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Temporal and Spatial Dynamics of Soil Salinity in Wasit Governorate: A Remote Sensing and GIS Analysis

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Abstract: This research investigates the temporal and spatial dynamics of soil salinity in Wasit Governorate during the hot dry summer season from 1979 to 2022. Using satellite imagery and GIS techniques, the Soil Salinity Index (SI) was analyzed to assess changes in soil salinity levels over the study period. The findings reveal significant temporal and spatial variations in soil salinity, influenced by climatic factors such as temperature, precipitation patterns, and evaporation rates. Overall, there was an increasing trend in soil salinity, with certain years showing higher salinity levels. The study highlights the impact of soil salinity on land degradation and underscores the importance of continuous monitoring and management of soil salinity levels to ensure land sustainability. Recommendations for further research and targeted interventions to mitigate soil salinity are provided. This research contributes to our understanding of soil salinity dynamics and informs strategies for sustainable land management in Wasit Governorate.

Keywords: Soil Salinity, Remote Sensing, GIS Analysis, Temporal Dynamics, Spatial Dynamics, Environmental Monitoring

1. Introduction

Soil salinization is a primary agricultural issue in countries situated in arid and semi-arid climates, now posing a common threat as a form of soil degradation, a dynamic phenomenon representing a serious challenge and one of the most widespread environmental problems globally (Singh, 2022; 2021; Ibrahim, 2016). Salinity presents a problematic issue for agriculture in the Mesopotamian Plain, Iraq, since around 2300-2400 BCE (Wu et al., 2014). Soil salinization is a significant environmental and ecological problem in dry and semi-dry regions worldwide. Unfortunately, soil salinity has become a serious threat, endangering environmental stability, regional ecosystems, sustainable agricultural development, and global food security (McBratne et al., 2014). It is crucial to understand the spatial distribution of soil salinity, as it enriches the soil with soluble salts, leading to soil salinization, accelerating desertification, and causing environmental deterioration. It is one of the major and principal problems globally (Wang et al., 2020; Zaman et al., 2014). Variations in salinity levels are observed from one location to another due to natural and anthropogenic processes, posing a significant environmental risk. This phenomenon is globally distributed across various geographic regions characterized by different climates. However, flat, low-lying, semi-arid, and arid landscapes are the most affected, facing significant challenges of spatial and temporal distribution of soil salinity, particularly during drought periods, due to declining groundwater quality, rising temperatures, and scarce rainfall (Okur & Örçen, 2020; Kurylyk & MacQuarrie, 2013). Consequently, it is primarily a temporal and spatial dynamic movement resulting from various complex processes of redistributing salt-affected lands, depending on natural conditions, agricultural practices, and poor sewage management exploited by humans in their daily lives. Increased salinity is a major factor significantly affecting land fertility and productivity (Kulmatov et al., 2020). Salinity-affected lands are found in more than 100 countries, with no continent entirely free from salinity. The severity of salinity issues varies across countries and even within countries due to differences in locations, terrains, irrigated agricultural areas, and farmers' fields defined by climatic, environmental, and local administrative conditions (Mosleh Ghahfarokhi & Bagheri Bodaghabadi, 2023; Shrivastava & Kumar, 2015).

Remote sensing plays a vital role in detecting, mapping, and monitoring surface features affected by salinity. The method of extracting saline lands from remote sensing (RS) imagery demonstrates the potential for economical and

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effective detection and monitoring of salinity and its mapping. Previous studies' methods for extracting soil salinity information from satellite images have been moderately successful. Numerous studies have shown that remote sensing is a useful tool for identifying highly salinity-affected soils and utilizing remote sensing data due to the complex soil context (vegetation cover, moisture, surface roughness, organic matter) and the weak spectral characteristics of saline soil (Ben-Dor et al., 2009). The aim of the research is to investigates the temporal and spatial dynamics of soil salinity in Wasit Governorate during the hot dry summer season from 1979 to 2022.

