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Spatial Analysis of Soil Salinity in Basrah Province by Using Geographical Information System (GIS) & Remote Sensing (RS): A Review

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Abstract
Soil salinity is a phenomenon that reduce fertility, directly impacting the environment and society. In Iraq, Basrah governorate, salinity is a pressing challenge due to its hot desert climate, where summer temperature's exceed 50°C. Integrating geographic information system (GIS) and remote sensing (RS), researchers can identify high-risk area, monitor temporal changes in salinity, and develop predictive models for agriculture planning and water resource management. Literature review shows that these systems are effective for analyzing salinity in Basrah, providing spatial and temporal understanding that support data-based reclamation plans. However, research gaps remain. Most studies lack temporal updating, relying on satellite data prior to 2015, leaving no updated picture of recent changes despite available high-resolution data. In addition, most focus solely on electrical conductivity (EC) as an indicator, without linking it to the soil's chemical and physical properties. There are no clear attempts to build spatial and temporal predictive models using artificial intelligence or geospatial modeling. Furthermore, the relationship between salinity and hydrological and climatic factors such as groundwater depth, irrigation water quality and evaporation has not been systematically addressed. Research must therefore be intensified, as salinity has long plagued the region and solutions are needed to prevent further exacerbation.

Keywords : **Electrical conductivity, GIS, Remote Sensing, Soil Salinity, sensing Indices**

I. Introduction

Soil salinity poses a critical environmental and agricultural challenge, particularly in arid and semi-arid regions. When too much salt builds up in the soil, plants struggle to grow, crop yields drop, and food security comes under threat. This issue not only harms agriculture but also damages the environment and weakens local economies [1]. According to established standards, soils with an electrical conductivity (EC) greater than 4 dS/m at 25 °C are considered saline, this condition affects negatively on the crop growth and yield [2]. Iraq is currently facing serious environmental challenges, with Basrah Governorate among the most severely affected. Located in the far south of Iraq, Basrah serves as Iraq's only gateway to the Arabian Gulf and spans an area of about 19,070 km² [21]as shown in Fig. 1. The governorate is characterized by a hot desert climate (Köppen–Geiger classification) with extremely hot summers that can exceed 50 °C and mild winters. Annual rainfall ranges from 100–150 mm, mostly during winter months [30]. Evaporation rates are high, exceeding 300 mm per month in some summer periods, which exacerbates the risk of soil salinity by leaving salts in the surface soil layers [3, 4]. In addition to its climatic conditions, several hydrological and geographical factors accelerate salinization in Basrah. These are: diminution in water level in the downstream of Shatt al-Arab, increase in the influence of sea water intrusion in the vicinity of the lower segments, low discharges of Tigris and Euphrates rivers, high saline water tables, and bad management of irrigation water [5,6]. Basrah's agriculture relies on the Shatt al-Arab and the numerous waterways that branch off from it. 'Officials from Basrah province reported a drop in freshwater flow to the city, which has caused saltwater intrusion as the freshwater has mixed with seawater. It has led to accumulation of salt in agricultural lands across the region.

Fig.1. Study area location [29]

The topographic nature of the governorate is characterized by a level plan break of very low elevation thus rendering it highly susceptible to salinity compared to the other parts of Iraq[21]. Increased salinity has already affected major crops directly, either by reducing yield, increasing the degradation of soil, and negatively affecting the means of livelihood of many inhabitants for which farming plays a significant part [2]. To solve this problem, we need to find strategies that are sustainable and also effective. We need to measure and assess how bad soil salinity is and how much it affects the land. Geographic Information Systems (GIS) and Remote Sensing (RS) are of paramount importance in this regard. These methods have enabled researchers to collect, process, and analyze environmental data with high accuracy, bringing about more knowledge on the spatial variability of salinity and its controlling factors [7, 2]. By integration of GIS and RS, we could find the high-risk regions. We can also follow how salinity changes over time. This is what lets us build models that can predict what will happen in the future. These simulations contribute to improved agricultural planning and water resources management. In this study, some previous studies that used GIS and RS to soil salinity in Basra Governorate were reviewed to discuss the distribution of salt affected soil and the more heavily area affected.

