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Soil Salinity Monitoring in Irrigated Areas of Rishtan District of Ferghana Valley, Uzbekistan

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Abstract. The salinization of soils impacts many arid areas. In the world, about 62 million hectares of agricultural land are subject to salinization. At present, about 47% of the irrigated lands in Uzbekistan are subject to some degree of salinity. Landsat satellite photos taken across an exact time span (from 1993 to 2021) with timeframes of 8 to 10 years were utilized in this study to monitor soil salinity. To analyze soil salinity level, salinity index, and classification method using Google Earth was performed. During the entire study period, changes in the indicator of soil salinity improvement work were shown. Especially related to non-saline soil, which was around 4,670 ha in 1993, and it increased to 10,533 ha in 2021 and reached 19.2 % after thirty years. Slightly saline soil class has the propensity to decrease and included its largest area of 15,941 ha (52.1 %) in 1993, but then dropped quickly to 9,649 ha (31.5 %) in 2021. Saline soil maximum increased in 2001 to 10.251 ha (33.5 %), then started steadily contracting and reaches a minimum of 7,440 ha (24.3%) in 2011. Strongly saline soil starts reaching from 1,771 ha to 5,069 ha between 1993-2001.

1 Introduction

The role of irrigated lands in agriculture is unique, therefore, studying it, its scientific justification, and solving existing problems is one of the tasks at the state policy level. In Uzbekistan, irrigated agriculture is one of the primary sectors of agriculture. Various crops are grown in the country, irrigating more than 4.3 million hectares. Many nations around the world struggle with the issue of the salinization of the land. In salty soils, plant productivity, especially that of industrial crops, is drastically reduced, necessitating adequate reclamation effects on the soil [1].

One of the elements that adversely affect agriculture is the salinity of the soil. The International Institute for Environment and Development estimates that saline soils cover around 10% of the continent's surface [2]. The most typical method of desalinating soil is to run it against the drainage system's backdrop. The quest for high-tech, science-intensive, resource-saving solutions for soil desalinization, maintaining the conservation of soil

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fertility, and boosting agricultural yields is pertinent due to Uzbekistan's limited water resources. Salinity can be detected by implementing remote sensing techniques [3].

The salinity process is not exclusive to the surface, but the whole profile, causing a limitation in the use of optical sensors. However, there are ways to potentiate salinity detection by satellite through the use of diverse quantitative models, using the spectral signature of each of the components of the study area [4].

According to data from the Ministry of Water Resources' reclamation monitoring service, 2,5% of Uzbekistan's irrigated land is strongly salinized (ECe = 8–16 dS/m), 13,3% is moderately salinized (ECe = 4–8 dS/m), and 30,9% is slightly salinized (ECe = 2–4 dS/m). This means that more than 46,6% of the country's irrigated land is affected by saline [5].

To enhance the soil's quality, it is important to carry out reclamation measures, reduce the salinization of land, and the effect of soil salinization on the yield of crops. Soil salinity assessment is essential to prepare for action. Having data on the salinity of agricultural land helps to make the right decisions and control soil salinity [6]. However, conventional techniques for measuring soil salinity are slow and expensive because sampling is time-consuming, but geographic information systems and remote sensing technologies can make the assessment more cost-effective and faster.

On the other side, multi-temporal NDVI gives an additional temporal dimension to reveal the dynamics of the vegetation. Using data from the multi-temporal vegetation index, remote sensing phenology calculates phenological growth stages, encompassing the beginning and conclusion of the season. NDVI is a good indicator for separating vegetation into sparse and dense vegetation. It is an index adapted to study the condition of vegetation cover using satellite imagery [14].