2. Methodology

Although various methods have been developed and utilized, such as soil spectral reflectance, the Salinity Index (SI), which utilizes soil spectra exclusively, may not effectively and quantitatively detect soil salinity. This is due to the correlation between soil spectral properties and its components under different conditions, where reflectance values vary due to differences in chemical and physical properties (Mosleh Ghahfarokhi & Bagheri Bodaghabadi, 2023). Significant technological advancements have resulted in the integration of Geographic Information Systems (GIS) and Remote Sensing (RS), which are modern tools for studying natural materials, including soil salinity. This involves inputting, storing, and analyzing data, information, and maps to analyze electromagnetic energy collected from the sun's rays on the Earth's surface, interacting with it either through absorption, transmission, reflection, or emission (Lyon & McCarthy, 1995). The Salinity Level Index (SI) is used to estimate the extent of salinity's impact on soil moisture. This index relies on the direct relationship between excessive water retention and soil salinity concentration, where salt accumulation on the soil surface leads to the deterioration or complete absence of vegetation cover, resulting in the exposure of the surface layer of soil in the salinized area. The index utilizes the fourth spectral band (R) and the third spectral band (NIR), representing a measure of surface reflectance of salinity-affected land. It calculates the relationship between the blue, red, and green bands to determine salinity-affected land and is used in producing maps of soil moisture content levels through the mathematical relationship of the following equation (Badapalli et al., 2023).

$$SI = \frac{R}{NIR} \times 100 \qquad (1)$$

Where:
SI = Salinity Index
R = Fourth spectral band (Red band)
NIR = Third spectral band (Near-Infrared band)

The study area is located in Wasit Province, situated in the eastern part of central Iraq, between latitudes (31°-33' - 45°-30') north and longitudes (44°-31' - 46°-34') east. It is bordered to the north by Baghdad and Diyala provinces, to the south by Dhi Qar Province, to the southeast by Maysan Province, to the west by Babil and Diwaniyah provinces, and to the east by the Islamic Republic of Iran. Thus, it falls within the central region of Iraq, covering an area of 17.235 km², which constitutes 3.95% of the total area of Iraq, which is 434.128 km². The administrative units include seventeen administrative units, including six districts and eleven sub-districts, namely Al-Suwaira, Al-Aziziyah, Al-Nu'maniyah, Al-Kut, Badrah, and Al-Hayy. The climatic characteristic indicates that it falls within the dry desert climate, with temperatures exceeding 42°C during the hot summer season (Al-Hameedi et al., 2022; Muslim et al., 2019), (See Fig. 1).

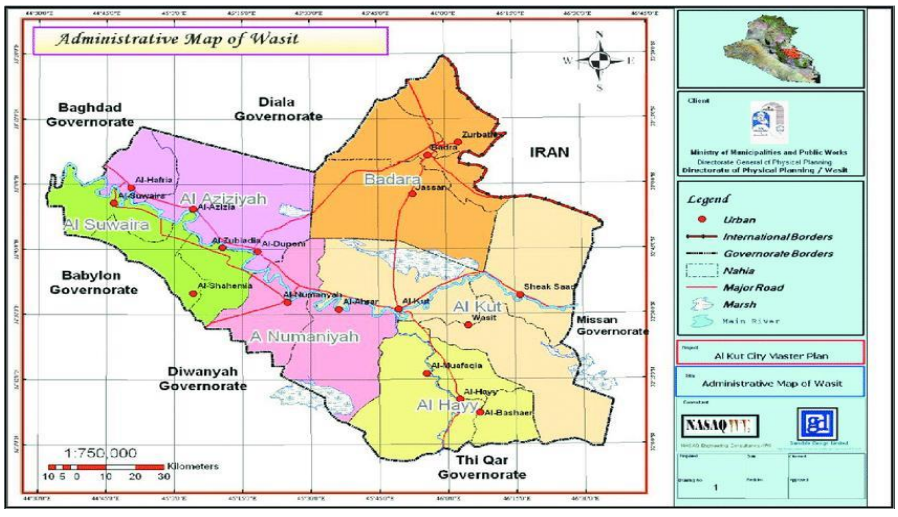


Fig. 1: Study Area for Wasit Province.
Source: Ministry of Water Resources, General Authority for Survey, Administrative Map of Wasit Province, Scale 1: 1.150.000.

