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ORIGINAL PAPER

Assessment of soil salinity in delta areas using GIS: a case study of the Meriç Delta*

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Abstract

The Meriç Delta is an important wetland in northwestern Turkey, where soil properties have been degraded due to environmental changes. Salinity is a serious threat in the Meriç Delta region, especially in wetlands and agricultural lands, and this situation negatively affects the ecological balance and agricultural productivity of the region. The aim of this study is to investigate in detail the salinity status of the soils of the Meriç Delta using Geographic Information Systems (GIS) and remote sensing techniques, employed to map the soil salinity in the region based on the data obtained, and to evaluate the effects of salinity on agricultural activities and the ecosystem in the region. Soil samples were collected from different parts of the delta and analyzed in a laboratory for such parameters as electrical conductivity (EC), pH and sodium absorption rate (SAR), and the data obtained were analyzed in a GIS environment to produce salinity maps of the Meriç Delta region. The spatial distribution of salinity levels at different depths was revealed by combining satellite imagery with ground observations. It was found that high salinity levels in the region affect plant root development and limit water use, especially in agricultural production areas. Inadequate irrigation and drainage systems also contribute to the salinity problem. Compared to similar research in the literature, this study has highlighted the extent of the soil salinity problem in the Meriç Delta and shown that strategic steps should be taken to solve this problem. In particular, it is recommended to improve drainage systems, adopt sustainable irrigation methods, and to optimize crop cultivation in saline areas. These results are important for the protection of a delta ecosystem and the sustainability of agricultural production.

Keywords: agricultural sustainability, electrical conductivity (EC), Geographic Information Systems (GIS), Meriç Delta, soil salinity

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INTRODUCTION

Integration of modern technologies such as Geographic Information Systems (GIS) plays an important role in the assessment and management of soil salinity. GIS can be used to make a spatial analysis of soil properties, identify areas exposed to salinity, and categorize landscapes for agricultural interventions. For example, Vilček et al. (2019) conducted a study using GIS in order to identify soils suitable for reduced tillage and no-tillage farming. This study shows that GIS helps to effectively categorize agricultural landscapes based on soil salinity and other soil properties (Vilček et al. 2019).

The Meriç Delta is a wetland system with extensive reed beds, freshwater and saltwater lakes that forms the border between Turkey and Greece. This important delta, located in north-western Turkey, is part of an extensive river system of the Meriç River, which flows from Mount Rila in Bulgaria and extends into Turkey, including important tributaries such as the Tunca, Ergene and Arda. The Meriç River, which forms a large delta north of İpsala before flowing into the sea, is an area that supports both ecological diversity and agricultural production (Er 2018). The delta is a biologically rich ecosystem and also stands out as one of the most important wetlands in Turkey (Erkmen, Kolankaya 2006).

The total area of the Meriç Delta is approximately 15,209 ha, and part of this area used to be a nature reserve, later transformed into a national park. In addition, some parts of the delta are still protected as nature reserves (Anonymous 2010). However, the Meriç Delta, which is expected to meet the RAMSAR criteria for the protection of international wetlands, has not yet been included in the list of RAMSAR sites (Gardner et al. 2011). This situation is considered critical for the protection and sustainable use of the Meriç Delta ecosystem.

While being one of the important centers of agricultural productivity in Turkey, the Meriç Delta faces the problem of soil salinity. Soil salinity in this region is caused by various factors, such as climate change, wrong irrigation methods and agricultural practices (Yerli et al. 2019, Dirik et al. 2020, Erdoğan 2024). Salinity negatively affects plant growth and reduces agricultural productivity, which poses serious threats to agricultural sustainability (Dengiz et al. 2022, Abdulrasaq 2024). Gümüş and Durduran investigated the use of multi-criteria decision support systems to determine optimal agricultural areas for sustainable land management. Such systems are crucial for assessing the effects of salinity in wetlands like the Meriç Delta, and contribute to the development of agricultural strategies (Gümüş, Durduran 2020). In addition, remote sensing data can be used to determine the spatial distribution of soil salinity and to plan agricultural practices (Altun, Türker 2021, Koca 2024).