The plains of Central Asia are mainly naturally saline and are considered a potential threat to the development of secondary salinization of the soil [7]. The semi-desert and arid portions of this region's agricultural products are being severely harmed by the salinization of irrigated farmland. In particular, 11.5% of 1.08 million ha of irrigated land in Kyrgyzstan, 16.0% of 719,200 ha in Tajikistan, 33.0% of 2.31 million ha in Kazakhstan, 95.9% of 1.74 million ha in Turkmenistan, and around 50% of 4.28 million ha in Uzbekistan are prone to soil salinization at different levels [7-8]. Many scientists and experts in developed and developing countries have studied the relationship between the salinity levels of irrigated areas and groundwater levels and its mineralization, and other anthropogenic influences using and comparing GIS-based methods (interpolation, vegetation, and hydrological indices) [9-11].

2 Materials and methods

2.1 Research area

Rishtan is a district which is located in Ferghana province eastern Uzbekistan. Rishtan borders Kyrgyzstan and is located around 270 kilometers east of Tashkent and 50 kilometers west of Fergana (Figure 1).

The district covers a total area of 310 km2. It is situated at an elevation of 482 meters above sea level in the southern Ferghana Valley on the foothills of the Alai Range, on the right bank of the Sokh River. The district is located south of the Central Fergana Desert, along the Sokh River and the Great Fergana Canal. The territory consists mainly of plains. Minerals include oil, gas, loam, and gravel. It has a distinctly continental climate. January's typical temperature is -6.7 °, the lowest temperature is -27 °, the average temperature in

July is 23.6 °, and the highest temperature is 42 °. It receives 180 mm of rain per year. Farms and lands are irrigated by the Sokh River and the Great Fergana and Andijan canals.

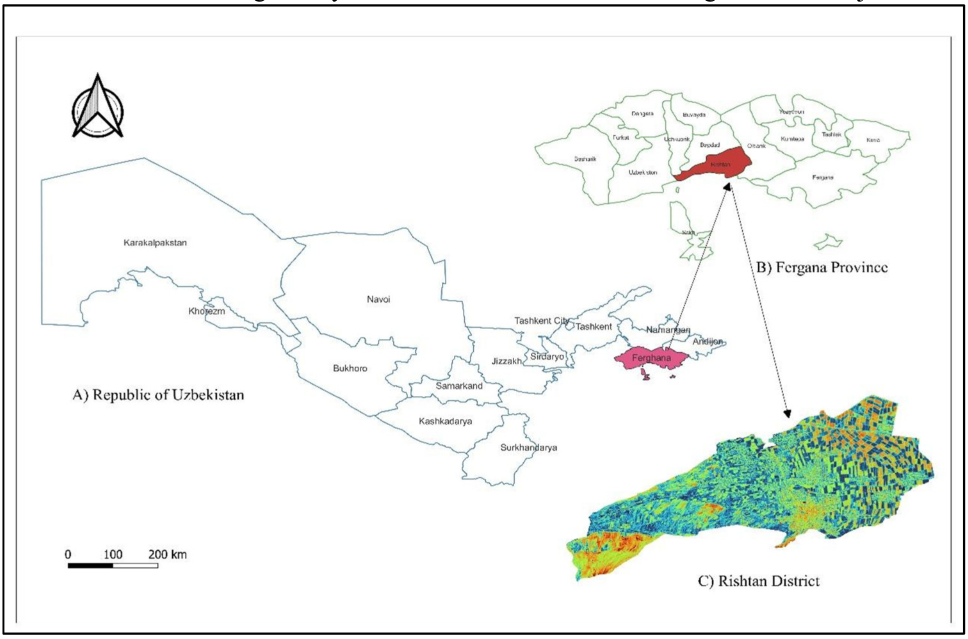

Fig. 1. Map of the research area in the Fergana province's Rishtan district.

2.2 Soil

According to the FAO soil classification database the Fergana province consists of 4 types of soil, which are as follows Gleysols calcaires (Gc), Lithosols (I), Xerosols calciques (Xk), and Solonchaks gleyiques (Zg) (Figure 2). The research area is composed of two types of Gc and Xk of soil, according to the map created using the results [12].