3. Results and Discussion

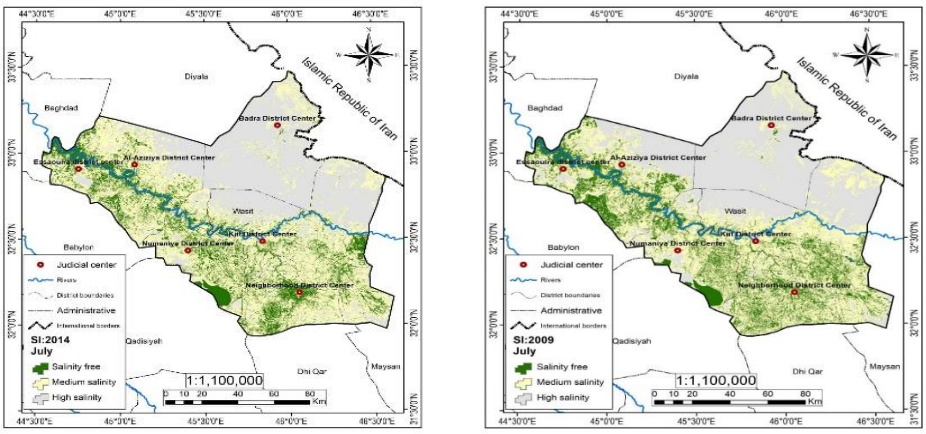
3.1 Low Salinity Category

This category appears third among the study categories for the hot dry season According to Table (1) data, in 1984, it ranked first among the study areas, covering an area of 4286 km², constituting 24.24% of the total area. These lands appeared in the southeastern part and the areas surrounding the Tigris River in the central and northwestern regions bordering Baghdad Province. In 1989, there was an increase in area to 6557 km², representing 37.08%. The lands in the northwestern and central areas of the province and the southern areas showed an expansion (Qassim & Abduljabbar, 2020). In 1994, there was a decrease in area to 4635 km², accounting for 26.21%. The lands shifted from the southeastern area to the northwestern bordering Baghdad Province. In 1999, the area covered was the lowest, with 2123 km², constituting 12.01%. The distribution of these lands is evident in the districts of Al-Aziziya, Al-Suaira, Al-Nu'maniya, Al-Kut, and Al-Hayy. The most prominent feature of the decline in low salinity (SI) is observed in 2004, with an area of 2518 km², accounting for 14.24% (Hassoon & Ibraheem, 2022). The non-saline lands accompanied the Tigris River from the northwestern part towards the central region to the eastern and southwestern lands.

Table 1: The area of Soil Index (SI) Low Salinity Category in Wasit governorate for the Hot Dry Season For The Period (2022-1979)

Month	Year	Saline free (km2)	Saline free (%)	Total (km2)
July	2022	2730	15.44	17684
July	2019	3467	19.6	17684
July	2014	2882	16.3	17684
July	2009	3154	17.84	17684
July	2004	2518	14.24	17684
July	1999	2123	12.01	17684
July	1994	4635	26.21	17684
July	1989	6557	37.08	17684
July	1984	4286	24.24	17684

In 2009, the sixth period with a salinity-free index recorded a clear increase to 3154 km², constituting 17.84%. The lands appeared in the central and southwestern regions. The decline in 2014 coincided with the appearance of lands covering 2882 km², representing 16.30%. The decrease in area corresponded to the distribution of lands in the eastern and southern sections to the central region adjacent to the Tigris River and extending to some lands in the northwestern part bordering Baghdad Province. In 2019, the area covered ranked fourth among the study areas, reaching 3467 km², constituting 19.60%. The lands were distributed in the northwestern part, the central region, and some lands in the southeastern section. In 2022, the area covered was the lowest compared to previous years, reaching 2730 km², with no increase in percentage, at 15.44% (Atta, 2020). These lands were located in the southern part of the Jassan district towards the central, southern, and northwestern parts, adjacent to the Tigris River in Wasit Province, (see Fig. 2).



