

SOIL SALINITY STATUS IN NAMANGAN REGION, UZBEKISTAN

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Abstract

Understanding soil salinity levels is essential for effective agricultural planning and, consequently, for ensuring food security and sustainability. However, poor practices have significantly impacted soil salinity levels in many developing countries. In Uzbekistan, soil salinity levels have not been adequately assessed and documented over the past decades, leading to adverse effects on agricultural food production. This paper presents a first attempt to systematically document soil salinity levels in the Namangan area of Uzbekistan. Data on soil salinity from the last 22 years (2000-2022) were obtained from the Namangan Regional Department of Agriculture. Additionally, soil samples from the Uychti district of Namangan, collected in 2013, 2014, and 2017, underwent thorough laboratory analysis. Documented soil salinity levels in the Namangan region highlight a need for significant attention to mitigate these impacts. Experimental findings demonstrate the effectiveness of mulching agro-technologies in reducing soil salinity. However, a comprehensive assessment and an adaptive approach to mitigate soil salinity in the Namangan region are urgently needed to ensure long-term agricultural productivity.

Keywords: Irrigated land areas; Mulching; Namangan; Salinity indicators; Soil salinity; Uzbekistan

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Introduction

Salts are naturally present in both land and sea (Davies, 2017). Salinization occurs when the concentration of salts in soil or water exceeds levels that are undesirable for a society's productive, aesthetic, or environmental needs. Land and water resources may be naturally saline, known as primary salinity, or can experience increased salt concentration due to human activity, known as secondary salinity (Foley *et al.*, 2005; Koch *et al.*, 2013; Nachshon, 2018). Soils with high soluble mineral salt content are harmful to plants (Shahbaz and Ashraf, 2013; Shrivastava and Kumar, 2015), posing a global issue that can economically impact societies through land degradation and desertification. Anthropogenic salinity contributes significantly to this problem, reducing irrigated land by over one million hectares annually (Mohanavelu *et al.*, 2021). Saline soils cover more than 25% of the Earth's surface, underscoring the widespread nature of the issue (Shahid *et al.*, 2018). The problem is categorized into primary and secondary soil salinization. Primary soil salinization occurs when various salts accumulate due to geographical factors or uneven distribution of substances on and above soil horizons. Secondary salinization, however, results from poor irrigation practices, such as excessive irrigation that raises salty groundwater or using overly saline water in crop production (Mkilima, 2023).

Mitigating the adverse impacts of soil affected by salinity and sodicity globally poses a significant challenge. Effectively reducing or overcoming these issues involves eliminating salts from the root zone, which is identified as the most efficient method (Shrivastava and Kumar, 2015). However, worldwide soil reclamation encounters difficulties due to a lack of awareness, high costs, and limited access to advanced technologies (Mohanavelu *et al.*, 2021). Despite these challenges, different countries employ various traditional methods to address soil salinity and sodicity, with the most effective strategy encompassing proper tillage, seedbed preparation, land leveling for uniform water distribution, cyclic irrigation with both fresh and saline water, transitioning to organic manures, and adopting soil conservation practices (Diacono and Montemurro, 2015; Mohanavelu *et al.*, 2021).

Various anthropogenic activities significantly changed land use patterns and, therefore, unbalanced the water cycle (Makubura *et al.*, 2022), which impacted soil moisture. The aggressive development of irrigation in Central Asia during the 1960s and 1970s represents this soil salinity issue (Högselius, 2021). Intensive irrigation efforts

targeted steppes and desert regions, aiming to cultivate cotton in the Amu Darya and Syr Darya river basins (Saiko and Zonn, 2000). Despite these intentions, the reliance on ancient irrigation methods led to a rise in groundwater levels, triggering secondary salinization of the land due to irrigation surplus (Karimov, 2011). This phenomenon resulted gradual decline in agricultural crop production, with salty soils covering a staggering 50% of Central Asia's landmass by 2018 (Yu and Wu, 2018).

The deserts and semi-deserts in Central Asia, characterized by high temperatures, arid climates, and limited rainfall, often exhibit widespread salinity in their soils (Pankova and Konyushkova, 2013). Salt removal is observed in mountainous areas and foothills. However, as salt-rich underground and surface waters move from higher elevations to the plain, they spread out or become more distributed across the plain (Dustnazarova *et al.*, 2021). In an arid climate where evaporation surpasses precipitation, coupled with poor soil drainage, there is a tendency for the soil's salt content to increase (Pankova and Konyushkova, 2013).

Salinity-induced land degradation is a pressing global issue affecting both developed and developing countries, with serious implications for agricultural productivity, food security, and economic stability. In regions like Central Asia, where agriculture forms the backbone of the economy, rising salinity levels threaten to exacerbate desertification, reduce arable land, and increase food insecurity. Despite the global recognition of salinity as a major environmental challenge (FAO, 2019), there has been limited attention paid to the precise extent and impact of soil salinization in certain high-risk regions such as Uzbekistan. (Gafurova and Juliev, 2021).

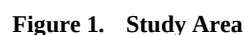
Currently, 53% of Uzbekistan's 4.3 million hectares of irrigated land is affected by salinity, leading to significant annual losses in agricultural production across all crop types. Different regions within Uzbekistan exhibit varying degrees of soil salinity. Notably, in the Namangan region, adverse agricultural practices have led to several forms of land degradation over time. These practices include secondary salinity, soil erosion from irrigation, rising groundwater levels, deflation, and diminished soil fertility (Gafurova and Juliev, 2021). Therefore, this study aims to address the lack of recent documentation of salinity levels in the Namangan region, offering the first comprehensive assessment of soil salinity in decades.

focused on mitigating the adverse effects of soil salinity. Lessons from this research could be applied to similar arid and semi-arid regions worldwide. Furthermore, the conclusions drawn from the research can greatly assist farmers by providing them with knowledge to mitigate the negative impacts of soil salinity on crop yields. Armed with an understanding of the salinity levels in their fields, farmers can implement targeted strategies to improve soil quality. Additionally, the paper's focus on assessing soil salinity contributes to ensuring the sustainability of agricultural production in the Namangan region and beyond. By addressing soil salinity issues proactively, stakeholders can safeguard agricultural productivity, enhance food security, and promote sustainable land management practices.