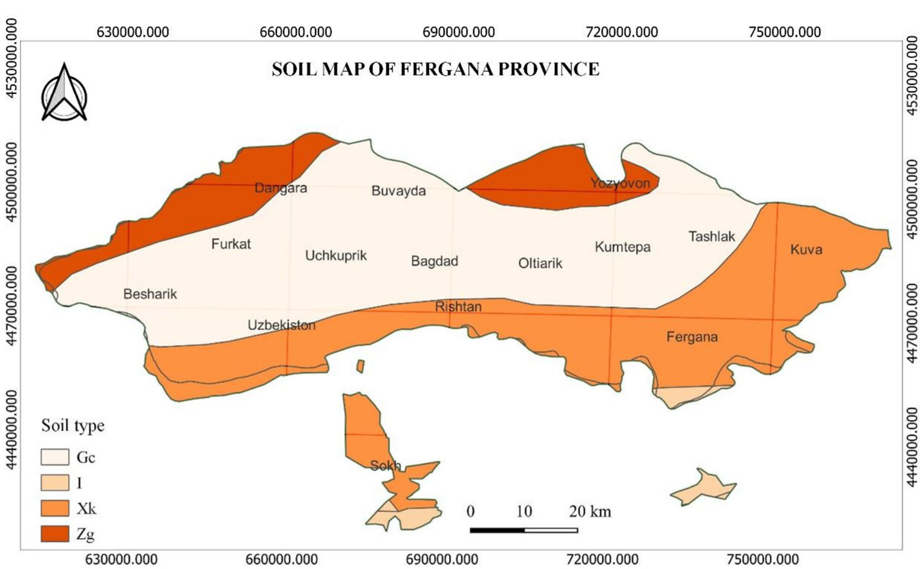

Fig. 2. FAO soil classification of Fergana province.

The geological and surface structure, climate, and characteristics of the groundwater of Fergana province are not the same. In the lower part of the center, on the slopes of the Syrdarya, in the meadows, meadows, and swamps, on the surface of the groundwater, there are swamps, sandy loams, and sandy soils in the Yazyovan and Karakalpak deserts. In the deep plains and hills of the district, where the groundwater is deep, there are light, simple (dark), and dark grey soils [13].

2.3 Research methodology

The identification of the soil salinity monitoring varied analyses and methods, which include remote sensing and spatial modeling with GIS, and the salinity index was utilized to establish the feasibility of RS and GIS for mapping soil salinity indirectly from the soil. The studies were carried out in conditions based on generally accepted geographical and cartographic methods.

There are several indices in the determination of soil salinity, among which the most optimal was selected. Main selected remote sensing indices such as salinity index (SI) [14].

Salinity index (SI),

$$SI = \sqrt{Green * R} \quad (1)$$

Where Green and Red correspond to the surface reflectance of the narrow Hyperion bands.

Noteworthy is the fact that the bands obtained for the determination of soil salinity for the Landsat 5 and 7 images differ from the bands in the Landsat 8 image. Therefore, the image of Landsat in satellite imagery is downloaded depending on its type.

The work also used the methods of spectral data analysis for remote sensing, data collection, research, experimental, statistical, and observational research methods. The study's methodology demonstrates how satellite image processing may be utilized to assess soil salinity.

The United States Geological Survey (USGS)'s Earth Explorer application, a browser for open Landsat satellite imageries, was used to obtain Landsat images for analysis of the research area [15]. This may browse, filter, arrange, and download photographs using it. Images were especially acquired for the months of late May, June, or July, which have little cloud cover and the biomass indication spire. To calculate of RS index was selected specific images with the highest vegetation are based on the cropping calendar. Therefore, these days were chosen as images for calculating RS indices and correlation analysis between index values and soil salinity.