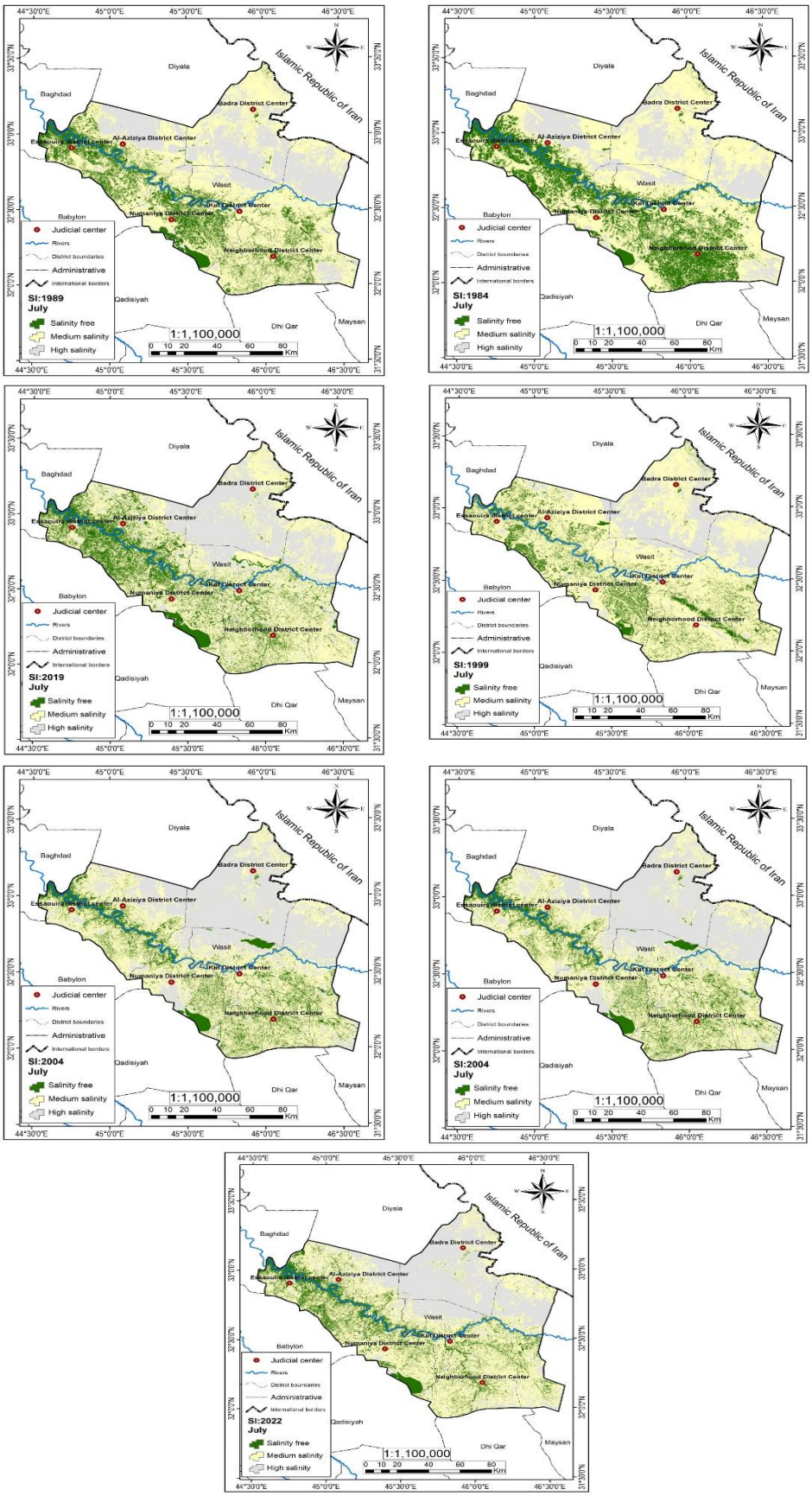


Fig. 2: Low Salinity Category.
Source: Researcher Relied on: Satellite Imagery from Landsat 5, 7, 8. ArcGIS 10.2.2 Software

