indicator of soil fertility and biological activity. The organic matter content of the soils in the study area varied between 0.84% and 4.76% and the average value was determined as 2.5%. These values indicate that the soils have moderate organic matter content. Organic matter improves soil structure and increases water holding capacity, aeration and microbial activity. However, especially values below 2.5% indicate the importance of management practices (e.g. organic fertilization, green manuring) to increase organic matter content. The available water content ranged between 1.06% and 25.27% with an average of 10.15%. This wide range reflects the diversity in soil characteristics such as texture, structure and organic matter content. Irrigation management and soil improvement practices are of great importance, especially in areas with low available water content. Cation exchange capacity (CEC) values ranged from 35.38 cmol.kg^{-1} to 85.28 cmol.kg^{-1} and the average was 60.53 cmol.kg^{-1}. These high CEC values indicate that the soils are rich in clay minerals and organic matter content. High CEC increases the nutrient retention capacity of the soil and positively affects plant nutrition.

Assessment of Soil Quality

Soil quality assessments are a highly effective method to ensure the sustainability of farmland and to detect the negative impacts of farm management early (Askari and Holden, 2015). Experts generally define soil quality as the capacity of the soil to fulfil its functions within the ecosystem (Andrews et al., 2004a). However, due to dynamic and genetic effects in the ecosystem, the ability of soils to maintain their basic functions such as plant growth is becoming more complex with the increase in agricultural practices (Govaerts et al., 2006). Especially agricultural lands with low capacity to fulfil their genetic functions face the risk of becoming barren by experiencing degradation and loss of biological productivity over time (Acar, 2023).

Organic matter, plant-available water content, and cation exchange capacity (CEC) are critical indicators of soil quality and play a vital role in maintaining soil health and productivity. Organic matter improves soil structure, enhances water retention, and provides essential nutrients for plant growth (Reeves, 1997). It also supports microbial activity, which is crucial for nutrient cycling and soil fertility (Lal, 2015). Plant-available water content determines the soil's ability to supply water to plants, which is essential for sustaining crop growth, especially under drought conditions (Doran and Parkin, 1994). Cation exchange capacity, on the other hand, reflects the soil's ability to retain and supply nutrients such as calcium, magnesium, and potassium, which are vital for plant development (Brady and Weil, 2008). These properties collectively influence the soil's capacity to support agricultural productivity and maintain ecological balance, making them indispensable for sustainable land management.

Developed agricultural countries have developed various standards and improvement methods against soil pollution and degradation. Countries such as the United States, Germany, the United Kingdom, Australia, Canada, Canada, the Netherlands, Japan and Taiwan have established comprehensive guidelines and legal regulations for the assessment and rehabilitation of contaminated soils (ICRCL, 1987; USEPA, 1989; Alloway, 1990; Jacobs, 1990; Tiller, 1992; Ministry of Housing Netherlands, 1994; Chen et al., 1996; Adriano et al., 1997; Chen, 1998). These countries recognise the protection of soil quality as an essential element for agricultural sustainability.

The European Commission, in a statement published in 1997, emphasised that soil quality conservation is a fundamental requirement for sustainable agriculture (Audsley et al., 1997). Accordingly, policies for monitoring, assessing and improving soil quality are gaining importance on a global scale, both to increase agricultural productivity and to maintain environmental balance. Such efforts aim to keep soils healthy in the long term and ensure food security for future generations.

Organic Matter Content of Soil in the Study Area

Soil organic matter is defined as a component that includes the remains of living or dead plants and animals and their wastes. Organic matter plays a vital role for the soil ecosystem and provides many benefits. Firstly, it is an essential source of energy for microorganisms and other living organisms living in the soil. It also increases resistance to erosion by holding soil particles together and improves the water holding capacity of the soil. Besides, it regulates the aeration of the soil and meets the oxygen needs of plant roots and microorganisms.

The map showing the organic matter content in the study area is presented in Figure 2. As a result of the analyses, it was determined that the organic matter content of the area varied between 0.84 % and 4.76 % and the average value was determined as 2.50 %. Since this value corresponds to the range of 1.71-3.00 % determined by Emerson (1991) and Charman and Roper (2000), the organic matter content is classified as 'medium'.