II. Soil salinity: Concept and Causes

Soil salinity According to the Food and Agriculture Organization (FAO), is the accumulation of water-soluble salts like sodium, calcium, and magnesium in the root zone of the soil [8]. Accumulation of the latter can affect plant growth and, in some cases, also plant yield, resulting in their reduced fitness. It may also change the physical and chemical characteristics of the soil. The physical and chemical characteristic of soil that influence the saltiness of the soil are water content, pH, and sodium adsorption ratio. Values greater than 4 dS/m at 25°C are generally indicative of saline soils. The majority of agricultural crops are at risk in these soils [1]. The most immediate reasons of soil sogged and environmental salinity are from:

a. Irrigation with highly saline water

One of the primary causes of soil salinity, using irrigation water containing high concentrations of dissolved salts leads to the build-up of these salts in the soil. This problem is particularly evident in arid and semi-arid regions where high evaporation rates and plant transpiration cause water to evaporate while the salts remain and accumulate in the root zone. Rengasamy(2006)[9] indicates that this process has two major consequences for soil: first, it significantly increases soil salinity, and second, it reduces soil productivity and affects crop growth.

b. High Water Table

Capillary action moves water containing salts upward when the water table is very close to the soil surface. As this water evaporates at the surface, it leaves the salts behind, leading to increased soil salinity [10]

c. Poor Agricultural Drainage:

In areas where there are no proper drainage systems or where drainage is inefficient, water tends to build up in the soil. This buildup traps salts within the root zone, especially in low-lying fields or regions with intensive irrigation. Ultimately, this worsens salinity problems [8].

d. Natural Weathering of Rocks and Minerals

Rocks and minerals in their natural state contain soluble salts. Over time, weathering processes release these salts into the soil, gradually increasing the saltiness of the soil [12].

E. Climate Change

Increasing temperatures and higher evaporation rates, particularly in hot and dry regions, accelerate the buildup of salts in soil. The problem is worsened by reduced rainfall because less water is available to flush salts away from the root zone [11].

III. The importance of GIS applications in analyzing soil salinity

Gathering, processing, and representing spatial information on soil salinity are all practiced with the support of a strong framework offered by GIS. These methods are applied to the generation of salinity distribution maps from multiple data sets [13]. A typical technique involves the use of traditional field survey data, such as the obtaining of soil samples at several sampling locations, which are then sent to a laboratory for chemical analysis. In unsampled areas, salinity can be predicted using interpolation methods as Kriging, Inverse Distance Weighting (IDW), etc. This enhances decisions around land management, land reclaim and so on [14].

IV. Remote Sensing and GIS technique approach

Geospatial technologies, particularly geographical information systems (GIS) and remote sensing (RS), have been extensively applied to study and analyze the spatial distribution of soil salinity in Basrah Governorate [3,7,17,20,22,23,24]. These technologies offer effective data collection, processing, analysis, and visualization tools for a better understanding of the phenomenon at hand and to determine the affected areas [1].

A. *Geographic Information Systems (GIS)*

The environmental and agricultural studies have been significantly changed with the use of geographic information systems (GIS) and remote sensing (RS). This technology has significantly facilitated and improved the previously difficult and time-consuming monitoring and analysis of soil salinization on a broad scale. Effective instruments were given to acquire information ant to transform them to maps and pictures. These maps and images well demonstrate the distribution and influence of salinity. Nowadays, the most useful techniques for dealing with current environmental and agricultural problems are GIS and RS [15].

Key applications include the following:

Management: Organization working on the subject can benefit from GIS which facilitates the storage and management of the various geohydrologic data on soil salinity and other relevant geographic data. Several key components are needed for a comprehensive database: sampling sites, satellite imagery, water quality measurements, climate factors, and vegetation parameters [1].