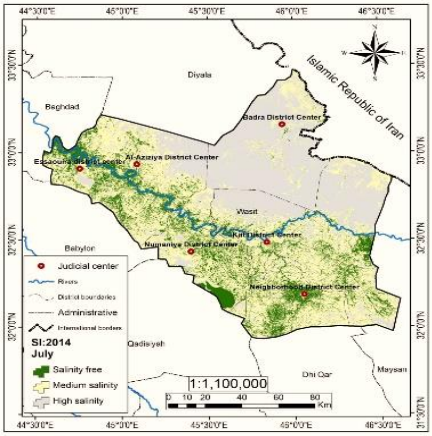
3.2 Medium Salinity Category

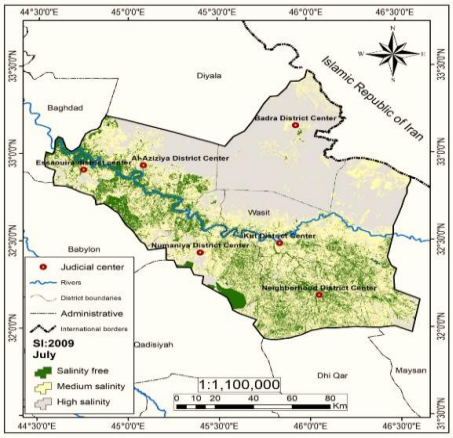
This type ranked first among the SI categories in terms of area for Wasit Province from 1979 to 2022, as shown in Table 2. The area of medium salinity lands fluctuated over the years, with visible changes in area observed through satellite imagery. In 1984, the area covered by medium salinity lands was 10.023 km², constituting 56.68% of the total area. These lands covered all study areas. In 1989, it ranked eighth in terms of area among the study areas, with a decrease of 7.425 km², representing 41.98%. Medium salinity lands were absent in the surrounding areas of the Tigris River and the northeastern part towards the eastern and northwestern lands. The area covered in 1994 was 9.940 km², accounting for 56.21%, showing a clear increase. These lands extended from the eastern part surrounding the Tigris River southward to the southern and central regions to the northwestern part of the province. The area covered in 1999 witnessed a significant increase to 12.118 km², with a percentage increase of 68.53%. These lands did not appear in the districts of Al-Aziziya, Al-Suaira, Al-Kut, Al-Nu'maniya, and Al-Hayy.

Table 2: The area of Soil Index (SI) Medium Salinity Category in Wasit Governorate For the Hot Dry Season for The Period (2022-1979)

Month	Year	Medium Saline (km2)	Medium Saline (%)	Total (km2)
July	2022	9011	50.96	17684
July	2019	9219	52.13	17684
July	2014	7893	44.63	17684
July	2009	8367	47.31	17684
July	2004	7419	41.95	17684
July	1999	12118	68.53	17684
July	1994	9940	56.21	17684
July	1989	7425	41.98	17684
July	1984	10023	56.68	17684

The decrease in area in 2004 marked the sixth decline in area ranking, with the absence of these lands in the areas of Sheikh Saad and Jassan, as well as in the northeastern and northwestern parts of Al-Aziziya district. The area covered in 2009 ranked last among the study areas, reaching 7.419 km², with a percentage of 41.95%. These lands did not appear in the areas of Jassan, Sheikh Saad, and the northeastern part of Al-Aziziya district. All medium salinity lands experienced a clear increase in area in 2014, with an area of 7.893 km², constituting 44.63%. These lands covered all districts of Wasit Province. Consequently, the area covered in 2019 showed a significant increase, reaching 9.219 km², with a percentage of 52.13%, except for the central region, where no registration was made. The area covered in 2022 was the smallest for this category, totalling 9.011 km², representing 50.96% of the total area. Registration disappeared in the central region of Wasit Province, (see Fig. 3).