Data and Study Area

The study was conducted in the northern part of the Uychi district in Uzbekistan's Namangan region hills as depicted in Figure 1. The Namangan region is located in the southern Fergana Valley, between latitudes 40°38'53" N and 41°32'39" N and longitudes 70°20'23" E and 72°10'48" E. It has an area of around 7440 km². The mountainous areas of the region, which are located more than 1000 meters above mean sea level (MSL), receive annual rainfalls of 600-700 mm (Chathuranika *et al.*, 2023). Lower portions in this hilly terrain with elevations of 500-1000 m above MSL receive 200-300 mm of yearly rainfall.

Understanding the local dynamics of salinity not only contributes to regional agricultural strategies but also informs global initiatives aimed at combatting land degradation and promoting sustainable land management practices. By documenting soil salinity in the Namangan region, this research not only addresses a critical gap in Uzbekistan's agricultural data but also contributes to the growing body of international research



Data Sources

The data used in this study were sourced from two primary institutions. The salinity status of irrigated land areas in the Namangan region was obtained from the Namangan Regional Department of Agriculture, Uzbekistan from 2000 to 2022. This institution provided annual data on the salinity status of irrigated lands in the Namangan region from 2000 to 2022. These data include the total irrigated area, the total saline area, and the degree of salinity categorized as lightly, moderately, or strongly saline.

In addition, the soil salinity maps of three districts were obtained from the Soil Monitoring Department of the Uzbekistan State Institute for Land Reclamation and Land Monitoring (Uzdaveroiyiha) for the year 2017. These maps detail the spatial distribution of soil salinity in these districts.

Methodology

Determination of the level of salinity in the arable lands of the region from 2000 to 2022.

The data, sourced from the Department of Agriculture of the Namangan region, has been summarized in Supplementary Table S1, including information on the total irrigated area. Annually, on the 1st of October, the Department of Agriculture conducts soil salinity measurements, exclusively in laboratory settings. These measurements encompass the total saline area and categorize the degree of

salinity ranging from lightly salted to strongly salted, for each year spanning from 2000 to 2022. Trend analysis (Chatfield, 2003) was conducted by plotting the trend of the total irrigated area over the years using a line graph. This visual representation aids in identifying significant increases or decreases. Subsequently, the saline area was graphed over the same period to scrutinize the rate of decrement and identify periods of notable change. Finally, the degree of salinity was compared along the timeline to comprehend the impact of varying salinity levels on the total saline area.

Comparative analysis of salinity status in irrigated land areas

The salinity status of arable lands in the Namangan region was analyzed using data provided by the Namangan Regional Department of Agriculture in 2022, and a corresponding soil salinity map was created (refer to Table 1 and Figure 2). Table 1, derived from supplementary Table S2, was integrated into the attribute table of the geo-referenced soil map (Kimerling *et al.*, 2016). The total irrigated area and total saline area were mapped by district and overlaid onto the geo-referenced soil map. This data was integrated with the Namangan district map, visualizing both total irrigated and saline areas. A comparison was then conducted, aligning the findings with the map provided by the Namangan Regional Department of Agriculture, and interpretations were drawn based on this visual data analysis.

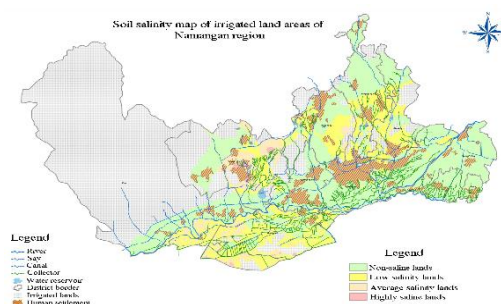


Figure 2. Soil salinity map of the Namangan region

Table 1. Salinity status of irrigated land areas in Namangan region in 2022

Name of districts	Total irrigated area (thousand ha)	Total saline area (thousand ha)
Mingbulak	38.19	15.052
Kasansay	25.206	0.229
Namangan	21.748	0.075
Norin	16.938	0
Pap	40.659	7.705
Turakurgan	19.035	0.261
Uychi	20.513	0.063
Uchkurgan	24.103	0
Chartak	20.357	0.162
Chust	33.942	0.416
Yangi kurgan	27.837	0.139

Comparative analysis of salinity indicators of irrigated areas in the region

Data on the total saline area from both sources (Supplementary Table S3) were mapped together using multiple quantities (Slocum *et al.*, 2008). Variations in salinity assessments were then observed, and possible reasons for these differences were considered. The degree of salinity was summarized in graphs for specific districts, highlighting differences in assessments between the Namangan Regional Department of Agriculture (RDA) and the Atlas of Soil Covers (ASC), obtained from the Committee of Land Resources, Geodesy, Cartography, and State Cadastre of the Republic of Uzbekistan.

Comparison of data on salinity in Mingbuloq (Mingbulak), Pop, and Chust districts

Table 2 presents salinity data for Mingbuloq (Mingbulak), Pop, and Chust districts, sourced from both the “Soil Inspection” subsidiary of the “Uzdaverloyiha” Institute and the Department of Agriculture of the Namangan Region (2017). The “Uzdaverloyiha” Institute typically does not engage in ongoing soil salinity determination efforts. However, in select years, as per specific directives from the Ministry of Agriculture, it undertakes soil salinity assessments. These assessments are conducted exclusively in laboratory settings. Notably, in 2017, the Ministry of Agriculture allocated resources for the subsidiary of the “Uzdaverloyiha” Institute to conduct soil salinity determination tasks, in line with a special directive. The detailed table is available in Supplementary Table S2. The Soil Monitoring Department of the Uzbekistan State Institute for Land Reclamation and Land Monitoring (Uzdaverloyiha) conducted soil salinity mapping in three districts of the Namangan region namely Mingbulok, Pop, and Chust districts in 2017. This data was further analyzed and compared with the data from the Department of Agriculture for the same year (2017).

