Analysis of soil salinity in irrigated agricultural land using remote sensing data: case study of Chinoz district in Uzbekistan

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Abstract. Soil salinity is a serious agricultural concern in Uzbekistan, causing plant growth to be hampered and crop productivity to be diminished. This issue is especially prevalent in semi-desert and desert regions, compounding problems such as soil erosion, land degradation, subsidence, corrosion, and poor groundwater quality. On the other hand, Geographic Information Systems (GIS) and Remote Sensing (RS) technologies provide more efficient, cost-effective, and timely tools and procedures for mapping soil salinity. Different indices and methods can be used to detect and quantify soil salinity levels using the spectral information acquired by the Landsat-8 OLI sensor. Among these are the Normalized Difference Salinity Index (NDSI) and the Normolazed Difference Vegetation Index (NDVI). GIS software integrates satellite imagery with auxiliary data such as soil type and topography, allowing for a thorough assessment of soil salinity distribution over the research area. Compared to traditional methods, integrating remote sensing data with GIS analysis provides a more efficient and cost-effective approach to soil salinity assessment. The findings of this study will help us understand the distribution of soil salinity in the study area and provide insights for decision-making processes connected to sustainable land management.

1 Introduction

Soil salinity is a major challenge facing winter agriculture in Uzbekistan. It adversely affects the growth and productivity of crops, resulting in significant portions of agricultural land being rendered unusable year after year. As a result, regular assessment and monitoring of soil salinity levels are crucial. However, traditional methods of soil salinity assessment, such as collecting soil samples and conducting laboratory analyses, are both time-consuming and expensive.[1,2]. In this regard, the utilization of modern technologies is crucial, and one such technology is the integration of Geographic Information Systems (GIS) and Remote Sensing (RS) technologies. This approach enables faster and more efficient data sharing for soil salinity assessment and mapping. [3,4]. Currently, two primary organizations are tasked with assessing soil salinity levels on agricultural land in

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Uzbekistan, and both employ GIS technologies for data mapping and visualization. However, their approach is limited to manual mapping, and remote sensing data analysis is not currently utilized. [5–7]. The State Research Institute of Soil Science and Agrochemistry has developed a methodology for assessing soil salinity levels; however, it does not incorporate remote sensing technologies. Consequently, this methodology incurs significant costs and requires substantial investment. [8,9]. To evaluate the effectiveness of the new technology, we have chosen the Chinoz district as the focus of our research. This district is particularly suitable due to its specialization in agriculture, and its agricultural lands are significantly affected by soil salinity resulting from the proximity of saline groundwater to the soil surface [26]. We utilized Landsat-8 OLI satellite images to map the spatial distribution of soil salinity in the area and to analyze the correlation between these results and traditional soil salinity analysis methods. Landsat images are widely utilized due to their popularity, extensive database, and ease of use.[10,11]. The research findings broadly apply to scientific researchers, farmers, and agricultural experts. [12–14]. This study utilizes advanced techniques, including GIS and RS technologies, to enhance the efficiency and precision of soil salinity assessment. [15]. Satellite remote sensing is widely employed across the globe to study soil salinity and is considered one of the most efficient and cost-effective methods for conducting such research. [16]. These advanced methods enable the effective monitoring, maintenance, and enhancement of soil fertility on existing irrigated land, ensuring its targeted and efficient use [17]. The study of soil salinity using advanced technologies is essential for efficiently utilizing irrigated lands and preventing damage to land reclamation efforts. [18–20]. Some researchers have expressed concerns that using GIS and RS technologies to study land salinity may result in a loss of accuracy. In this study, we propose that both methods can be utilized to develop efficient and rapid tools for soil salinity mapping and assessment without compromising the traditional method [27]. Using the widely utilized Landsat-8 OLI satellite imagery, this study maps the spatial distribution of soil salinity in the Chinoz district and compares the results with traditional soil salinity analysis methods. The study aims to demonstrate the effectiveness and validity of utilizing GIS and RS technologies in tandem for soil salinity assessment [21,22]. The results of this study can be viewed as the initial step toward conducting further large-scale research. These findings provide valuable insights for young researchers as they continue to enhance their knowledge in developing advanced soil salinity assessment methods utilizing GIS and RS technologies.