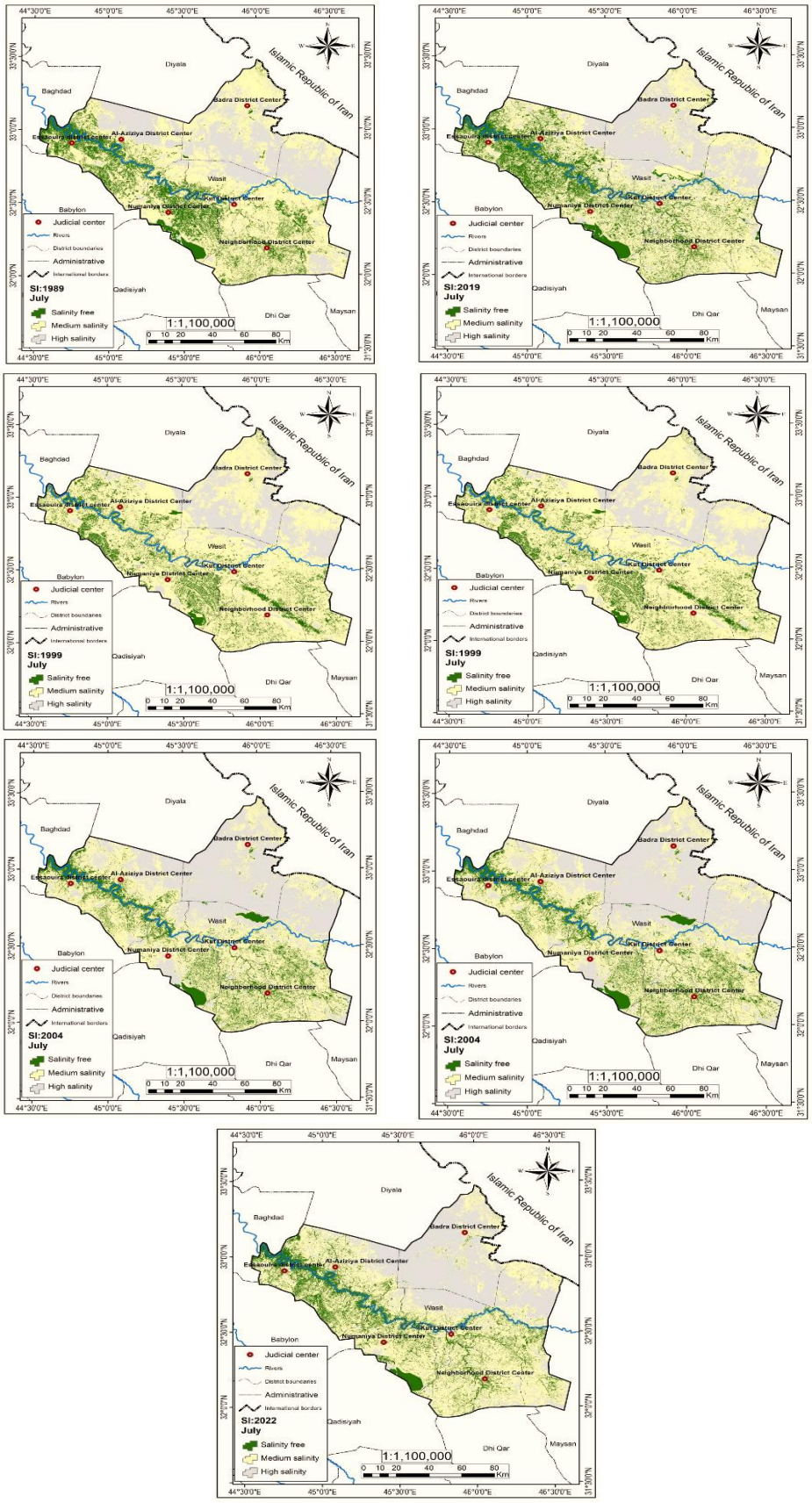


Fig. 3: Medium Salinity Category.
Source: Researcher relied on: Satellite imagery from Landsat 5, 7, 8. ArcGIS 10.2.2 software