The average depth of groundwater in Namangan region and its districts in 2021-2022

This information is derived from the Soil and Irrigation Water Monitoring Department of the Department of Agriculture for the Namangan region. It encompasses data spanning 2021-2022, offering a comprehensive overview which is presented in the supplementary Table S4. The department conducts measurements of underground water depth every 10 days, employing a simple thread meter technique. These measurements are conducted at existing wells across the Namangan region, providing valuable insights into groundwater levels.

Effects of terracing and mulching on soil salinity (laboratory analyses conducted in 2023)

Laboratory analyses were conducted in 2023 at the Agrochemical Laboratory, following specific standards. Among these, water absorption analysis is a pivotal method used to assess saline soils under controlled laboratory conditions. This analysis measures the soil’s water absorption capacity, offering insights into the presence and composition of water-soluble substances, which are crucial for determining soil salinity levels.

Common water-soluble salts found in soils include calcium, magnesium, sodium, and potassium sulfates, chlorides, and bicarbonates. Water absorption analysis collects data on these substances to enable a comparative evaluation of soil characteristics. Additionally, parameters such as dry residue, total alkalinity, specific alkalinity due to carbonates and bicarbonates, and concentrations of Cl^- , SO_4^{2-} , Ca^{2+} , Mg^{2+} , K^+ , Na^+ , and water-soluble humus are determined.

Furthermore, this analysis may also detect nitrates, nitrites, oxides, and other compounds in certain cases. Typically, soil salinization mitigation involves extensive water washing, a resource-intensive process. However, to explore more efficient alternatives, innovative approaches are being sought to address soil salinity concerns while

Table 2. Comparison of data on salinity in Mingbuloq (Mingbulak), Pop, and Chust districts

Districts	Organization providing information	Total irrigated area. (1000 ha)	Total saline area		The degree of salinity					
					Lightly salted		Medium salted		Strongly salted	
			1000 ha	%	1000 ha	%	1000 ha	%	1000 ha	%
Chust	Uzdaverloyiha	27841	7461.4	26.8	4960.5	17.8	2314.8	8.3	186.1	0.7
	Department of Agriculture	33319	627.1	1.9	367.1	1.1	238.9	0.7	20.7	0.06
Pop	Uzdaverloyiha	33273	19896	59.0	9724.5	29.2	7174.6	21.6	2996.9	9
	Department of Agriculture	39618	7810	20	4883.7	12.3	2316.6	5.8	609.7	1.5
Mingbulak	Uzdaverloyiha	34753	26543	76.3	10785.0	31.1	13673.7	39.3	2084.2	6
	Department of Agriculture	37863	15368.7	40.5	11449.2	30.2	3804.9	10	114.6	0.3

minimizing water usage and costs. These details are given in Table S5 which is available in the supplementary document. The measurements include the soil layer depth and total salinity, which are summarized to identify the effects of terracing and mulching on soil salinity. Subsequently, the chemical compounds that can dissociate into ions when dissolved in water are compared to assess their impact on soil salinity.

Results

Level of salinity in the arable lands of the region from 2000 to 2022

When the trend was graphed over the years, as shown in Figure 3(a), the Total Irrigated Area exhibited an overall increase from 2000 to 2022. However, a noticeable and abrupt drop occurred in the year 2021, attributed to water shortage (Ministry of Uzbekistan, 2022). Since 2006, there has been a slow upward trend in total irrigated area, but the exact reason could not be determined. One possible explanation could be the gradual improvements in irrigation infrastructure or policies aimed at expanding agricultural land use. However, without specific data on policy or environmental changes,

further investigation would be needed to determine the cause of this trend.

Comparatively, when examining the Total Saline Area from 2000 to 2022, as depicted in Figure 3(b), there is an observable decline over the years. The rate of decrement slowed down from 2005, reducing by approximately 24 hectares. Over the past 22 years (2000-2022), saline areas have, on average, decreased by 0.5 hectares (0.2%) annually. Table S1 further provides information on the degree of salinity, which is categorized into three levels: lightly salted, medium salted, and strongly salted. The following graph illustrates how the degree of salinity has varied over time (refer to Figure 4). Notably, more than 50% of the land belongs to the lightly salted category, while less than 10% is classified as strongly salted. Post-2001, there is an increase in lightly salted areas, coinciding with a decrease in strongly salted areas. This shift may be attributed to the implementation of strategies aimed at addressing salinity issues in Uzbekistan.

Variations in the degree of salinity may be influenced by factors such as land management practices, infrastructure, agricultural methods, and climate change. The impact of these factors requires further consideration.

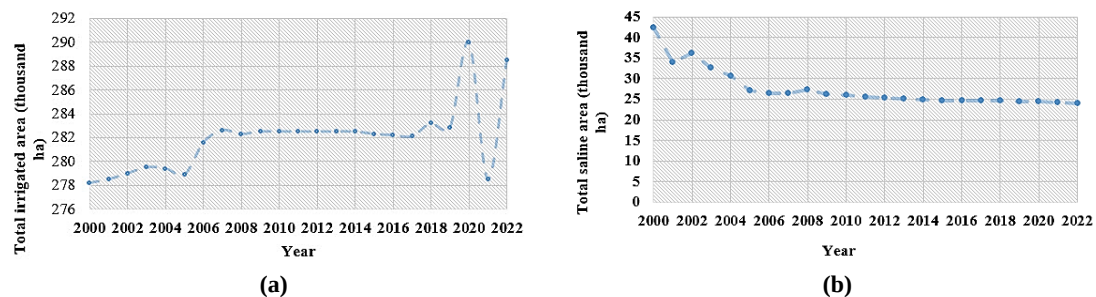


Figure 3. Salinity status of irrigated land areas in Namangan region (2000-2022) (a) Total Irrigated area (b) Total Saline area