2 Materials and methods

2.1 Study area

The study area is situated in the Chinaz district of the Tashkent region. It spans from latitudes 40°58'06" to 41°05′47″ N and longitudes 68°52′36″ to 69°04′44″ E, covering an area of 340 square kilometers (Fig. 1). Based on the reports of the "State Cadastre Agency" it is estimated that 59% of the lands in the study area are impacted by varying degrees of salinity[23].

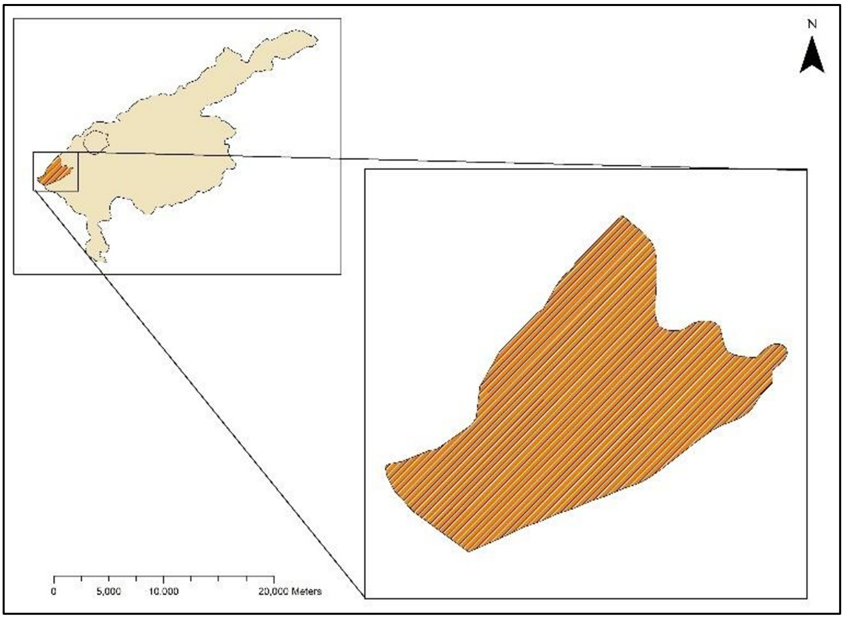

Fig. 1. Study area (Source: www.diva-gis.org adapted via ArcGIS tools)

Preserving soil quality and natural fertility is one of the most important factors in agricultural production. Soil salinity levels also reflect compliance level values when comparing soils with average levels. Landsat space data was used in this study, and ArcGIS analysis methods were employed. Space data for the years 2012 and 2022 were obtained, and the study area was determined along with its coordinates. The data and map of soil salinity and action level values for 2012 and 2022 were digitized and analyzed using ArcGIS software. The final result is presented in Fig 2.