- Analysis: Advanced analytical operations in GIS permit the relationships between soil salinity and other environmental factors to be investigated. Using overlay analysis, for instance, the impact of salinity on elevation, nearness of rivers and canals and local drainage can be studied [16].
- Mapping: soil salinity Mapping and its classification in space is one of the best possible applications that can derived using the GIS. According to “Hassan and Al-Khateeb [2018]”, these maps are necessary to explicit the scale of the issue as well as the high-priority zones to be rehabilitated [17].
- Spatial modeling: GIS facilitates prediction models that estimate current as well as future soil salinity patterns. According to “Abbas [2020]”, scientists can combine field measurements and remote sensing data to forecast the potential of salinity changes and to sustain earth techniques [1].

B. Remote sensing (RS)

Remote sensing is metaphorically the science and art of 'sensing' (detecting) things (information) without being in physical contact with them [32]. The US Department of Agriculture describes remote sensing in the following terms: Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation [18]. In the perspective of soil salinity, remote sensing is a process of obtaining information from the earth's surface through sensors, which are placed on aircrafts or satellite. It has been reported in studies that salting’s deposit on the soil surface. And that can affect how the soil reflects energy. It can alter the way energy is reflected in certain areas of the electromagnetic spectrum. This is particularly the case in the NIR and MIR. These spectral changes can be used as input in statistical models that can accurately predict the soil salinity [19]. Salinity mapping at broad scale and monitoring of land degradation and seasonal or yearly changes can be done in high temporal and spatial resolution without field-based sampling over large extent [19]. The possibility to map salinity distributions at basin scales and trace land degradation over the time is particularly valuable, as it can provide the researchers’ community with the tools to monitor seasonal or annual changes at fine spatial resolution across large coverage areas. This can substantially reduce the extent and cost of detailed field surveys.

These are its primary uses:

1) ***Satellite***: Satellite platforms such as Landsat and Sentinel provided valuable datasets, and are representative example of such platforms. These datasets are widely used for observation of soil surface. satellite image data have been frequently applied for environmental studies due to their continuous observations, broad area coverage with a long period’s spectral libraries. “Wang et al. [2020]” demonstrated that satellite imaginary contains rich information about different landscape, making it effective for estimating soil salinity [28].
2) ***Spectral Indices***: many indices have been developed. These indices are derived from satellite spectra measurements. The objective here is to improve salinity detection and monitoring. Some examples include

2.1 Normalized Difference Salinity Index (NDSI): Saline zones are detected by exploiting the reflectance characteristics of soil in specific spectral bands.

2.2 Salinity Indices (SIs): Several indices (SI1–SI7) have been introduced to improve the accuracy of estimating different salinity levels under varying soil and environmental conditions [19].

2.3 Normalized Difference Vegetation Index (NDVI): Commonly used to distinguish between cultivated and uncultivated land. Salinity negatively affects vegetation health. NDVI can serve as an indirect indicator of soil salinity stress. This was confirmed in a 2022 study by "Al-Asadi" [19].

3) ***Field verification (ground truth data)***: Collects field data on soil salinity (measuring the electrical conductivity (EC) of the soil) to be used in calibrating and correcting remote sensing data and verifying the accuracy of the maps produced.