This study analyzed performance over 10 decades between 1993 and 2021, one of the most challenging challenges in the research throughout these years was locating high-performance photographs of the research object. To obtain information about the state of the crop and soil salinity, images of a certain period are required, and also on the areas of saline soils, it is necessary to use highly informative images with a resolution of about 30 m. Information concerning the early phases of salinization of irrigated lands may be lost when using photos with a lower resolution. When compared to the picture on the photograph taken on the chosen shooting date, which reflects the condition of the item, saline soils, which have a homogenous (no spots) image, and soils with a spotty image, which describe cotton fields, are easily discernible. The spots on the sections might range in size from 5 to 10 to 100 meters and beyond. It is feasible to estimate the extent of saline soils within the irrigated field and the irrigated massif using the fraction of spots in the soil contour. It has been statistically demonstrated that this condition enables evaluation of the salinity of a meter-long soil layer within the entire contour based on a significant volume of field research. Selected photos of the research region were used to generate the SI index. It was decided to use the Landsat bands that were already accessible because not all of the Landsat bands we wanted are in the database (particularly for the 1990s years) Table 1.

Table 1. Bands added to Landsat photos during the study.

Year	Date	Sensor	Wavelength (micrometers)	Resolution (meters)
1993	May 30th June 18th July 19th	Landsat 5	0.64-0.67	30
2001	May 19th June 17th July 15th	Landsat 7	0.64-0.67 0.85-0.88	30
2011	May 25th June 24th July 29th	Landsat 5	0.64-0.67 0.85-0.88	30
2021	May 21th June 14th July 12th	Landsat 8	0.64-0.67 0.85-0.88	30

Images were recovered and trimmed after being combined using the raster computation tool to cover the whole Rishtan district, Ferghana province after Landsat images were acquired for the study time and the study area.

Afterwards, the study area was used with SI analysis in the software of Open Source QGIS (Figure 3).

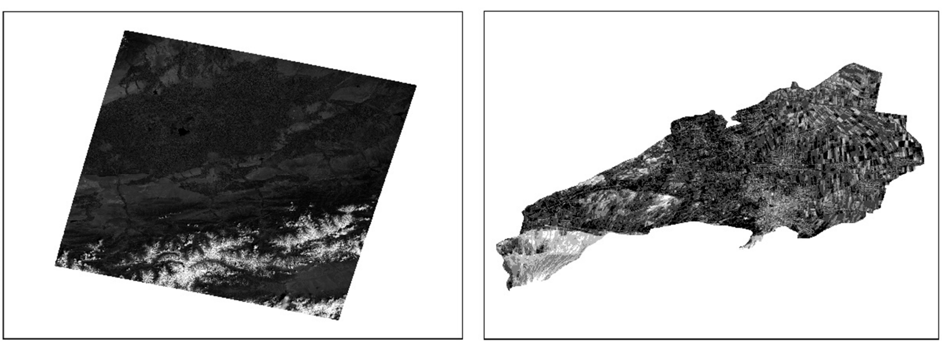

Fig. 3. Landsat 8 image in 2021 before and after extraction of Rishtan district, Ferghana province.

We made the decision to conduct radiometric and atmospheric correction before moving further with picture classification in order to ensure that the results are accurate and comparable. Radiometric adjustment transforms initially the digital numbers on the sensor to brightness (watts per square meter), after that to the albedo of the upper atmospheric boundary for Landsat using the following formula:

$$L\lambda = gain * DN + bias \quad (2)$$

Where: Lλ- the radiance of pixel (watts/m2 srad).

The electromagnetic spectrum reflected from the surface is affected by atmospheric gases (aerosols, dust, carbon dioxide, and nitrogen oxide), which must be removed or reduced by this procedure. During the post-classification correction, clouds that could not be removed during the atmospheric adjustment were.

The soil salinity map of the study region and the images of the indices are overlay. The research area's soil salinity map was acquired and digitalized. Using the tool "Zonal Statistics" QGIS, the average values of indicators were calculated for each soil salinity polygon.