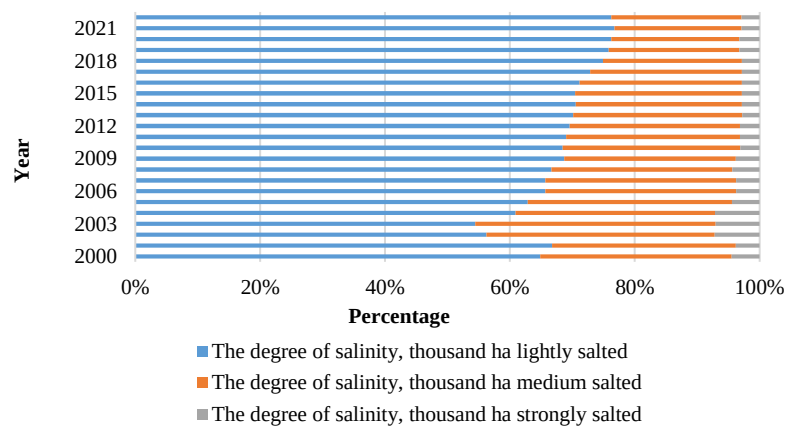


Figure 4. Degree of Salinity from 2000 to 2022

Comparative analysis on salinity status of irrigated land areas in Namangan region

According to the data in Table 1 and Figure 2, the highest salinity levels in the districts are observed in Mingbulak and Pap districts. As depicted in Figure 5, the Pap district has the highest irrigated area but the second highest in salinity. In contrast, Norin district has the lowest irrigated area and a lower salinity area. When compared with the map provided in Figure 2, Pap is mainly composed of irrigated areas, which may be the cause of salinity. Over-irrigation, especially without proper drainage, can raise the water table, bringing salts closer to the surface as the water evaporates (Ritzema, 2016). This leads to salt accumulation in the root zone, reducing soil fertility. On the other hand, in Mingbulak district, where salinity is highest, it is associated with collector channels. These channels, intended for water distribution, may carry water with a high salt content, especially if sourced from rivers or groundwater with elevated salinity levels (Khamidov *et al.*, 2022). When this water infiltrates into the soil or evaporates from the surface, it concentrates salts in the top layers of the soil (Rye and Smettem, 2017).

leading to salinity problems. Similarly, soil salinity is low in the Norin district, as its boundary is adjacent to a major river and some collector channels from the river. When compared with Mingbulak, the area is primarily composed of irrigated lands. However, in Tuakurgan district, despite having a high proportion of irrigated land, soil salinity is also high. The area consists of both water features irrigated and non-irrigated lands and the reason might be poor agricultural practices.

In conclusion, both natural and human-induced factors are responsible for soil salinity in the Namangan region. Geography, such as proximity to rivers, helps reduce salinity through natural leaching, while human factors like irrigation practices and water management can either exacerbate or mitigate salinity (Ritzema, 2016). Future studies should further explore these dual influences to develop more effective salinity management strategies.

Comparative analysis of salinity indicators of irrigated areas in the region according to the data of the Namangan Regional Department of Agriculture (RDA) and the Atlas of Soil Covers (ASC) of the Republic of Uzbekistan

The salinity data from both datasets were compiled into Figure 6, and significant differences can be noted in terms of soil salinity information. The red palette shows the salinity from RDA, and the green symbol represents the data from ASC. For example, according to the RDA, the highest salinity is reported from Mingbulak while according to ASC, the highest salinity is reported from Mingbulak. In comparison to ASC, the highest salinity reported for the percentage of arable lands in the districts varied from 0 to 42.1%, whereas the Atlas reported figures ranging from 10.0 to 83.0%. Specifically, in the Mingbulok district, according to the Department of Agriculture, 42.1% of the arable lands are saline, whereas the Atlas data suggests that 83.0% of the arable lands in the Mingbulok district are saline, nearly twice as high. Similar substantial differences exist in other districts as well. This situation raises concerns, especially regarding

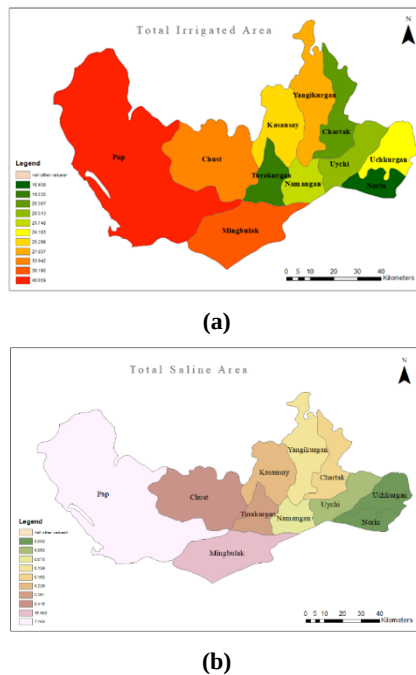


Figure 5. Salinity status of irrigated land areas in Namangan region (2022)

Collector channels designed for drainage may contribute to soil salinity if they are not properly managed (Ritzema, 2016). Inadequate drainage can lead to waterlogging in certain areas, causing the water table to rise. As water evaporates from the soil surface, it can leave salts behind (Nachshon, 2018),

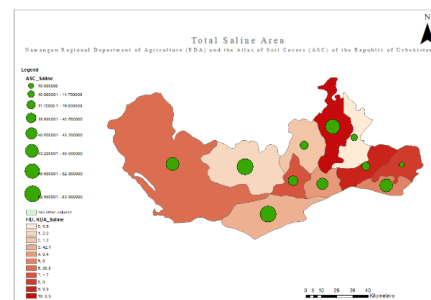


Figure 6. Total Saline Area from RDA and ASC

the significant saline areas reported in the main arable fields located in certain districts.