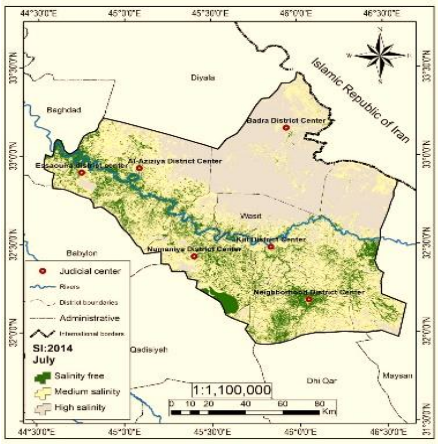
3.3 High Salinity Category

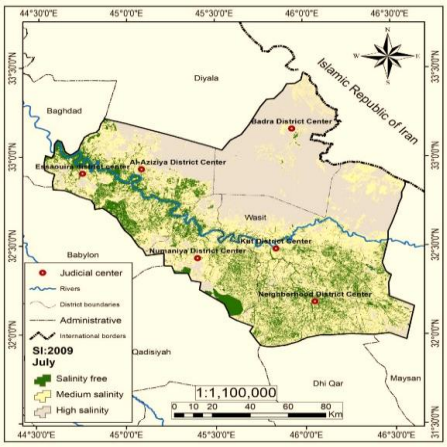
According to the data in Table 3, this category ranks second in terms of area after the salt-free category. There is spatial and temporal variability in the area of lands with high salinity during the hot dry season. In 1984, the area decreased to 3376 km², accounting for 19.09%. The decrease in area occurred in the northeastern part of Al-Aziziya district towards the central and eastern regions and the northeastern part of Badra district, as well as in the southwestern part of Al-Nu'maniya district and the southeastern part of Wasit Province. The area also decreased to 3703 km², representing 20.94% in 1989. High salinity lands were present in the northeastern part, the central region, and the northeastern part of Al-Aziziya district, as well as in some southwestern areas of Al-Nu'maniya district. In 1994, the area decreased to 3109 km², constituting 17.58%. The lands were present in the northeastern part, the central region, and the southwestern areas of Al-Nu'maniya district. The decrease continued in 1999, with lands appearing in the southern part of Badra district, the central region, and extending to the neighbouring boundaries of Baghdad Province. Some lands in the southern part of Al-Suaira district and the southwestern and northwestern parts of Al-Nu'maniya district, as well as in Al-Hayy district, were also affected.

Table 3: The area of Soil Index (SI) high salinity category in Wasit Governorate for the Hot Dry Season For The Period (2022-1979)

Month	Year	High Saline (km2)	High Saline (%)	Total (km2)
July	2022	5943	33.6	17684
July	2019	4999	28.27	17684
July	2014	6909	39.07	17684
July	2009	6799	38.44	17684
July	2004	7111	40.21	17684
July	1999	3443	19.47	17684
July	1994	3109	17.58	17684
July	1989	3703	20.94	17684
July	1984	3376	19.09	17684

In 2004, there was a significant increase in area to 6799 km², accounting for 38.43%. These lands were distributed in the northern part of Al-Aziziya district, the northeastern part towards the central region, and the eastern boundaries of Wasit Province, as well as some lands in the southwestern part of the province. In 2009, the area ranked first in terms of area, covering 7110 km², accounting for 40.21%. The lands occupied the northeastern part, the central region, extending towards the eastern and northeastern parts of Al-Aziziya district, as well as several lands in the southwestern, northwestern, and southwestern parts of Al-Nu'maniya district. The decrease in area continued in 2014, with an area of 6909 km², accounting for 39.07%. The lands extended to the central region, the eastern part, and the northeastern part of Al-Aziziya district, as well as some lands in the southwestern part of Al-Suaira district and the northwestern and southwestern parts of Al-Nu'maniya district. The decrease was further recorded in 2019, with an area of 4999 km², representing 28.27%. The lands were confined to the eastern and northeastern parts and the central region. In 2022, there was also a clear decrease in the area occupied by high salinity soils, reaching 5943 km², accounting for 33.60%. Their appearance was observed in the central and northeastern parts, as well as the southwestern part, (See Fig. 4).