3 Results and discussion

Utilizing an accuracy assessment tool, accuracy was evaluated. To assess the audience's reception of the identified photos, we chose to randomly sample the entire research region. The final map was contrasted with more recent, higher-resolution Google Earth pictures. The original Landsat satellite image was used for verification in the absence of an image. Checking each sample point and comparing it to the categorized pixels required a lot of time. All temporary data were generally examined. A second post-classification correction was applied if the classification accuracy was less than 80% (Table 2).

Table 2. Assessment of image accuracy

Year	Bands	Accuracy
1993	2 and 3	86%
2001	2 and 3	87%
2011	2 and 3	89 %
2021	3 and 4	87 %

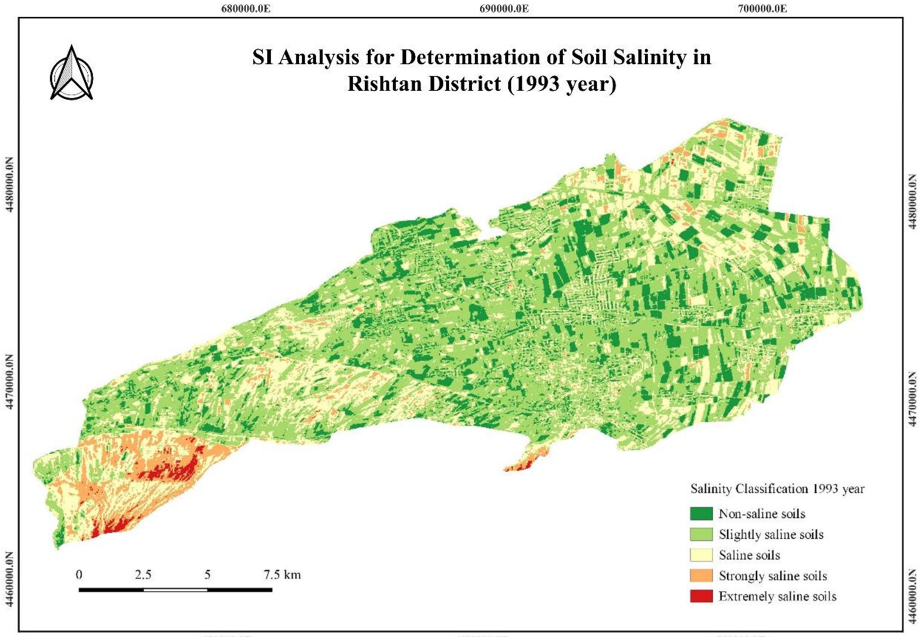

Fig. 4. Soil salinity map processed from RS image for 1993 of Rishtan district.

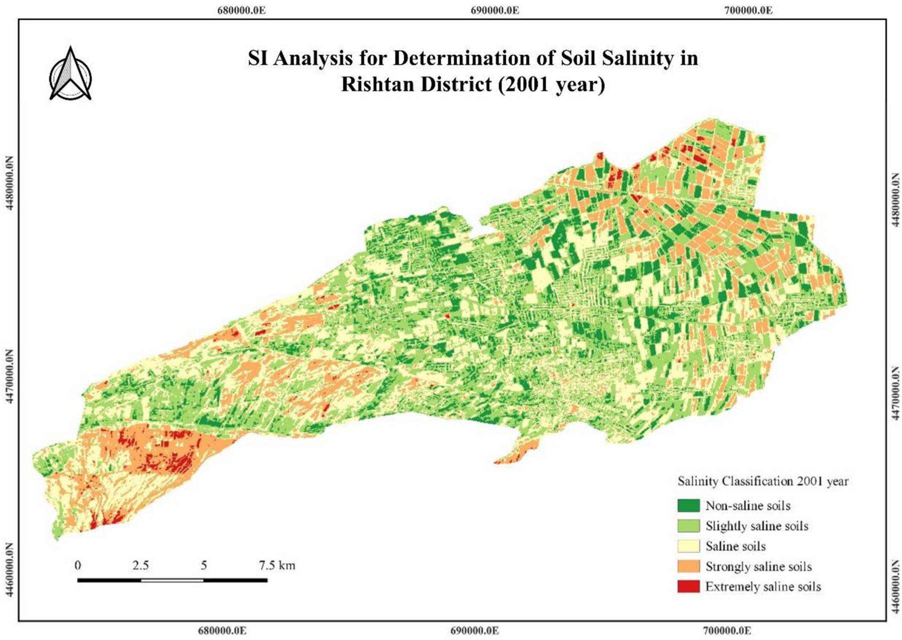

Fig. 5. Soil salinity map processed from RS image for 2001 of Rishtan district.