The degree of salinity is then summarized in Figure 7. In Figure 7(a) ASC_LS, ASC_MS, and ASC_SS mean light soil salinity, medium soil salinity, and strong soil salinity from ASC. On the other hand, Figure 7(b) RDA_LS, RDA_MS, and RDA_SS means light soil salinity, medium soil salinity, and strong soil salinity from RDA. According to the RDA, Turakurgan, Namangan, and Uychi consist of light salinity, while according to ASC, the area consists of a combination of three degrees of soil salinity: light, medium, and strong. According to ASC, Uchkurgan consists of light salinity soil.

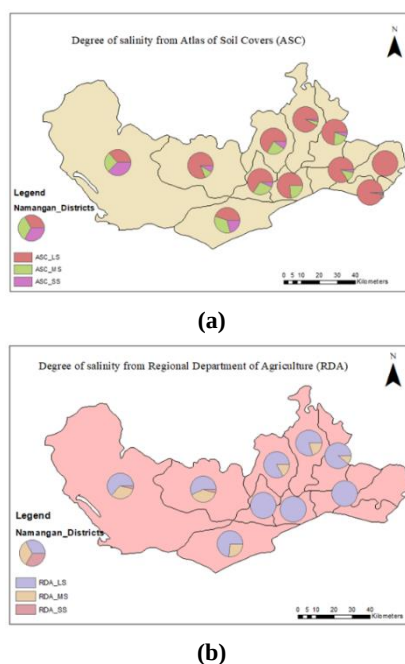


Figure 7. Degree of salinity from (a) Degree of Salinity from ASC and (b) Degree of Salinity from RDA

According to the RDA map, Kasansay, Yangiurgan, and Chartak districts consist of light and medium salinity, while according to ASC, they have a mixed combination.

These variations may be due to various reasons, including differences in data collection methods, sampling techniques, time frames of data acquisition, and data processing practices. Soil salinity can fluctuate seasonally, depending on factors such as rainfall, evaporation rates, and irrigation practices (Ritzema, 2016). If the RDA and ASC collected their data at different times of the year or during different climatic conditions, this would account for some of the variations in the salinity levels they report. Another potential source

of variation could be differences in how the datasets were processed and cleaned before analysis. These inconsistencies highlight the need for standardized data collection and processing methodologies to ensure more reliable and consistent assessments of soil salinity.

In summary, the variations in salinity data between the RDA and ASC point to the importance of harmonizing data collection methods, timeframes, and processing techniques. Without such harmonization, discrepancies in reported salinity levels will continue, complicating efforts to manage and mitigate soil salinity in affected regions.

Comparison of data on salinity in Mingbuloq (Mingbulak), Pop and Chust districts of the “Soil Inspection” subsidiary of the “Uzdaverloyiha” Institute and the Department of Agriculture of the Namangan Region (2017)

Upon analyzing the data from Table 2, it becomes evident that there is a significant difference between the data collected by the “Uzdaverloyiha” Institute and the Department of Agriculture of the Namangan Region. The information from the “Soil Monitoring” department confirms the data provided in the Soil Compendium Atlas of the Republic of Uzbekistan, reaffirming that the salinity levels are indeed very high. When comparing the total irrigated land, depicted in blue, with the salinity area, a difference in salinity levels becomes apparent. Although the irrigated area is reported as high by the Department of Agriculture, the salinity level is low in their data collection. However, according to the two datasets, the highest salinity is reported from the Mingbuloq (Mingbulak) district (refer to Figure 8). Further clarification is needed for the datasets, including the method of data collection, equipment used, and other relevant information pertaining to data collection.

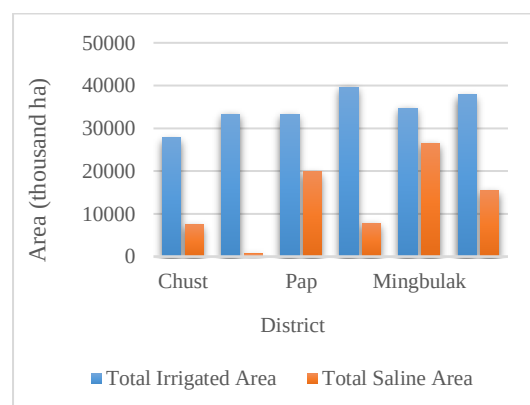


Figure 8. Salinity in Mingbuloq (Mingbulak), Pop, and Chust districts

The average depth of groundwater in Namangan region and its districts in 2021-2022

The Department of Agriculture for the Namangan region reported that, out of the total cultivated area of 288,528 hectares, approximately half, or 136,757 hectares, were equipped with drainage systems. Primarily, surface drainage systems covered most of these areas. However, the remaining approximately 151,771 hectares lacked drainage systems due to the presence of saline lands and sandy-dune areas. These areas are considered unsuitable for drainage installation due to their natural drainage through springs and lowlands.

In regions with saline lands, the absence of drainage systems has resulted in the accumulation of excess water not only in the lowlands but also in the districts surrounding saline lands. Studies conducted by Umurzaqova underscore this situation, particularly in Norin and Mingbulok districts. These studies reveal significant amounts of water collected annually from drainage systems in areas with saline lands. For instance, Norin district annually collects 400 to 600 million cubic meters of water from drainage systems, 3 to 10 times more than water collected from irrigation sources. In Mingbulok district, this amount ranges from 144 to 282 million cubic meters per year, 1.3 to 1.8 times more than water collected from irrigation sources (Karimov, 2011).