V. PREVIOUS STUDIES RELATED TO REMOTE SENSING AND GIS. THEIR APPLICATION TO SOIL SALINITY.

In the past 30 years there have been significant advancements in the techniques for the monitoring and controlling of salt-affected soils using remote sensing, geographic information systems, and spatial analysis. The first stage was initiated with the application of satellite extracted spectral indices. For instance, Jabbar & Zhou (2012) employed satellite images of Landsat TM (1990) and ETM (2003) to create indices such as Normalized Difference Salinity Index (NDSI) and Salinity Index (SI) in order to evaluate the variations in vegetation cover and soil salinization distribution [20]. The present study demonstrated the efficiency of spectral indices in monitoring saline expansion, although they noted that, salinity signals could be confounded with backscattering from bare soils.
Later, with the advancement of geographic information system (GIS), researcher began integrating digital classification and GIS technologies to improve the accuracy of spatial discrimination. Al-Mudhafar (2016) applied digital classification techniques using GIS and ERDAS software to map highly saline areas in Abu Al-Khasib and Al-Zubair districts. This approach revealed correlations between soil salinity, land use, and physical properties. This helped to gain more insight in the spatial dynamics of salinity, with human influence and groundwater as natural drivers of salinization [6].
At the early stage of the second decade of the millennium, research integrating data of satellite image with data from the field began to appear. "Jabbar et al. [2018]' also used Landsat and field measurements to assess soil salinity dynamics between 2000 and 2015 in southwestern Basrah as shown in Fig. 2. Their finding showed that, low-salinity land decrease from 47.8% to 35.9%, while highly saline land increased from 13.3% to 19.4%. respectively, with a high positive correlation between groundwater salinity and soil salinization. This integration increased the accuracy and reliability of the remote sensing outcomes and proved their effective role in the planning of land management. Fig. 3 showed salinity index SI for this period of study [7].
More recent studies have focused on building comprehensive spatial model that integrate satellite imagery, GIS, and geostatistical tools and highlighted the importance of time series analysis for monitoring soil salinity dynamics. Bandak et al. (2024) demonstrate that, multi- temporal landsat-8 and sentineal-2 imaginary combined with machine learning algorithms can effectively capture temporal variations in soil salinity providing valuable insights into the long-term evolution of salinization in semi -arid regions [31]. Awadh& Al-Dabbas (2024) developed an integrated model for detecting soil salinization in southern Iraq, including Basrah using Landsat images and spatial analysis functions in the GIS. This methodology allowed to identify some of the main driving forces such as bad draining systems, high evaporation rate and saline water for irrigation as key drivers of salinization, emphasizing the urgency of sustainable management strategies [21].

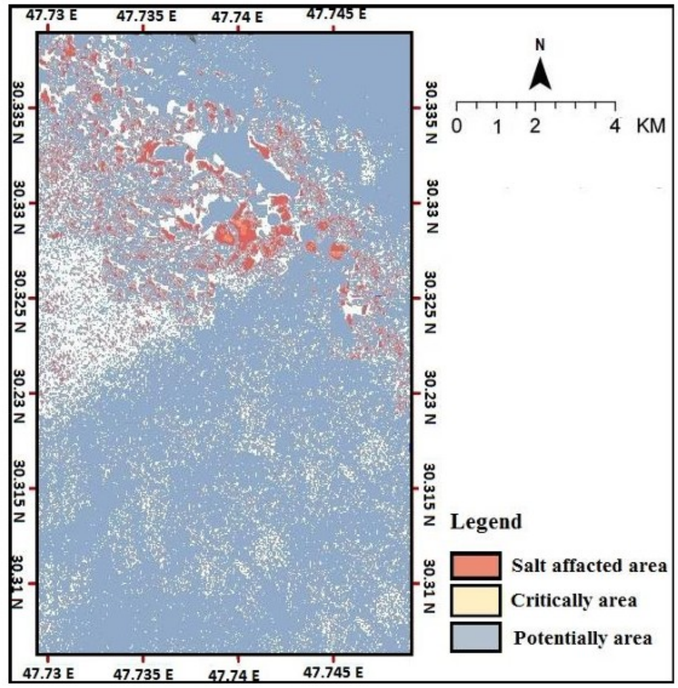

Fig.2 Geostatistical distribution of salt affected area in the Basrah province [7]

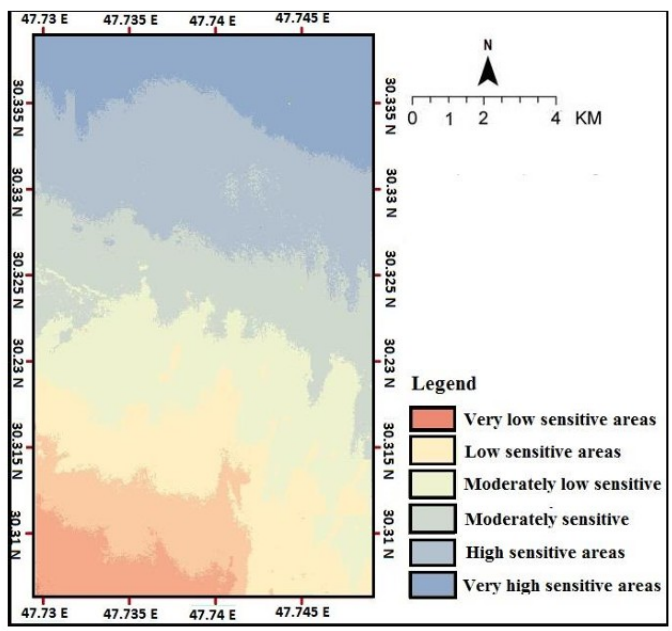

Fig.3. Salinity index (SI) for the periods 2000 and 2015 [7]