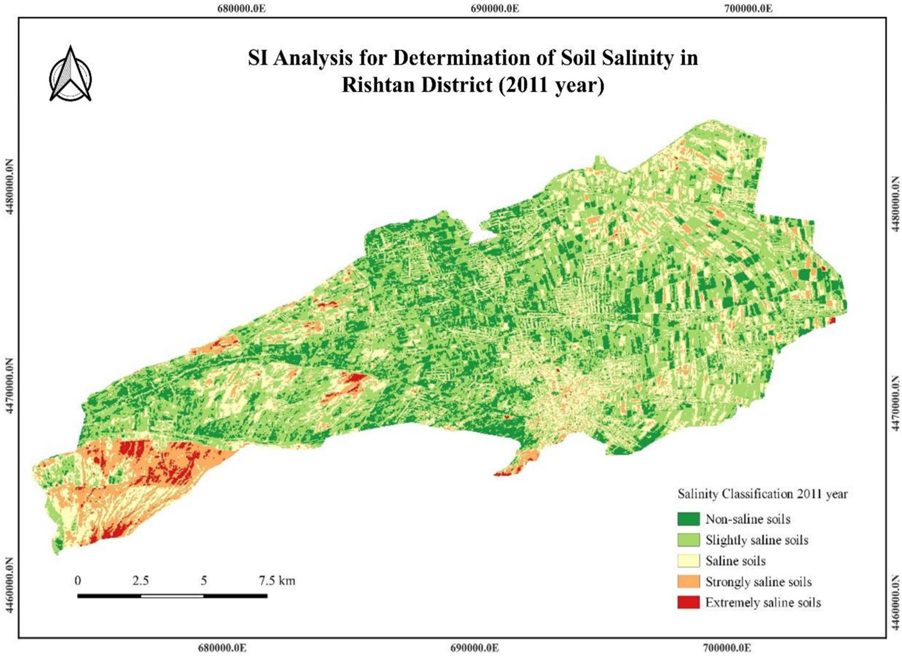

Fig. 6. Soil salinity map processed from RS image for 2011 of Rishtan district.