This highlights a crucial physical process which is subsurface water movement. In saline areas, irrigation water that seeps into the soil can contribute to a rising water table, particularly when drainage is inadequate (Ritzema, 2016). Once the groundwater reaches shallow depths, it brings dissolved salts closer to the surface. As the water evaporates, especially during dry periods, it leaves behind salt deposits, leading to increasing salinity in both irrigated and non-irrigated areas (McFarlane *et al.*, 2016). This dynamic is exacerbated in areas without adequate drainage systems, where excess irrigation water remains trapped in the soil.

Hence, a substantial portion of water used for irrigation in saline areas seeps down to the groundwater table, subsequently moving from groundwater to the surface in non-saline areas. This conclusion is drawn from data provided by the Soil and Irrigation Water Monitoring Department of the Department of Agriculture for the Namangan region, covering the period of 2021-2022, and is detailed in Supplementary Table S4.

Upon comparing average values for the vegetation period and non-vegetation period for the years 2021 and 2022, the figures reveal minimal differences. The comparison then shifts to the difference between annual averages and the difference between cultivated lands.

The discrepancy between the average groundwater table for the autumn-winter period (period without vegetation) and the irrigation period (vegetation period) is calculated, as shown in the subsequent Figure 9. The monitored area difference between 2022 and 2021 is also computed.

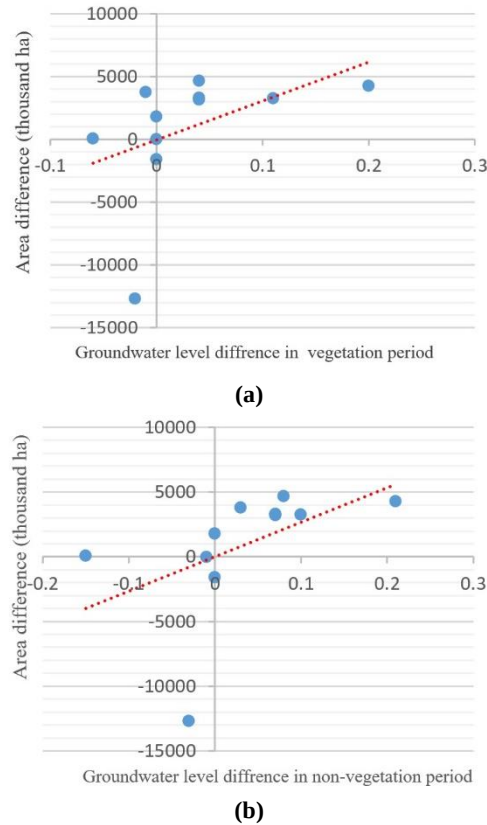


Figure 9. Average area difference (a) Difference between average in vegetation period and (b) Difference between average in non-vegetation period

Subsequently, the relationship between the difference in monitored areas and the autumn-winter period (period without vegetation) versus the irrigation period (vegetation period) was examined. In the vegetation period, the difference between average values between depths of the groundwater table is high in Uchkurgan district and low in the Turakurgan district. On the other hand, during the non-vegetation period average groundwater table depth is high in Uychi province. When compared with the cultivated area difference between 2021, and 2022 the highest variation can be seen in the Namangan district which decreases the cultivated area. Among the districts studied in this analysis both Mangam, Norin, and Uchkurgan are low in cultivation than in 2021. In order to identify the variations of the average values between the vegetation period and non-vegetation period, factors

The scatter plot illustrates the relationship between the monitored area and the difference between average values during the vegetation and non-vegetation periods (see Figure 10). While the plot indicates no strong correlation between these two datasets, there is a strong correlation between the difference in the irrigation period and the monitored area difference.



(b)

Laboratory assessment

establish a garden without irrigation using terracing and mulching techniques in the hilly areas of the Uychti district of the Namangan region in 2013, 2014, and 2017 (Karimov, 2011; Chathuranika *et al.*, 2022; Chathuranika *et al.*, 2023). Soil samples were collected from the experimental area, and laboratory analyses were performed. The results of these analyses are presented in Table 3, which summarizes measurement options, the year the mulching experiment began, and total salinity.

Table 3. Summary of measurement depth and total salinity

These findings indicate that mulching significantly reduces surface evaporation, limiting the capillary rise of salts to the topsoil and preventing the accumulation of salts in the root zone. By creating a barrier that conserves soil moisture, mulching slows down the evaporation process, thereby reducing the upward movement of salts typically driven by the evaporation of water from the soil surface. Terracing, implemented alongside mulching, further contributes to salinity reduction by improving water infiltration and reducing surface runoff. By slowing down the movement of water down slopes, terracing allows more time for water to percolate into the soil, carrying salts deeper into the soil profile. This process dilutes the salt concentration in the root zone, helping plants to access less saline water and thus improving soil health and agricultural productivity.