While the Delta region is of great importance for agricultural activities and settlement, it has also been severely affected by human impacts and environmental changes. Particularly in the 1940s, attempts to drain marshes and expand farmland for agricultural purposes led to an increase in soil salinity in the region, and the expected increase in agricultural yields was not achieved; instead, there were negative consequences such as drainage problems and flooding (Karakoç 2011). Interventions in the natural flow of the water system since the 1970s have destroyed some of the wetlands and disturbed the balance of the ecosystem. In particular, the opening of the dam gates in Bulgaria has damaged the delta ecosystem by causing flooding, changing the habitat of many species and threatening the biodiversity of the delta coasts due to water level fluctuations (Er 2018).

Increasing salinity has serious negative impacts on the ecosystem and agricultural activities in important wetlands such as the Meriç Delta. The spread of saline soils in the region has put pressure on rice cultivation and other agricultural activities, threatening the wetland ecosystem. Increased salinity has not only negatively affected agricultural production, but also the livelihoods of farmers in the delta's coastal areas (Nguyen et al. 2019). In addition, water level changes and salinity increases due to climate change in the delta coastal areas threaten the balance of aquatic life and agricultural production (Feyrer et al. 2011).

Recent advancements in Geographic Information Systems (GIS) have enhanced the ability to assess and manage soil salinity effectively. GIS provides a spatial framework for analyzing soil properties and allows for the identification of salinity-affected areas. For instance, Setia et al. (2011) demonstrated the use of high-resolution multispectral satellite imagery to accurately detect and classify salinity at a paddock scale, confirming the correlation between soil EC and salinity classes through ground truthing. This approach highlights the potential of remote sensing combined with GIS to provide detailed insights into soil salinity distribution (Setia et al. 2011).

Moreover, Narjary (2024) explored the use of electromagnetic induction (EMI) and GIS techniques for spatiotemporal soil salinity assessment in waterlogged saline soils. The study found that subsurface drainage significantly reduced soil salinity and improved the spatial correlation of salinity classes, thereby facilitating better land management practices. This indicates that GIS can be instrumental in planning agricultural practices that consider the dynamic nature of soil salinity (Narjary 2024).

In addition, Zhou and Liu (2010) emphasized the use of GIS to simulate temporal and spatial changes in soil salinity, providing valuable data for predicting salinity trends and informing management decisions. Similarly, Khasanov et al. (2023) utilized remote sensing data to map soil salinity in irrigated agricultural land, demonstrating the effectiveness of GIS in assessing salinity distribution compared to traditional methods. These studies collectively illustrate the importance of GIS as a tool for identifying and categorizing landscapes, which is essential for implementing differentiated cultivation systems that can adapt to varying salinity levels (Zhou and Liu 2010, Khasanov et al. 2023).

In this study, the soil salinity status in the Meriç Delta was investigated in detail, and its impact on ecosystem dynamics and agricultural systems was analyzed using GIS (Geographic Information Systems) and remote sensing methods. Soil samples collected in the delta region were analyzed to understand the impact of salinity on agricultural productivity and environmental sustainability. At the same time, the causes of salinity increase in the delta region were analyzed in the context of climatic conditions, water management and human impacts, with the aim of developing strategies to address the problem of soil salinity (Sönmez, Sönmez 2007).

In conclusion, salinity studies in the Meriç Delta are of great importance not only for the protection of the delta ecosystem, but also for the sustainability of agricultural activities. Sustainable management of the delta ecosystem and measures to reduce soil salinity will contribute to agricultural policies and environmental management (Nguyen et al. 2019). In this context, understanding the current state of the Meriç delta and developing strategies to protect the delta ecosystem is critical for both the biodiversity and economic productivity of the region.

MATERIALS AND METHODS

The Meriç Delta is located within the borders of İpsala and Enez districts of Edirne Province in the Marmara region, northwestern Turkey (Köse 2015) – Figure 1. This region, one of the most important wetlands in Turkey, is located in square A1/E according to Davis' quadrangulation method (Davis 1970). The delta has a total area of 111,937 km² and is of great importance in terms of its ecological and biological diversity (Anonymous, 2023). The parts of the study area within the borders of Turkey are delineated by the Meriç River in the west, the Aegean Sea in the south, the province of Edirne in the north and the Meriç River in the west (Kibaroğlu and Garipağaoğlu 2022).