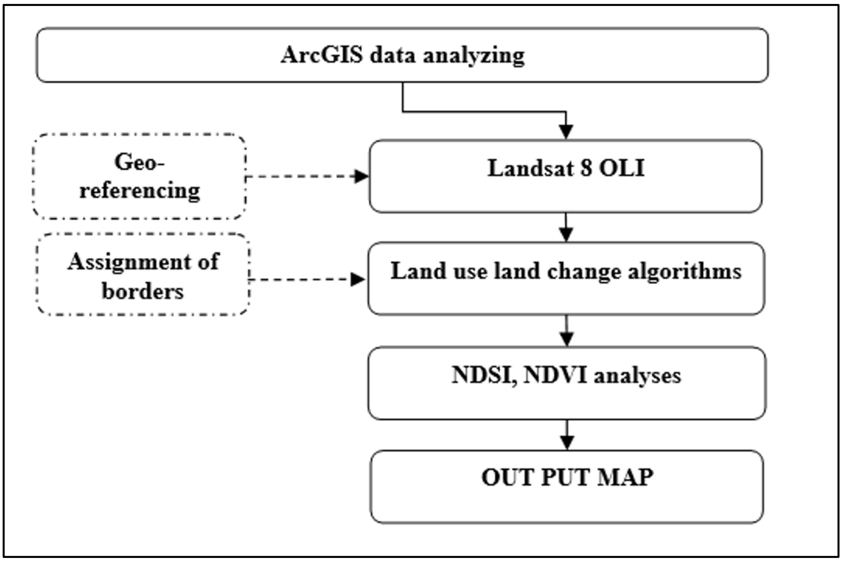

Fig. 2. Flow chart for adopted methodology of study

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Data: The study area's satellite images for the years 2012 and 2022 were obtained from open sources, specifically the Landsat OLI 8, which is after the vegetation period when the peak salinity level of arable land occurs, usually in the second half of October and the beginning of November. The satellite captures an image of the entire worldview every 16 days using high spectral sensors. The spatial resolution of the images is 30 meters, meaning that one pixel of the image represents a 30 x 30 meter ground view (U.S. Geological Survey, 2012 & 2022)[24,25].

Data processing: Initially, the Landsat 8 OLI image obtained through remote sensing was projected onto the WGS 1984 UTM Zone 42N coordinate system and then clipped to match the extent of the study area. Subsequently, we utilized an NDVI and NDSI mask to isolate the saline areas. The Normalized Difference Vegetation Index (NDVI) was calculated using an equation formula, specifically for Landsat OLI 8 satellite sensor raster layers, presented below. (Equation 1):

$$NDVI = (NIR - RED)/ (NIR + RED) \quad (1)$$

there NIR is Near InfraRed band of Landsat sensor, Red is the red band of Landsat sensor.

Soil salinity levels were categorized into five classes based on the NDSI values (Table 2), ranging from no salinization to very severe salinization. To examine the soil type, a multiband raster object of Landsat 8 OLI was employed to compute the NDVI, resulting in a raster object that indicates index values. The NDVI is a vegetation index that addresses the influence of soil brightness by incorporating a soil-brightness correction factor. This index is frequently employed in agricultural lands where vegetation cover is scarce, and soil salinity is high.

Table 1: Relationship between Normalize Difference Salinity Index range and Soil salinity categories

Normalize Difference Salinity Index range	*Soil salinity categories*
0.15-0.25	Very high salinization
0.26-0.40	High salinization
0.41-0.55	Medium salinization
0.56-0.70	Low salinization

Soil salinity can be detected using multi-temporal satellite imagery by directly identifying salinity features on the soil surface or indirectly through indicators like the presence of halophytic plants, utilizing the NDSI. For this research, salinity indices were developed for soil salinity mapping and were applied to Landsat images using the red and near-infrared bands. Regions impacted by salinity display higher spectral radiance in bands 1 and 3 of the Landsat images. Therefore, the difference between red and near-infrared bands can provide specific details about the salt-affected area in an image. This information is represented by the following (Equation 2).

$$NDSI = (Green - SWIR)/ (Green + SWIR) \quad (2)$$

There Green is the green band of Landsat sensor, SWIR is short-wave infrared wavelength bands

Since the Landsat OLI 8 sensor automatically carries out atmospheric and radiometric corrections while acquiring remote images, there is no requirement for atmospheric and radiometric corrections in this scenario. To distinguish the spectral reflectance of soils with high salinity from those with low salinity, it was essential to graph the spectral reflectance of different degrees of soil salinity. This procedure will facilitate the creation of a soil salinity index that is customized for desert soils.