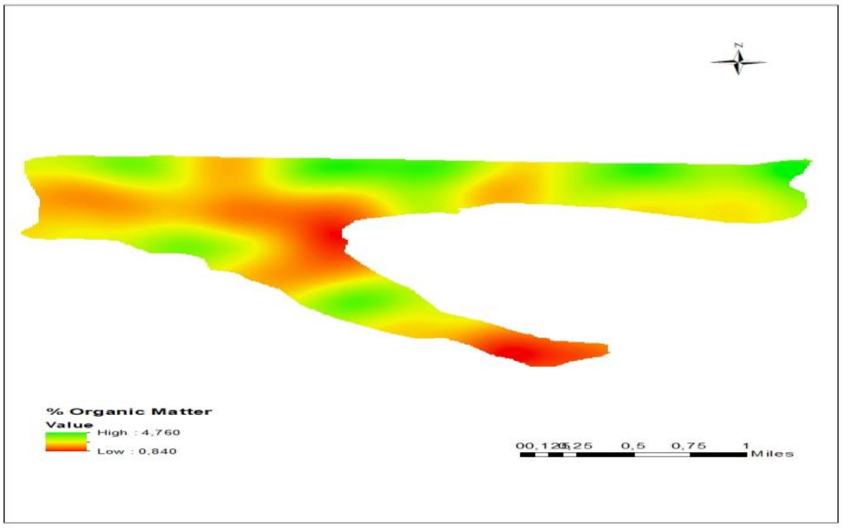

Figure 2. Organic Matter Map of the Study Area

Organic matter contains nutrients such as nitrogen, phosphorus and sulphur which are necessary for plant growth and prevents these elements from being washed away by keeping them in the soil. At the same time, by reducing the volume weight of the soil, it increases its resistance to compaction and makes the soil easier to work. This increases the efficiency of agricultural activities. Organic matter plays an important role in combating climate change by contributing to the storage of atmospheric carbon in the soil. It also protects soil health by reducing the negative effects of pesticides, heavy metals and other pollutants (Anonymous, 2015).

With these properties, organic matter contributes to the sustainability of agricultural production by improving the physical, chemical and biological properties of the soil. The organic matter content of the soils in the study area was analysed by considering these factors and evaluated as an important parameter in determining soil quality.

There are various factors behind the moderate organic matter content of the soils in Solhan Plain. These include:
Factors such as intensive agricultural practices, continuous cultivation on the same soil, monoculture agriculture and excessive use of chemical fertilisers are important factors that reduce the organic matter content of the soil (Lal, 2015). In addition, water and wind erosion cause organic matter loss by transporting the upper layers of the soil (Pimentel et al., 1995). Heavy rainfall can increase water erosion. Especially sudden and heavy rainfall causes the soil to move away from the surface rapidly (Morgan, 2005). Wind erosion is more common in arid and semi-arid regions. Wind can easily carry soil devoid of vegetation (Pimentel et al., 1995; Lal, 2001). Improper tillage methods, especially deep ploughing and frequent tillage, lead to rapid decomposition and removal of organic matter from the soil (Reicosky, 2003). In addition, not adding enough organic materials such as compost, green manure or animal manure to the soil prevents the accumulation of organic matter (Diacono & Montemurro, 2010). Excessive use of chemical fertilisers negatively affects organic matter accumulation by reducing microorganism activities in the soil (Geisseler & Scow, 2014). Climatic conditions are also an important factor; in hot and arid climates, organic matter decomposes rapidly and is removed from the soil, while in regions with low rainfall, organic matter accumulation is lower (Six et al., 2002). Excessively acidic or basic soil pH increases the rate of decomposition of organic matter and reduces its persistence (Brady & Weil, 2008). Decreased activity of soil organisms such as microorganisms and earthworms prevents the decomposition of organic matter and its incorporation into the soil (Brussaard et al., 2007). Improper irrigation practices, especially excessive or insufficient irrigation, cause organic matter loss by disrupting the soil structure and problems such as salinisation negatively affect organic matter accumulation (Qadir et al., 2000).

These factors cause the organic matter content of the soils in Solhan Plain to remain at a moderate level. Measures such as adoption of sustainable agricultural practices, improvement of tillage methods and regular addition of organic materials to the soil are of great importance for maintaining and increasing the organic matter level. Such steps can increase agricultural productivity by maintaining soil health and contribute to environmental sustainability in the long term.

Cation Exchange Capacity Content of Soil in the Study Area

Cation exchange capacity (CEC) of soil refers to the ability of soil to exchange and retain cations (such as Ca^{2+} , Mg^{2+} , K^{+} , Na^{+} , H^{+} , Al^{3+}) held on negatively charged clay minerals and organic matter. CEC is critical for soil fertility and its capacity to provide nutrients to plants. Soils with high CEC retain nutrients better and provide the nutrients needed by plants for longer periods of time. Therefore, CEC is considered an important indicator of soil quality.