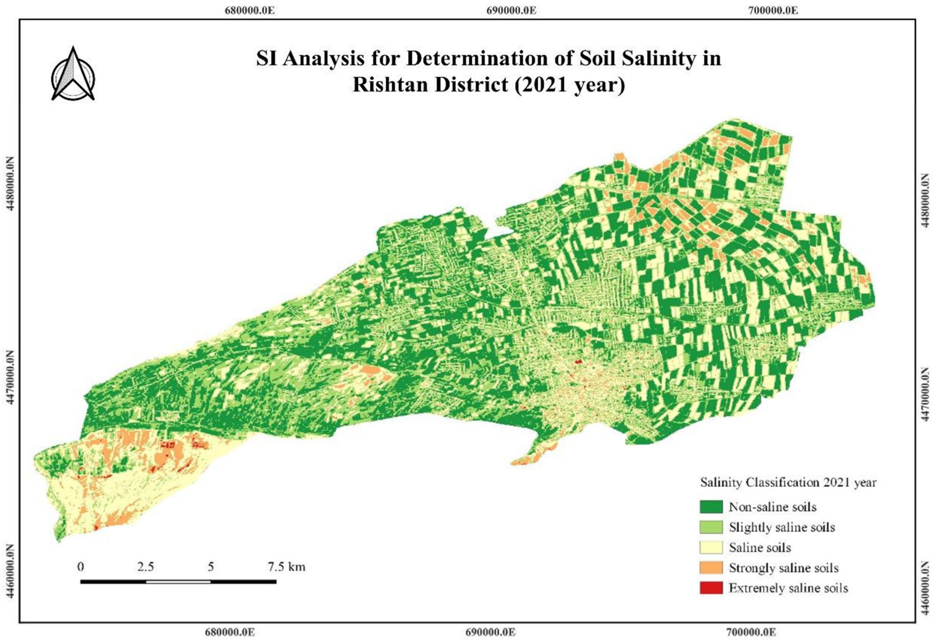

Fig. 7. Soil salinity map processed from RS image for 2021 of Rishtan district.

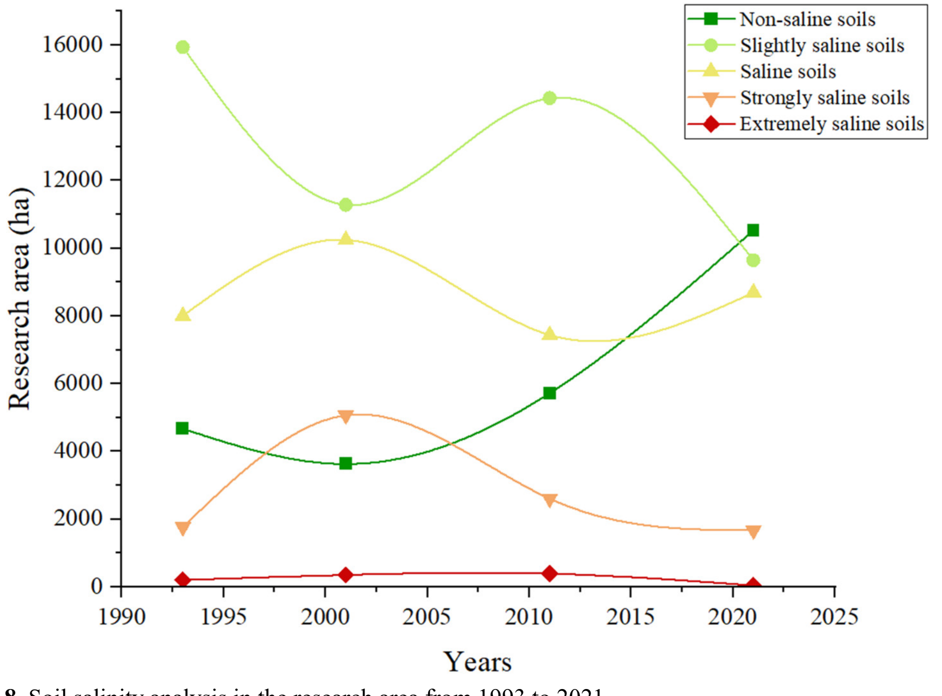

Fig. 8. Soil salinity analysis in the research area from 1993 to 2021.

The results of the remote sensing classification of soil salinity in the research area show that despite the proximity of groundwater in the Rishtan district, from 1993 to 2021, the district's level of soil salinity substantially decreased. According to data presented in Figure

8 the data from 1993 show that after the allocation of agricultural land in the province to farms, in the research area's western and upper north regions, the level of soil salinity started to rise dramatically. Salinity was observed in 26.2% of the total area, while slightly saline soils accounted for 52.1% (Figure 4). Due to the imbalance of ameliorative conditions in agricultural lands and the situation with drainage, collector systems, and various other factors, according to 2001 data, the salinity of the soil in the region increased by 7.3% compared to 1993. Strongly saline soils were 5.8% in 1993, but by 2001 it had risen to 16.6%. This year, the amount of non-saline soil was the lowest at 11.9% (Figure 5). The slightly saline level decreased from 15,941 hectares in 1993 to 11,287 hectares, which is a difference of 15.2% from the previous decade. The extreme salinity result is observed in 2011 at 1.3%. Of course, this is not a high-performance result compared to the total area, but an increase of 0.5% compared to 1993 (Figure 6).