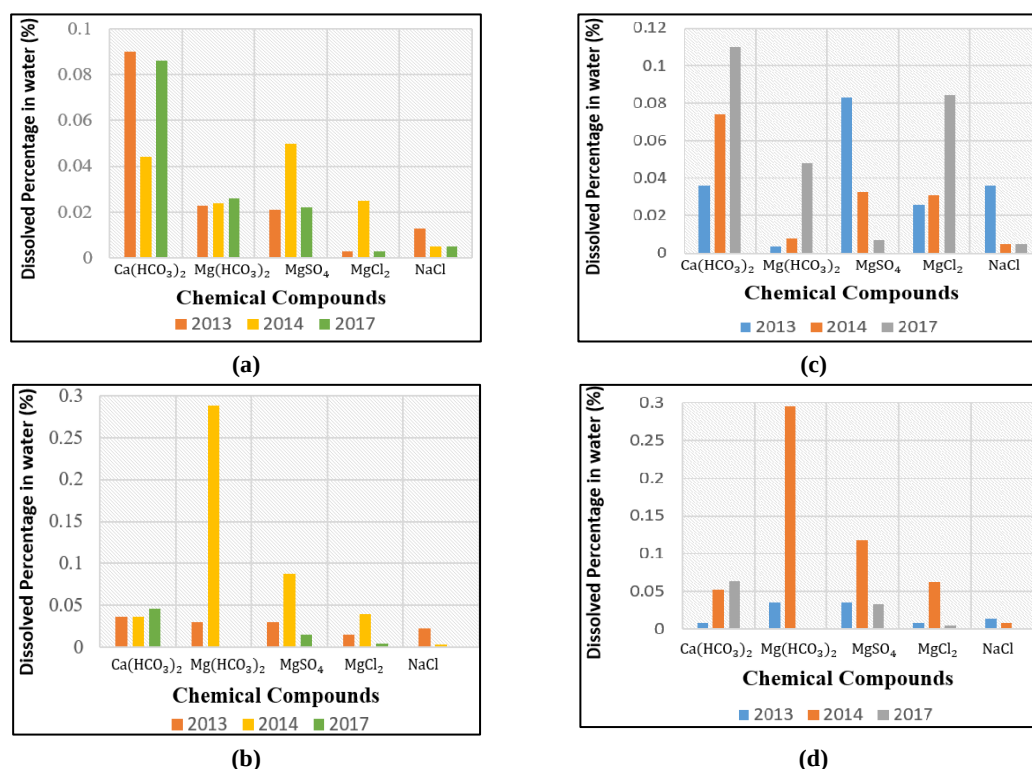


Figure 11. Cations and anions dissolved in water on non-mulched and organic mulched in different depth of soil layers (a) Organic_Mulched 0 - 30 cm depth; (b) Organic_Mulched 30 - 50 cm depth; (c) Non_Mulched 30 - 50 cm depth and (d) Non_Mulched 30 - 50 cm depth

This trend was also observed in the experimental field, where terracing and mulching practices were initiated in 2013 and continued through 2017. However, salinity was high in 2014 in both non-mulched and organic areas. Other than that, in the organic mulched area, salinity is decreasing. Therefore, it can be concluded that both terracing and mulching agrotechnologies have contributed to reducing soil salinity in this experimental field. Moreover, the results from the third experimental site, where both organic and plastic mulching practices have been implemented since 2017, further support the positive impact of mulching agrotechnologies in reducing soil salinity.

In the areas of organic mulching, Ca^{2+} from $\text{Ca}(\text{HCO}_3)_2$ is the main contributor, while other salts are at lower levels in the topsoil layer. There was a high contribution from Mg^{2+} from $\text{Mg}(\text{HCO}_3)_2$ in 2014, and it needs to be studied further. Mulching, particularly organic mulching, seems to contribute to lower total salinity compared to non-mulched conditions (El-Mageed *et al.*, 2016). Different salts have varying impacts on soil salinity, and their concentrations can change over the years.

Monitoring and managing these salt concentrations are crucial for sustainable

agriculture, as high salinity can negatively impact soil quality and plant growth. Management strategies may include proper irrigation practices, soil amendments, and selecting salt-tolerant crops.

Discussion

Understanding salinity trends over time

Observing the salinity trends over the period revealed a complex relationship between irrigation projects and salinity levels. Although the irrigated areas decreased in 2021, the saline area gradually declined from 2000 to 2022. This reduction may be attributed to changes in irrigation policies, climatic conditions, or specific projects implemented during that time. This trend is a positive indication of soil health and agricultural sustainability in the Namangan region, reflecting improvements in soil conditions and reduced salinity, which benefit agricultural productivity. Similarly, the percentage of salinity changed over time from 2000 to 2022. The overall decrease in the saline area, despite fluctuations in irrigated land, suggests that effective irrigation management practices may have been implemented, leading to improved soil conditions and reduced salinity. Future research should focus

on identifying the specific drivers behind this positive trend, particularly during key periods where significant changes were noted.

District-level disparities and influencing factors

Mingbulak and Pap districts are identified as areas with the lowest salinity levels. The large percentage of irrigated land in Pap and the efficient connection between Mingbulak and collector channels highlight the effectiveness of infrastructure in reducing salinity. This makes these districts ideal for agricultural activities due to better soil health. In contrast, Yangikurgan and Kasansay exhibit the highest salinity levels. Despite significant irrigation efforts, the salinity remains high, indicating the need for targeted soil treatment and improved irrigation management. Similarly, despite having significant irrigated areas, Turakurgan shows high salinity levels. This contrast suggests that other factors, possibly soil type or irrigation practices, are contributing to the elevated salinity.

Norin district on the other hand has low salinity levels, likely due to its proximity to a river. The natural water flow likely helps in leaching salts away from the soil, reducing overall salinity.

Understanding and managing soil salinity requires a comprehensive approach that considers both geographical and human-induced factors. Effective infrastructure, such as irrigation systems and collector channels, plays a crucial role in managing salinity levels. However, the complexities observed in districts like Turakurgan and Yangikurgan indicate that additional factors must be addressed to achieve sustainable soil health and agricultural productivity across the Namangan region.

To achieve sustainable soil health and agricultural productivity across the Namangan region, a comprehensive management approach is needed. This approach should combine infrastructure improvements with tailored soil treatments, addressing both natural and human-induced causes of salinity. Targeted interventions are essential to mitigate the disparities in salinity levels and promote sustainable agriculture throughout the region.

Discrepancies in data sources and implications

The comparison of salinity indicators from different data sources, such as the Namangan Regional Department of Agriculture (RDA), the Atlas of Soil Covers (ASC), and “Uzdaveroiyiha” Institute, exposes substantial differences. The variations in reported salinity levels for specific districts raise concerns about data reliability and consistency. These disparities underscore the

importance of standardizing data collection methods and enhancing collaboration between relevant agencies for a more accurate assessment of soil salinity. Without reliable data, it is challenging to implement effective salinity management strategies or track progress over time.