The map showing the Cation Exchange Capacity (CEC) values of the soils in the study area is presented in Figure 3. As a result of the analyses, it was determined that the CEC values of the area varied between

35.38 and 85.28 cmol.kg^{-1} and the average value was 60.53 cmol.kg^{-1}. These values indicate that the capacity of the soil to retain nutrients and provide them to the plants is high.

CEC is significantly influenced by factors such as the clay content of the soil, the amount of organic matter and pH. Clay minerals (such as montmorillonite, illite, kaolinite) and organic matter are the main components that increase the CEC of soil. Especially organic matter, due to its high CEC, significantly increases the nutrient retention capacity when added to the soil. This supports soil fertility and plant growth (Andrews et al., 2004b).

Research shows that soil management practices are effective in maintaining soil fertility by increasing the CEC. For example, the use of organic fertilisers, appropriate tillage techniques and the incorporation of organic materials into the soil are practices that increase CEC and improve soil health (Brady & Weil, 2008; Sparks, 2003).

The CEC content of the soils in the study area varies depending on factors such as clay and organic matter content of the soil. Therefore, it is important to increase the organic matter content, to adopt appropriate tillage techniques and to apply balanced fertilisation practices in order to increase the CEC content of the soil and to maintain soil fertility. Such practices contribute to the sustainability of agricultural production by increasing the nutrient retention capacity of the soil.

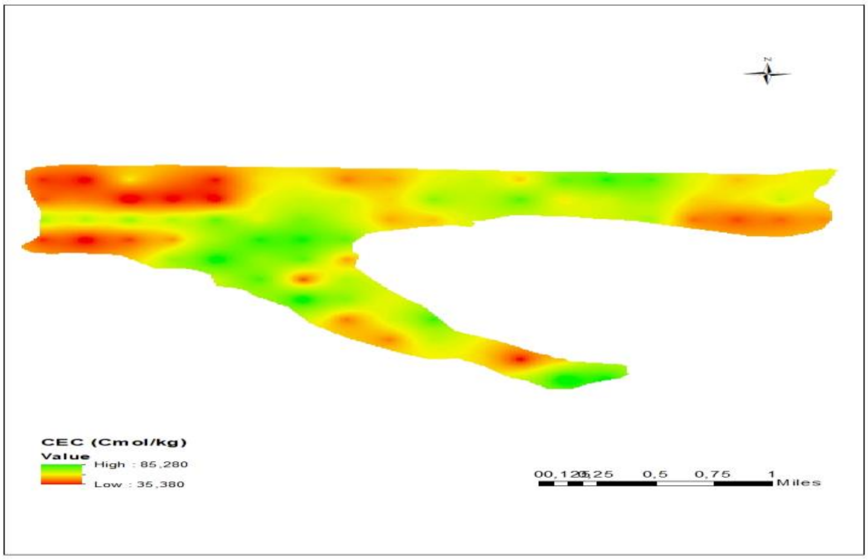

Figure 3. Cation Exchange Capacity Map of the Study Area

According to the classification made by Tan (2005), loamy soils have higher CEC than sandy soils. This is due to the higher clay and organic matter content of loamy soils. Clay minerals and organic matter hold cations more effectively by increasing the negative charge of the soil. Therefore, high CEC values of the soils in the study area can be considered as a positive indicator in terms of soil fertility and nutrient retention capacity.

Available Water Content of Soil in the Study Area

The useful water content of soil refers to the amount of water that plants can utilise in their growth and development processes. This value is defined as the difference between the field capacity of the soil (the maximum amount of water that the soil can hold) and the wilting point (the minimum amount of water that plants cannot absorb). Useful water varies depending on soil texture, structure, organic matter content and clay type.

The map showing the values of the useful water content of the soils in the study area is presented in Figure 4. As a result of the analyses performed, it was determined that the useful water content of the area varied between 1.06% and 25.27% and the average was determined as 10.15%. According to Soil Science Society of America (1997), loamy soils are the most suitable soil types in terms of useful water content.

The soil water content of the soils in the study area varies depending on factors such as soil texture, organic matter content and clay type. Therefore, it is of great importance to adopt organic matter utilisation, appropriate irrigation methods and tillage techniques to increase soil water content and support plant productivity. Such practices contribute to the sustainability of agricultural production by increasing the water holding capacity of the soil.