The Meriç River formed the border between Turkey and Greece by the Treaty of Lausanne signed in 1923. According to this treaty, the line passing through the middle of the main branch of the river was accepted as the border between the two countries. In a protocol signed in 1926, it was agreed that the border line would remain fixed and would not change even if the river bed changed over time (Sağlam 2015). The problems related to water resources in the Meriç River Basin are similar to other transboundary water basins in the European Union. Although there have been agreements between Turkey, Greece and Bulgaria at different times in the past, the fact that the three countries have not reached a comprehensive agreement on water use and basin management makes the management of water resources in the region difficult. In particular, Bulgaria has a common stance on the establishment of early warning systems and data sharing to prevent floods,

Fig 1. Study area map, topographic map of Meriç Delta natural areas, Meriç Delta wetland and buffer zone (red – wetland zone, blue – buffer zone)

but there is no concrete agreement on the use and management of water resources (Sağlam 2015).

Lake Gala, located in the Meriç Delta, is one of the most important water bodies in the region, reflected in its status of Lake Gala National Park. The lake is located between the districts of Enez and Ipsala, at the confluence of the Meriç River and the Aegean Sea (DSI 1986). This region, which includes about 3,000 ha of forest and 3,090 ha of wetlands, is of great ecological importance as it is a stopover and breeding ground for many migratory birds. There are also 20 species of fish, 40 species of plants and more than 200 species of birds found in the park (Kocaman 2011). The surroundings of the national park are swampy and covered with reeds. As the soil dries up in the summer months, the marshes also dry up and allow passage (Akova 2012).

Lake Dalyan is located in the south of Enez District and covers an area of 3.4 km², with a generally sandy soil structure. The lake is poor in natural vegetation and the water depth varies between 10 cm and 1.5 m. Due to the high salt and sodium content of the water, it is used for agricultural activities (Korkut 1972). Pamuklu Lake is one of the freshwater alluvial lakes in Edirne Province and its depth is about 70 cm (Korkut 1972). Similarly, Bücürmene Lake is located south of Dalyan Lake and covers an area of 76 hectares. The depth of the lake varies between 50 and 80 cm. It is not used as a source of drinking water due to its high salt and sodium content (Anonymous 2024).

In the Meriç Delta salinity study, field sampling was carried out in May, and a total of 89 soil samples were collected from 30 gridded points

Fig 2. Google Earth map showing sample locations

(Figure 2). These samples were collected at certain depths, taking into account the factors affecting salinity distribution and the specific objectives of the study.

At the 0-30 cm sampling depth, surface salinity can be strongly influenced by environmental factors, such as evaporation, precipitation and run-off. Therefore, samples taken from 0-30 cm depth are useful for determining salinity changes due to short-term environmental fluctuations (Narjary et al. 2019). Studies by Solangi et al. (2019) also suggest that this depth is suitable for monitoring sudden changes in salinity

Sampling at different that the 0-30 cm depth, such as the 30-60 cm, 60-90 cm sampling depths, allows for a more comprehensive examination of vertical salinity profiles in the soil. This method provides a better understanding of the effects of factors, such as groundwater inflow, soil structure and vegetation cover (Narjary et al. 2019). In the study by Narjary et al. (2019), a high correlation was found between samples taken from different soil depths, with coefficients of determination ranging from 0.88 to 0.9, especially in the 0-90 cm depth range.

Salinity levels in the Meriç Delta are influenced by several factors, such as groundwater dynamics, soil properties and agricultural practices. Therefore, sampling at more than one depth provides a more holistic perspective of salinity distribution in the delta. The decision on sampling depths should be made according to the research questions and the depth at which the most active salinity related processes occur. In this context, it was considered that sampling at depths of 0-30 cm, 30-60 cm and 60-90 cm would be more appropriate.

The pH and EC (electrical conductivity) values of the soil samples were measured using standard and commonly used methods. Following the method of Jackson (1958), pH measurements were made using a pH meter with glass electrodes at a soil to water ratio of 1:2.5. This method is a common reference point for accurate determination of soil pH.