Groundwater depth and its role in salinity

Supplementary Table S4 illustrates the differences in reported groundwater depths throughout districts, which highlights the complex hydrogeological features of the Namangan area. According to studies by (Rakhmatullaev *et al.*, 2012), a significant volume of water is drawn from drainage systems in saline areas, which emphasizes the intricate relationship between irrigation, salinity, and groundwater. This calls for a comprehensive strategy for managing water resources that takes into account both saline and non-saline regions. Future research should focus on the long-term relationship between groundwater depth and salinity and explore how water resource management practices can mitigate salinity in both saline and non-saline regions.

Laboratory assessments and mitigation strategies

The laboratory experiments on terracing and mulching (Table 3) provide valuable insights into potential mitigation strategies against soil salinity. The observed reduction in salinity levels in mulched areas highlights the effectiveness of these agrotechnologies. However, the fluctuations in salinity levels observed in 2014 indicate the necessity for continuous monitoring and adaptive management. Furthermore, understanding the specific contributions of different salts, as illustrated in Figure 9, can inform targeted interventions for sustainable agriculture. Going forward, it is crucial to integrate these mitigation strategies with modern technologies such as remote sensing and GIS for more comprehensive monitoring and assessment.

Overall understanding

Given the global significance of soil salinity, this study aims to provide a baseline understanding of the current status of soil salinity in the Namangan region of Uzbekistan. By doing so, we can assess how local trends compare to broader global patterns and identify areas most at risk for salinity-related degradation. Additionally, this study explores the potential role of modern technologies, such as remote sensing and GIS, in enhancing the accuracy of salinity monitoring. When combined with other parameters, such as groundwater salinity and soil type (e.g., clay vs. sandy soils), these technologies offer more comprehensive insights into the

distribution of saline areas and help identify regions suitable for salt-tolerant crops. Furthermore, this research will evaluate the socio-economic and environmental impacts of soil salinity in the Namangan region. Understanding these impacts will contribute to the development of sustainable saline agriculture practices, which are critical for mitigating the long-term effects of salinity on agricultural productivity and food security.

Globally, salty soils cover approximately 1.1×10^9 km² and are found in over 100 nations and regions. Soil salinity levels continue to rise (Metternicht and Zinck, 2003). Furthermore, soil salinity is regarded as the second main type of soil degradation after soil erosion (Shahid *et al.*, 2018) and generates annual economic harm of at least US\$27 billion to agricultural productivity globally (Qadir *et al.*, 2014). Among the countries that are affected by salinity, China, Australia, and Kazakhstan are the primary countries which are having salty lands. After adopting adequate agricultural circumstances, China, Argentina, and India have the greatest areas for rain-fed agriculture, followed by China, India, and Pakistan for irrigated agriculture. Moderate and extremely saline soils are the most critical for food security in terms of optimal agricultural productivity, as conventional crop production in these areas is suboptimal. It is primarily found in arid and semi-arid regions, as well as coastal places, with arid climates, limited rainfall, significant soil evaporation, a high groundwater table, and more soluble salts (Wen *et al.*, 2021).

However, research into the spatial distribution and management of soil salinity prevention, as well as improvements in monitoring accuracy is progressively becoming a hot topic in the field of saline soil research. Therefore, more research is required to better understand the social, economic, and environmental circumstances that will be affected by salinity as well as understand the status of salinity in order to promote sustainable saline agriculture. Our study seeks to serve as a starting point for focusing on the status of soil salinity in the Namagan region. Further study with modern technologies would apply such as the use of remote sensing and GIS in soil salinity mapping and incorporate with other parameters, such as the presence of saline groundwater or soil type (clay vs. sandy soils), which would allow for more advanced analysis and a comprehensive assessment of the area suited for salt-tolerant crops. The findings of this study may be useful for various stakeholders, including those involved in agriculture, water resource management, and environmental conservation.

Conclusions

In conclusion, addressing soil salinity in the Namangan region is crucial. Analyzing diverse data collected from multiple sources highlights that soil salinity has been consistently monitored in recent years due to its importance. Independent measurements from different organizations help minimize the risk of errors or biases associated with relying on a single source. Cross-verifying data from multiple organizations ensures accuracy and reliability, allowing discrepancies to be identified and resolved, ultimately leading to more precise findings.

However, this study did not employ statistical analysis due to the variability and inconsistency in data collection methods across different organizations, as well as the differing timeframes and regional focuses of the datasets. While this limitation is acknowledged, the inclusion of data from multiple sources allowed us to provide a broad and practical overview of the soil salinity issues in the Namangan region. A more rigorous statistical approach will be considered in future studies when more standardized, continuous data across all regions is available.

The sources of soil salinity in the Namangan region need to be identified with more robust research methodologies. Its impacts, such as environmental effects, agricultural productivity, and economic implications, require further study. Collaboration among organizations fosters interdisciplinary research, combining insights from agriculture, environmental science, economics, and social sciences to comprehensively address soil salinity.

In recent years, significant attention has been paid to observing soil salinity. Continuous monitoring by various organizations ensures that changes in soil salinity are tracked over time, helping to assess the long-term impact of management practices and environmental factors. Our study highlights that localized differences in soil salinity can be observed, as it can vary significantly across regions and even within small geographical areas. Different organizations may focus on specific regions, providing localized data that is critical for regional planning and interventions. Understanding regional variations helps in developing context-specific solutions that are more effective in managing soil salinity in different areas.

Our study serves as a starting point for understanding the status of soil salinity in the Namangan region. Further research, incorporating modern technologies such as remote sensing and

GIS, is necessary for more advanced analysis and comprehensive assessment. This will facilitate the identification of areas suitable for salt-tolerant crops and promote sustainable saline agriculture.

A holistic and adaptive approach, informed by ongoing research and collaboration, is imperative for devising sustainable solutions to mitigate soil salinity and ensure the long-term agricultural productivity of the region. The results of this study can provide valuable information for various stakeholders involved in agriculture, water resource management, and environmental conservation in the Namangan region and beyond.

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