A. Case study in Basrah Province

The soil salinity is a large issue to Basrah Governorate, south of Iraq; which is a major environmental and agricultural problem as well. This challenge has a direct effect on the fertility of arable land and decrease in productivity. The latter have been the subject of studies using field survey data in combination with spatial analysis and geographic information systems (GIS) and assisted by remote sensing.
Al-Timimi and Al-Bassam (2015) employed a combination of field measurements and spatial analysis using GIS and RS derived through measurements of electrical conductivity (EC) in 120 points located on the north of Basrah. The scientists generated exact salinity distribution maps, applying Kriging geostatistical interpolation. Findings also, that the areas around the Shatt al-Arab are subject to increased salinization, owing to the application of brackish waters for irrigation, combined with a tidal effect from the Arabian Gulf [22].
Distribution maps of salinity between Shatt al-Arab and Qurna regions was described in detail by Hassan & Al-Khateeb (2018) based on images of Landsat 8. They exploited the normalized difference vegetation index (NDVI) and the salinity index (SI) and their results were correlated with ground electrical conductivity (EC) measurements. Their research proved the utility of spectral indices in combination with ground measurements to generate reliable salinity distribution maps [17]. Abdullah and Hussein (2019), found that the main driver of salinity dilatation in Basrah not circulation (upward or outward) of saline bedrock water. They also tagged indiscriminate irrigation and high ground water table as contributory reasons, which have led to the degradation of vast tracts of agricultural land [23]. Al-Khafaji and Salman (2020) analyzed 90 soil samples in the center of the governorate and recorded their GPS with an available spatial database in ArcGIS. The authors studied the salinity patterns in relation to groundwater depth and found the depth-dependent trend of the salinity by stratigraphic correlation, indicating the geological hydrological correlation affecting the development and extension of the salinity [24]. Saleh et al. (2020) analyzed salt-affected soils in Basrah using field sample, laboratory tests and remote sensing indices (SI, NDSI, NDVI) integrated with GIS. Results showed higher salinity in the eastern and southern part of Basrah with lower levels near river and cultivated area. the study confirm strong correlation between spectral indices and laboratory data, highlights the effectiveness of combining remote sensing and GIS for monitoring soil salinity and supporting land management [25].
Mohammed et al. (2023) also studied salinization in Basrah by soil samples and satellite images. they discovered the majority of soils are moderately to very salty (more so in the east and upper layers and less so around rivers, in the west and around crops as shown in Fig. 4, [26]. Supporting these finding, the FAO (2017) emphasized the role of tidal flooding and saline irrigation in shaping long-term salinity pattern in coastal Basrah [27]. Table (1) summarizes major studies conducted on soil salinity in Basrah province and southern Iraq, highlighted data sources, methods and key findings.