Organic matter content was measured using the modified Walkley Black Wet Burning method (Walkley 1947). This is one of the most widely used methods for determining the amount of organic carbon in soil, and gives reliable results of calculations of amounts of organic matter in soil.

The sodium adsorption ratio (SAR) is an important indicator of the alkalinity of soils. The SAR coefficient expressed by Benice and Ağca (2022) helps to evaluate soil salinity by comparing the sodium content of the soil with other cations. The SAR formula is:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{(Ca^{+} + Mg^{2+})}{2}}}$$

This formula was applied to compare soil sodium (Na^{+}) with calcium (Ca^{2+}) and magnesium (Mg^{2+}) levels, and it can help to analyze soil salinity and alkalization trends. SAR and ESP classification values are given in Table 1.

RESULTS AND DISCUSSION

The analysis of electrical conductivity (EC) values plays a crucial role in the assessment of salinity levels in the Meriç Delta. The lowest EC value obtained at 30-60 cm depth at point MD3 was 0.11%, while the highest value was 26.90% at 60-90 cm depth at point MD4. These values clearly show the salinity differences in the soil profile.

According to the EC limits in Richard (1954): at point MD1, all depths (0-30 cm, 30-60 cm and 60-90 cm) are classified as very saline. At MD2, while a moderately saline condition was observed at the surface (0-30 cm), salinity reached very saline values with increasing depth. At MD3, while the surface (0-30 cm) and 60-90 cm depths were slightly saline, salinity decreased to unsaline levels at 30-60 cm depth. All depths at point MD4 (0-30 cm, 30-60 cm, 60-90 cm) were classified as very saline. At point MD5, while the surface (0-30 cm) was unsaline, salinity increased to moderately saline in the lower layers (30-60 cm and 60-90 cm). All samples between points MD6 and MD15 (at all three depths) were recorded as very saline. While at point MD16, a moderately saline level was observed at the surface (0-30 cm), reaching a very saline level at 30-60 cm depth. All samples between MD17 and MD30 are in the very saline category at all three depths.

Table 1

SAR and ESP values

Points	Depth S (cm)					
	0-30		30-60		60-90	
	SAR	ESP	SAR	ESP	SAR	ESP
MD1	6.3	7.4	11.4	13.4	16.9	19.1
MD2	1.1	0.4	1.5	0.9	2.0	1.6
MD3	10.1	12.0	9.4	11.3	13.1	15.3
MD4	141.2	67.4	188.9	73.5	195.4	74.2
MD5	1.5	1.0	2.1	1.7	2.0	1.6
MD6	13.0	15.2	11.2	13.3	11.9	14.0
MD7	11.2	13.2	16.7	18.9	19.1	21.2
MD8	1.5	0.9	2.1	1.7	3.6	3.9
MD9	18.0	20.2	16.6	18.8	11.7	13.8
MD10	6.4	7.6	10.6	12.6	14.2	16.5
MD11	17.7	19.9	19.4	21.4	17.7	19.9
MD12	8.3	9.9	18.0	20.2	16.8	19.0
MD13	2.4	2.2	2.1	1.9	3.0	3.1
MD14	14.5	16.8	22.6	24.3	38.5	35.7
MD15	13.9	16.1	20.9	22.8	25.4	26.6
MD16	4.4	4.9	1.9	1.6	-	-
MD17	17.9	20.0	7.3	8.7	6.4	7.5
MD18	17.3	19.5	24.3	25.7	31.6	31.2
MD19	15.4	17.7	23.4	25.0	27.3	28.1
MD20	5.5	6.4	6.2	7.3	5.3	6.2
MD21	10.6	12.6	9.2	10.9	9.0	10.7
MD22	30.2	30.2	25.5	26.7	22.6	24.3
MD23	20.7	22.7	25.8	26.9	31.0	30.8
MD24	17.9	20.1	27.3	28.0	37.7	35.2
MD25	25.5	26.7	27.2	28.0	23.1	24.7
MD26	6.4	7.6	9.9	11.8	28.2	28.8
MD27	17.9	20.1	17.4	19.6	17.6	19.8
MD28	14.1	16.3	16.8	19.1	19.1	21.2
MD29	5.9	6.9	10.1	12.0	12.7	14.9
MD30	5.0	5.7	27.4	28.2	37.6	35.1

According to these data, of the 89 samples analyzed, 2 are classified as not saline, 2 as slightly saline, 4 as moderately saline and 81 as very saline. This indicates that soil salinity is widespread throughout the Delta, and that there are regionally very high salinity levels. Maps of EC distribution are shown in more detail in Figures 3.