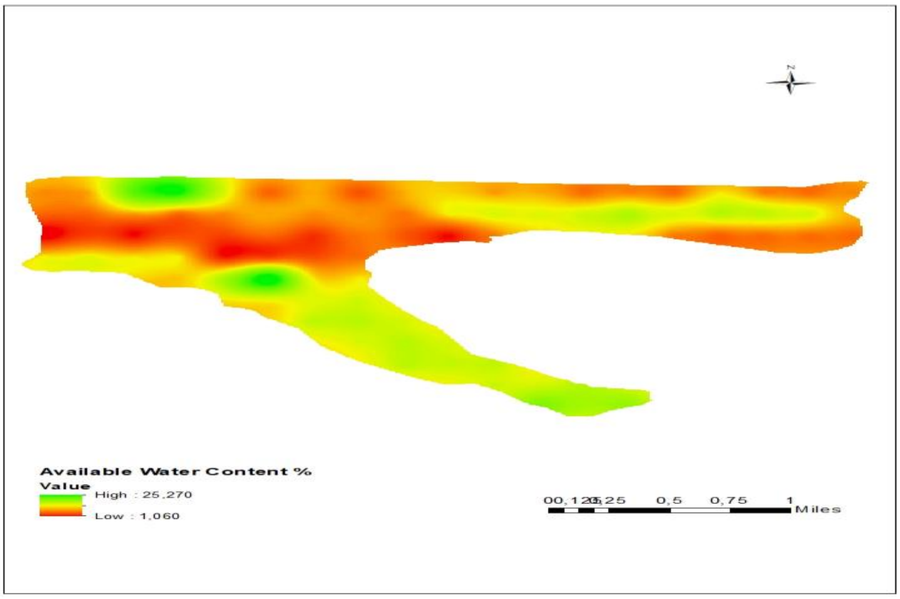

Figure 4. Map of Available Water Content of the Study Area

Research shows that soil management practices favour plant productivity by increasing the available water content. For example, the addition of organic matter to the soil, the use of appropriate irrigation techniques, and the improvement of tillage methods are important practices that increase the available water content and protect soil health (Hillel, 2004; Brady and Weil, 2008). The wide range in useful water content indicates that there is considerable spatial variability in the capacity of soil to hold water and provide water to plants. This variability is due to differences in soil texture, organic matter content and land use practices. Soils with low useful water content (close to 1.06%) are soils with low water holding capacity. In such areas, plants may experience water stress, especially during dry periods. These areas may require more frequent irrigation or soil improvement practices (e.g. adding organic matter).
Soils with high useful water content (close to 25.27%) are more suitable for agriculture because they can hold more water and provide continuous water to plants. These areas are less exposed to drought stress and can support the cultivation of more diverse and productive crops. The average useful water content was 10.15%. This indicates that the soils in the study area generally have a moderate water holding capacity. This is a positive indicator for agricultural activities, enabling plants to use water efficiently and reducing the risk of waterlogging.

Conclusions

Low soil organic matter negatively affects soil fertility, water holding capacity and biodiversity. Therefore, methods such as composting, green manuring, appropriate tillage techniques and organic farming practices should be used to increase organic matter. High CEC of soil is a great advantage in terms of soil fertility and nutrient retention capacity. Clay content, organic matter content, soil pH and appropriate soil management practices are the main factors that increase the CEC. These factors directly affect the agricultural production potential of the soil. As a result, the CEC values of the soils in the study area draw a favourable profile in terms of soil fertility and nutrient retention capacity. This situation may increase the success of agricultural activities in the region. However, sustainable practices need to be continued to maintain and improve soil quality. Organic matter addition (compost, animal manure, green manuring), appropriate tillage techniques (conservation tillage, mulching), soil structure improvement (clay-sand balance, soil additives), vegetation cover and rotation (cover crops, crop rotation) to increase the useful water content of the soil, Effective irrigation management (drip irrigation, irrigation timing), erosion control (terracing, windbreaks), soil pH regulation (liming, organic materials), increasing microbial activity (vermicompost, microorganism promoters), using water retaining polymers (hydrogels) and reducing salinity. These practices increase the water retention capacity of the soil, facilitate plant access to water and support agricultural productivity.

The results of the available water content analysis reveal important spatial patterns and variability in the study area. These findings have important implications for agricultural productivity, land management, and ecosystem health in the lowland. By understanding and developing strategies to address variability in available water content, it is possible to improve soil health, optimize water use, and promote sustainable land use practices. This study emphasizes the critical role of soil organic matter, CEC, and plant-available water content in maintaining soil quality and agricultural sustainability. The findings underscore the importance of adopting sustainable soil management practices to enhance soil fertility and productivity. Future research should focus on long-term monitoring of soil quality indicators, the impact of climate change on soil properties, and the development of innovative technologies for soil conservation. Additionally, region-specific studies should be conducted to tailor soil management practices to local conditions, ensuring the preservation of soil resources for future generations.

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