3 Results and discussion

Soil salinity is a significant environmental concern in the research area, resulting from natural and human activities. The impact of salinity on crop growth reduction is generally influenced by land use and type. In addition, high soil salinity can lead to inefficient land use and the accumulation of agglomerative materials on lands, limiting agricultural land in many regions worldwide. Our objective was to analyze and implement the NDVI. The soil salinity map (Fig. 3) shows that arable land without salt content is partially absent. In the study area, soil salinity is a major environmental hazard that arises from natural and anthropogenic processes. The impact of salinity on crop growth reduction varies according to land use and type. High soil salinity can lead to the inefficient use of land and the accumulation of agglomerative materials on land. In several parts of the world, soil salinity is a critical factor limiting agricultural land. Our analysis and implementation of the NDVI allowed us to achieve our goal. The NDVI map (Fig. 3) indicates that arable land devoid of salt content is partially nonexistent. This finding underscores the importance of addressing soil salinity in the study area and the need for appropriate management strategies to minimize its effects on crop growth and land use efficiency. Overall, our research highlights the significance of soil salinity as an environmental hazard in the research area and the need to address this issue to ensure sustainable agricultural practices. The implementation of the NDVI proved to be a valuable tool in identifying areas affected by soil salinity. It could aid in developing appropriate management strategies to mitigate its impact on agricultural productivity.

Fig. 3. Result of years 2012 and 2022 Normolazed Difference Vegetation Index (NDVI) analysis

The salinity map depicts that moderate and severe salt-affected soils were widespread in the Chinaz district, except for its northern part. However, in 2022, the topsoil in the central and southwest regions of the district exhibited very high concentrations of salt content.

Fig. 4. Result of 2012 and 2022 Normalized Difference Salinity Index (NDSI)

According to the NDSI analysis, the application of remote sensing technology can be useful for analyzing soils in the study area (Fig. 4), as indicated by the statistics presented in Table 2. When mapping soils from remotely sensed data, accuracy is crucial to ensure the correctness of classification. Therefore, a highly accurate map should be produced through the remote sensing classification process. The classification accuracy refers to how closely the map derived from remote sensing classification matches real-world field information. To reduce the cost of mapping soil salinization, Platonov et al. suggested using multi-temporal satellite images to create soil salinity maps and collecting soil samples from a limited number of points within fields with varying soil salinity levels. This method could increase the accuracy of soil salinity maps while minimizing expenditures on soil sampling. Akramkhanov et al. discovered significant correlations between quantifiable terrain attributes and soil salinity, which were successfully used to estimate soil salinity at the farm level based solely on quantified environmental variables. Therefore, high-resolution or easily measurable environmental variables must be accessible for the study area to use this approach. Overall, remote sensing technology and field measurements can produce highly accurate soil maps. Additionally, quantifiable environmental variables can aid in estimating soil salinity, reducing the costs associated with soil sampling.

4 Conclusions

Soil sampling can be a costly and time-intensive, with soil specialists and their assistants typically only able to sample 15-20 points per day. However, technological advancements have made satellite remotely sensed images widely accessible online. Our research shows that using satellite sensors, soil salinization can be measured with up to 85% accuracy, serving as an example of the effectiveness of this approach in mapping land degradation. Combining GIS with RS techniques in soil salinity mapping is a highly cost-effective method that provides a high degree of spatial precision. Our findings indicate that nearly all of the arable land areas in our study are at risk of varying soil salinity levels. Neglecting to implement prompt and appropriate measures to address this issue will likely negatively impact the economy and agriculture.

In light of these results, using RS and GIS techniques to monitor soil health and quality can be seen as a valuable and effective tool in soil analysis and management. With these technologies, large-scale soil sampling can be accomplished quickly and with a high level of accuracy, allowing for timely detection of soil degradation issues such as salinization. By providing detailed information on soil conditions, including salinity levels, GIS and RS mapping can also help identify areas requiring specific attention and management strategies. These techniques can aid in developing informed policies and interventions to safeguard soil health, productivity, and sustainable agriculture.

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