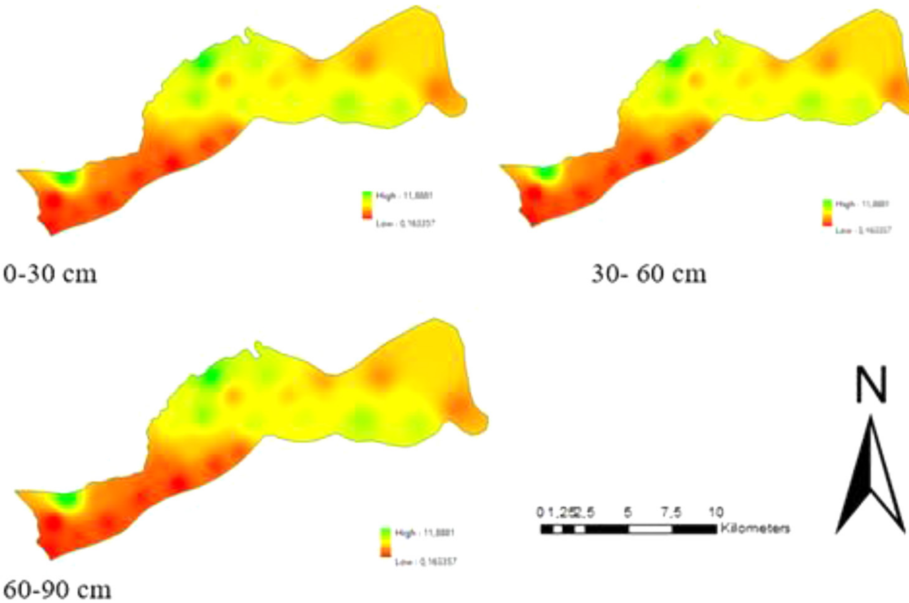

Fig 3. EC distribution map

When examining the pH values of the soils, the variations between different points and depths are remarkable. The lowest pH value was recorded at 0-30 cm depth at point MD5 (5.26), while the highest pH value was recorded at 30-60 cm depth at point MD1. Following the limitations of, these pH values were analyzed under different classes:

Point MD1 is classified as strongly alkaline at all depths (0-30 cm, 30-60 cm and 60-90 cm). Point MD2 was neutral at the surface (0-30 cm), while pH values decreased with depth, becoming slightly acidic. At point MD3, neutral values were observed at the surface (0-30 cm). However, with increasing depth, it increased to slightly alkaline at 30-60 cm and to moderately alkaline at 60-90 cm. At point MD4, the pH, which was moderately alkaline at the surface, decreased to slightly alkaline with increasing depth (30-60 cm and 60-90 cm). At point MD5, the pH was strongly acidic at the surface, but became moderately acidic at 30-60 cm and neutral at 60-90 cm with increasing depth. At MD6, all depths are moderately alkaline. Point MD7 was slightly acidic at the surface (0-30 cm), becoming neutral at 30-60 cm and moderately alkaline at 60-90 cm with increasing depth. At point MD8, all depths are in the moderately alkaline class. At point MD9, while the surface (0-30 cm) was moderately alkaline, the lower layers (30-60 cm and 60-90 cm) were slightly alkaline and strongly alkaline, respectively.

Similarly, other points had different pH values at different depths: MD10: slightly acidic at the surface, neutral in the middle layer and slightly alkaline in the lower layer. MD11: slightly alkaline in the upper and middle layers and moderately alkaline in the lower layer. MD12: moderately alkaline in the top and bottom layers and slightly alkaline in the middle layer. MD16: Moderately acidic on the surface, slightly acidic at 30-60 cm. MD17: slightly acidic at the surface, moderately alkaline at lower depths. According to this analysis, the pH distribution of the 89 samples is as follows: 1 is classified as strongly acidic, 2 as moderately acidic, 5 as slightly acidic, 7 as neutral, 30 as slightly alkaline, 40 as moderately alkaline, and 4 as strongly alkaline.