TABLE (1) SUMMARY OF PREVIOUS STUDIES ON SOIL SALINITY IN BASRAH PROVINCE AND SOUTHERN IRAQ

Author(S), Year	Study area	Data used	Methods/indices	Main findings
Jabbar & Zhou (2012)	Basrah (1990-2003)	Landsat TM, ETM	NDSI, SI	Efficient for monitoring salinity expansion; signals mixed with bare soils
Altimimi & Al-Bassam (2015)	North Basrah (120 sites)	Field EC& GIS	Kriging interpolation	High salinity near Shatt al-Arab due to brackish irrigation + tidal effects
Al-Mudhafar (2016)	Abu al-Khasib & al-Zubair	GIS +ERDAS, land use	digital classification	Showed correlation between salinity, land use and groundwater
FAO (2017)	Costal Basrah	Reports + surveys	RS + tidal analysis	Tidal flooding and saline irrigations are key long-term drivers
Jabbar et al. (2018)	SW Basrah (2000-2015)	Landsat + field EC	SI, salinity mapping	Low salinity land decreased (47.8%-35.9%), high salinity increased (13.3%-19.4%), groundwater influence
Hassan & Al-Khateeb (2018)	Shatt al-Arab-Qurna	Lansat8 + field EC	NDVI, SI	Spectral indices + EC effective for mapping salinity
Abdullah & Hussein (2019)	Basrah	Field+ GIS	hydrological assessment	Salinity expansion linked to irrigation
Al-Khafaji& Salman (2020)	Center of Basrah (90 samples)	Field EC+ GIS	Stratigraphic correlation	depth-dependent salinity trends related to geology
Mohammed et al. (2023)	Basrah	Soil samples + RS	Salinity mapping	Soil moderately to very salty; higher in east and surface layer
Awadh & al-Dabbas (2024)	Southern Iraq, Basrah	Landsat + GIS	Integrated spatial model	Driver: poor drainage, evaporation, saline irrigation