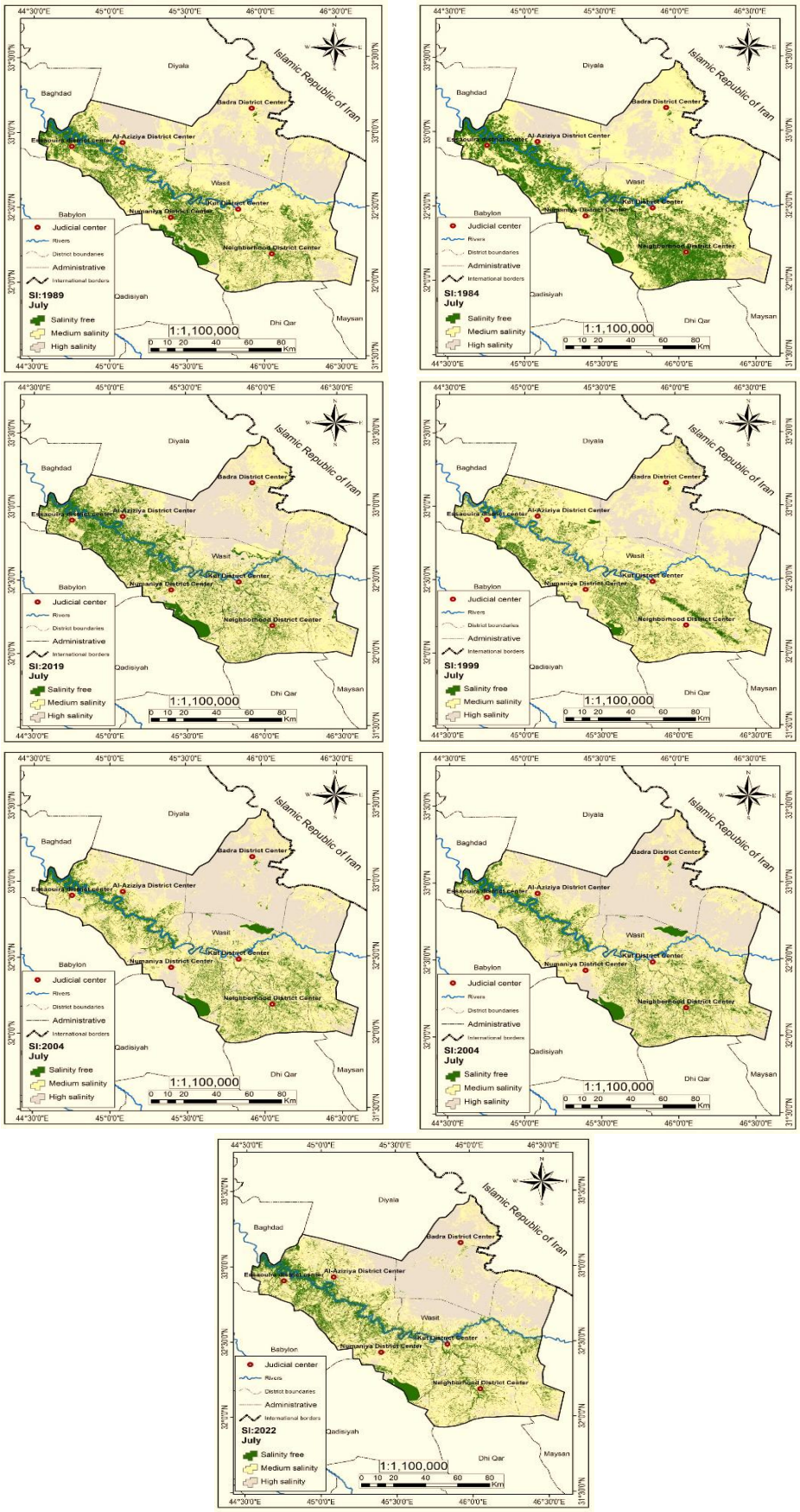


Fig. 4: High Salinity Category.
Source: The researcher relied on: Satellite imagery from Landsat 5, 7, 8. ArcGIS 10.2.2 software

4. Conclusion

In conclusion, the research provides valuable insights into the dynamics of soil salinity in Wasit Governorate, highlighting the need for proactive measures to address the challenges posed by soil salinity and promote land resilience in the face of changing climatic conditions. The research investigated the dynamics of soil salinity levels during the hot dry summer season in Wasit Governorate from 1979 to 2022. Through the analysis of Soil Salinity Index (SI) derived from satellite imagery and GIS techniques, several significant findings have emerged: 1) Temporal and Spatial Variations: The study revealed notable temporal and spatial variations in soil salinity levels across Wasit Governorate over the study period. These variations were influenced by climatic factors such as temperature, precipitation patterns, and evaporation rates; 2) Increasing Trend: Overall, there was an increasing trend in the extent of soil salinity observed during the study period. This trend was particularly evident in certain years, such as 1999, where the highest area covered by moderately saline soil was recorded, indicating a significant impact of climatic conditions on soil salinity; 3) Impact on Land Degradation: The findings suggest that soil salinity has contributed to land degradation in Wasit Governorate, with higher salinity levels posing challenges to agricultural productivity, vegetation health, and overall environmental sustainability; 4) Recommendations for Future Studies: The research recommends further studies to explore the underlying factors contributing to soil salinity variations, including the influence of groundwater levels, land use practices, and irrigation techniques. Additionally, it suggests the implementation of targeted interventions to mitigate soil salinity and restore affected lands; and 5) Importance of Monitoring and Management: The study underscores the importance of continuous monitoring and management of soil salinity levels to preserve soil fertility, protect ecosystems, and ensure the sustainable use of land resources in Wasit Governorate.

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Conflict of Interest

The authors declare no conflicts of interest.

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