About 50% of the country's irrigated agricultural plots have varying amounts of soil salinity, as part of the government program, control over this situation has been strengthened. In particular, it was accomplished to prevent salinity levels in the area thanks to the President of the Republic of Uzbekistan's Decree "On measures to radically improve the system of land reclamation" that radically improve the reclamation of irrigated lands and the development of agriculture. [16]. Specifically, non-saline lands accounted for 15.3% in 1993 and 34.4% in 2021 (Figure 7). Desalination of irrigated farmland depends significantly on the upkeep of collector-drainage networks. At the same time, complex agrotechnical measures will be required to de-saline irrigated lands, including leveling, salinization, and strict adherence to irrigation regimes. As Figure 8 shows non-saline soil increased from 4,670 hectares to 10,533 hectares an increase of 19.2%. between 1993 and 2021.

The digitalized maps demonstrate how advantageous it is to create soil salinity maps using GIS tools. It is evident that GIS tools enhance the region of interest's visualization. In addition, the analysis and monitoring of data are significantly productive and efficient. As with traditional mapping of soil salinity, it is necessary to collect soil samples and laboratory analyses of the collected samples to determine the chemical components. Additionally, because sampling takes time, traditional methods for determining soil salinity are labor- and money-intensive. But for measuring and mapping soil salinity, GIS and remote sensing technologies offer more effective, affordable, and quick tools and methodologies. It requires specialized knowledge for data analysis but takes less time and money [17].

Taking into consideration the surface of determination of salinity and irrigated lands of the study area, to obtain the results, the typical salinity indices (SI) were obtained using Landsat images which were selected according to the border of the study area. The results further clarify the mechanism and occurrence of soil salinization and therefore provide a scientific basis for preventing and treating soil salinization. However, further research is needed to elucidate the mechanisms underlying the soil salinization process and improve the inversion accuracy.

4 Conclusions

The study's findings indicate that the situation with soil salinization in the study area has decreased over the decades, especially after 2011, which has led to positive effects for many years. Meanwhile, the analyzed literature of government organizations also indicates that the state of soil salinity at the Republican and regional levels is improving, and areas with non-saline are decreasing. Such a reduction in soil salinity is a sign that drainage systems need to be repaired and maintained. Construction of melioration and irrigation facilities and irrigation networks, improvement of their rehabilitation and repair, and improvement of the water management system are one of the tasks set over the years. Such efforts have a significant role in enhancing the region's irrigated lands' condition. This allowed for the reduction of moderate to strongly saline soils and the reduction of areas with groundwater levels up to 2 meters.

The resources mentioned above enable us to take into consideration the following facts:

1. Satellite imagery data can be utilized as a starting point for monitoring the salinity of irrigated soils in arid areas since they provide accurate information on the measurement of soil salt levels. It is feasible to divide areas with saline and non-saline soils using photographs that satisfy particular criteria, estimate the proportion of saline soils, and calculate the salinity level in a meter layer.
2. The monitoring program for soil salinity in irrigated lands should include the solution of three tasks: 1) inventory of saline soils; 2) investigation of soil salinization dynamics and 3) forecast of salt processes and recommendations for their regulation.
3. Analysis of the image on the images allows the use of high-resolution images that meet the specified requirements to assess the degree. Five degrees of soil salinity are reliably distinguished: non-saline soils, slightly saline soils, saline soils, strongly saline soils, and extremely saline soils.

Overall, the research area's soil salinity has decreased, which has led to positive changes over the past decades. Crop yields decreased in accordance with the measured amount of soil salt, and the findings indicate that soil salinity significantly affects crop yields. Positive outcomes from the application of GIS and remote sensing techniques should be followed up on and made available to government agencies in order to enhance workflow.

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