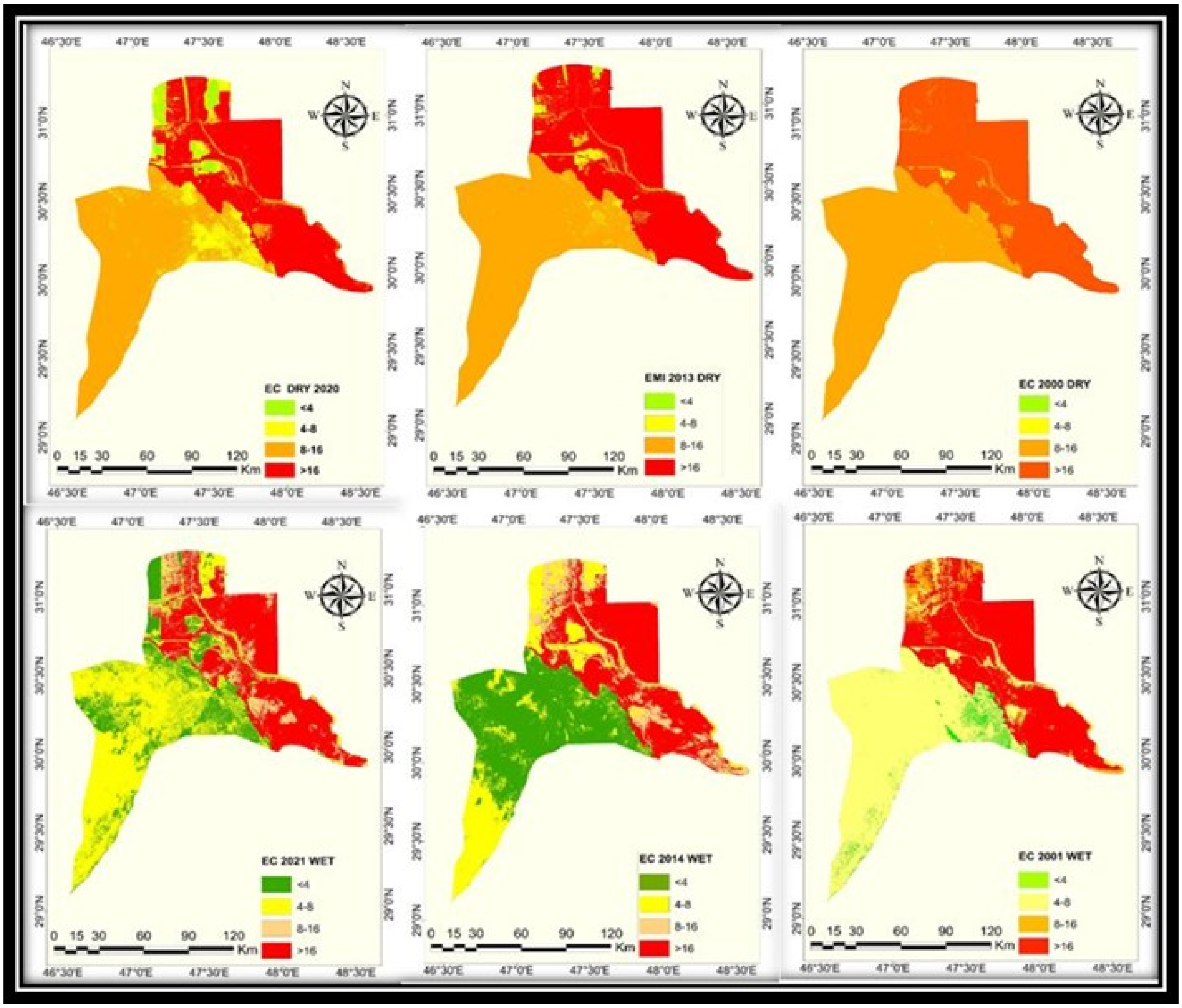

Fig. 4. The spatial distribution of electrical conductivity classes of the surface soil layer in the study area during the period from 2000 to 2021[26]

b. Criteria of selecting previous studies

the previous studies were selected according to several main criteria, the most important of these, is their direct relevance to the research topic (soil salinity in Basrah province) and their spatial coverage of agricultural area affected by salinity. In addition to their temporal coverage that reflects the changes over the past three decades. The selection also considered the scientific rigor of the methodologies employed in these studies such as the use of spectral indices, geostatic, and the integration of satellite imaginary with field data, as well as the recency of the sources published. In recent years that relied on advance techniques such as timeseries analysis and machine learning algorithms. Finally, emphasis was placed on methodological diversity in order to provide a comprehensive picture of salinity dynamics and it driving factors.

VI. CONCLUSION

Literature reviews have shown that GIS is a useful tool in analyzing soil salinity in affected areas such as Basrah province These techniques provide a spatial and temporal understanding of salinity distribution enabling the design of reclamation plans based on accurate data. Despite the numerous studies addressing soil salinity in Basrah province using (GIS) and (RS) techniques (e.g. Jabbar and Zhou, (2012); Jabbar et al., (2018); Al-Timimi and Al-Bassam (2015) and Wadh & Al-Dabbas, (2024)", several critical research gaps that remain and require further study and analysis:

a. **Outdated data sets**: Most of these studies suffer from poor temporal updating, as they are limited to satellite data from years prior to 2015, meaning there is no up-to-date picture of changes in soil salinity in recent years, despite the availability of high-resolution data from satellites such as Sentinel-2 a Planet Scope.

b. **Narrow focus on electrical conductivity**: the majority of research focuses on analyzing electrical conductivity (EC) as a single factor. This factor represents salinity. However, research does not comprehensively link EC to the chemical and physical (such as depth of groundwater, quality of irrigation water, evaporation rates) has not been systematically incorporated in most studies.
c. **lack of predictive modeling**: No clear attempts have been made to build spatial and temporal predictive models for future changes in salinity, such as using artificial intelligence techniques or geographic modeling. The relationship between soil salinity and hydrological and climatic factors
d. **limited recent field validation**: Most of the studies use field data from before 2020, indicating a clear lack of updated field verification, or ground truthing. This is a critical element to ensure the accuracy of spatial analysis when preparing salinity maps.

Soil salinity in Basrah Governorate is a complex, worsening environmental and agricultural issue resulting from a combination of natural and human factors. Studies show that salinity is distributed spatially in a way that varies significantly. Its intensity increases southward and it is concentrated in low-lying areas and the sedimentary plain. Rising water tables, dry climatic conditions, the use of saline irrigation water, and poor drainage all contribute to this issue Therefore, the study suggests the following:

1. improve water management by developing effective irrigation and drainage systems to ensure that salts are washed away and prevent their accumulation in the soil, with an emphasis on using better quality water sources for irrigation whenever possible.
2. Using modern irrigation techniques to reduce dependence on saline water.
3. Implementing a national program to periodically monitor soil salinity using remote sensing and GIS (IDW & Kriging) using satellite data to identify areas affected by salinity.
4. Develop a specific spatial database for soil salinity at the governorate level.
5. Artificial intelligence can be used to manage soil salinity.

Conflict of Interest

The authors have no conflict of relevant interest to this article.

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