The distribution and details of these pH data are shown in Figure 4. These results show that the majority of the soils in the Meriç Delta are alkaline, with acidic conditions observed in places.

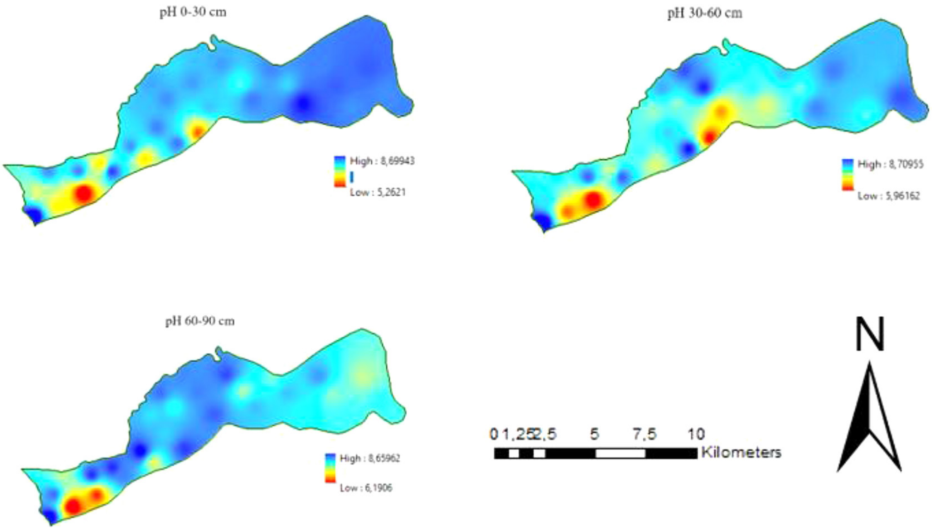

Fig 4. The distribution and details of these pH data

SAR is a measure of the presence of sodium in soil and its effect on soil structure. SAR is defined as the ratio of sodium (Na) ions to calcium (Ca) and magnesium (Mg) ions in soil water solution. High SAR values indicate an excess of sodium in the soil, which can adversely affect soil structure and make it difficult to retain water in the soil. This can reduce agricultural productivity and lead to soil erosion (Shrestha 2006).

ESP (exchangeable sodium percentage) refers to the percentage of exchangeable sodium in the soil. It indicates how much of the total cations (sodium, calcium, magnesium, etc.) present in the soil is sodium. ESP is an important parameter in assessing soil salinity and sodicity status. High ESP values indicate that soils are sodicised, which can be detrimental to agricultural productivity. Especially in irrigated areas, high ESP values can lead to deterioration of soil structure and reduce the water holding capacity of the soil (Shrestha, 2006).

SAR and ESP values for the region are given in the Table 2.

Table 2

SAR and ESP classification values (Richards 1954, Ayers, Westcot 1985, USDA, 1954)

SAR value	Class	ESP Value	Class
0-10	low risk (safe)	0-15	normal (no alkali problem)
10-18	moderate risk	15-30	slightly alkaline soil
18-26	high risk	>30	severe alkaline soil
>26	very high risk		

The SAR and ESP values of the soils in the Meriç Delta are crucial for understanding the salinity status of the soils and its effect on plant growth. The data obtained show that there are low and high ESP values at 15 points at 0-30 cm depth and 14 low and 16 high points at 30-60 cm depth. This indicates that the presence of sodium in surface soils and soil salinity can affect plant root growth. In particular, low ESP values at 10 points and high ESP values at 19 points at 60-90 cm depth indicate that deep soil layers also tend to be saline, which is related to groundwater levels and drainage conditions.

SAR values were low at 12 points, medium at 14 points, high at 2 points and very high at 2 points at 0-30 cm depth. This distribution indicates that sodium in the surface layers may adversely affect plant growth and irrigation practices in these areas should be carefully managed. SAR values at 30-60 cm depth were low at 10 points, medium at 9 points, high at 7 points and very high at 4 points. These data show that soil salinity tends to increase at medium depths, and this situation may have negative effects on plant health in terms of root depth. The results at 60-90 cm depth show a similar situation, with SAR values being low at 7 points, medium at 9 points, high at 5 points and very high at 8 points.

The soil analyses carried out in the Meriç Delta clearly show the heterogeneous structure of salinity and pH levels in the region. The electrical conductivity (EC) data obtained show significant differences according to the depth of the soil profiles. In particular, the EC value of 26.90% at 60-90 cm depth at point MD4 can be considered as a critical level that may negatively affect the intensity of salinity and the uptake of water and nutrients at this depth. The low EC values at point MD3 indicate that salinity in this area varies with depth.

According to Richard's (1954) classification, the salinity of soils was determined to be very saline, indicating that salinity is a widespread problem throughout the Delta. The fact that 81 out of 89 samples are classified as very saline poses serious risks to agricultural activities and ecosystem health. In areas of high salinity, agricultural productivity declines and plant diversity is inevitably reduced.

When analyzing the pH values, the fact that the majority are in the moderately alkaline class underlines the alkaline soil characteristic of the Meriç Delta. The fact that all depths at the MD1 point are classified as strongly alkaline should be considered as a situation that may adversely affect plant nutrition when combined with the salinity problem in this region. The observation of acidic conditions in places is another important issue to consider in terms of soil management.

Analysis of SAR and ESP values also plays a critical role in assessing salinity status. Low ESP values were observed at 15 points and high ESP values were observed at 15 points at 0-30 cm depth. This indicates that sodium accumulation in surface soils can have a negative effect on plant root growth. Particularly high ESP values at 60-90 cm depth indicate that deeper layers also tend to be saline and this is directly related to groundwater levels. SAR values at 0-30 cm depth were low at 12 points, medium at 14 points, high at 2 points and very high at 2 points, suggesting that the presence of sodium in the surface layers may adversely affect plant growth. The high SAR values at 30-60 cm depth indicate that salinity tends to increase at intermediate depths and this situation may have negative effects on plant health in terms of root depth.

The high salinity and alkalinity in the region requires appropriate crop selection and soil management in agriculture. Preferring crops with high salt tolerance may be an important strategy to ensure agricultural sustainability. Abdulrasaq (2024) concluded that potassium nitrate is effective in alleviating negative effects of salt stress. Further studies in line with these findings may contribute to the development of soil improvement methods and desalination techniques.

CONCLUSIONS

Soil salinity in the Meriç Delta is a major problem for the region's agricultural productivity and ecosystem health, and is highly varied, reflecting the heterogeneity of the soils and the effects of management practices such as irrigation. Salinity adversely affects growth by limiting plant roots' access to water and nutrients; concurrently, it can alter soil pH, creating acidic or alkaline conditions. Soil analyses show that SAR and ESP values are generally low or moderate in the region, but some areas have severe sodium and alkali problems. Sustainable agricultural practices and appropriate irrigation methods are recommended to reduce the impact of these problems. Strategies such as the use of low SAR and EC water, alternating freshwater with saline water (Zhangzhong et al. 2018), and soil amendments with gypsum or organic matter can be effective. In addition, the use of plant varieties with high salt tolerance (Eid and Mahmoud 2010), application of precision irrigation techniques such as drip irrigation (Rameshwaran et al. 2016), and development of efficient drainage systems support the maintenance of soil structure. Methods such as protecting freshwater aquifers through managed aquifer recharge techniques and preventing saltwater intrusion (Suribabu et al. 2012) are also recommended. In addition, less but more frequent irrigation can be used to prevent salt accumulation in the soil. Effective implementation of these strategies plays a crucial role in ensuring the agricultural sustainability of the Meriç Delta and contributing to the conservation of natural resources.

Author contributions

Huseyin SARI: designed the study, made revisions, performed statistical analyses, supervised and funded the study. Gökben TOPAL: analyzed the data and wrote the manuscript, conducted the experiments

Conflicts of interest

There is no conflict of interest.

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