Technical Report

# Water, Soil and Resilience: A Roadmap for Enhancing Agricultural Outcomes in Egypt’s Saline Environments

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**Front cover photo:** Water drainage canal in a salinity-affected area, Ezbet Abou Eita, Kafr Abou Ziada, Desouq, Kafr El Sheikh, Egypt.(*photo credit:* Dr. Ibrahim Gaafar).

**Back cover photo:** Surface salt accumulation and soil cracking in salinity-affected farmland, Ezbet Abou Eita, Kafr El Sheikh, Egypt**.** (*photo credit:* Dr. Ibrahim Gaafar).

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# Acronyms and Abbreviations

| | |
|---|---|
| Acs | Agricultural Cooperatives |
| AES | Agriculture Extension Service |
| AGERI | Agricultural Genetic Engineering Research Institute |
| AOAD | Arab Organization for Agricultural Development |
| ARC | Agricultural Research Institute |
| BCM | Billion Cubic Meter |
| CGIAR | Consultative Group for International Agricultural Research |
| CIHAM-Bari | Mediterranean Agronomic Research Institute of Bari |
| DCAs | Drainage Collectors Associations DCAs |
| DEAM | Department of Extension and Agricultural Management |
| dS/m | Decisiemens per meter |
| DEM | Digital Elevation Model |
| DRC | Desert Research Center |
| DRI | Drainage Research Institute |
| EALIP | Executive Authority for Land Improvements Projects |
| EC | Electrical Conductivity |
| ECe | Electrical Conductivity of saturated soil extract |
| EDP | Egyptian Pound |
| EPADP | Egyptian Public Authority for Drainage Projects |
| ESP | Exchangeable Sodium Percentage |
| EU | European Union |
| FAO | Food and Agriculture Organization |
| FGDs | Focus Group Discussions |
| GDP | Gross Domestic Product |
| GWS | Ground Water Sector |
| ICARDA | International Center for Agriculture Research in the Dry Areas |
| IDAS | Irrigation and Drainage Advisory Service |
| IFPRI | International Food Policy Research Institute |
| IIS | Irrigation Improvement Sector |
| IS | Irrigation Sector |
| IWMI | International Water Management Institute |
| KFW | Kreditanstalt für Wiederaufbau |
| LST | Land Surface Temperature |
| LR | Leaching Requirement |
| MALR | Ministry of Agriculture and Land Reclamation |
| MWRI | Ministry of Water Resources and Irrigation |
| MODIS | Moderate Resolution Imaging Spectroradiometer |
| NARSS | National Authority for Remote Sensing and Space Science |
| NDSI | Normalized Difference Salinity Index |
| NDVI | Normalized Difference Vegetation Index |
| NWRC | National Water Research Center |
| PPM | Part Per Million |
| PS | Private Sector |
| R&D | Research and Development |
| RIGW | Research Institute for Groundwater |
| RMSE | Root Mean Square Error |
| RS | Remote Sensing |
| SAR | Sodium Absorption Ratio |
| SIWARE | Simulation of Water Management in the Arab Republic of Egypt |
| SSD | Sub-surface drainage |
| SWERI | Soil, Water and Environment Research Institute |
| TDS | Total Dissolved Solids |
| USD | United Stated Dollar |
| WMRI | Water Management Research Institute |
| WUAs | Water Users Associations |

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## Summary

Soil salinity presents one of the most pressing challenges to agricultural productivity and food security in Egypt. Affecting approximately 30% to 40% of the Nile Delta's arable land, soil salinity undermines the livelihoods of farmers, threatens the national food supply and hampers economic growth. This summary synthesizes the comprehensive analysis presented in the "Maintaining the Productivity of Saline Landscapes in Egypt" report, highlighting key findings, socio-economic impacts, governance frameworks and strategic recommendations aimed at mitigating salinity-related challenges and enhancing agricultural sustainability.

Soil salinity affects nearly 10% of the world's arable land, with about 20% of irrigated lands globally experiencing varying degrees of salinity (FAO, 2021; Shrivastava and Kumar, 2015). In Egypt, the severity of soil salinity is acute, particularly within the Nile Delta, where estimates suggest that 30% to 40% of soils are impacted (SALAD, 2022). This issue not only threatens agricultural yields but also poses significant socio-economic repercussions for farmers and the broader national economy. Despite a long history of combating soil salinity, recent increases in salinity levels have intensified concerns among government authorities, farmers and the research community. The primary objective of this report is to provide a comprehensive analysis of the current state of saline landscapes in Egypt, identify best practices for managing salinity and propose strategic interventions to enhance agricultural productivity and sustainability. By updating existing knowledge and integrating adaptive measures into national development strategies, Egypt can effectively mitigate the adverse impacts of soil salinity.

Effective management of saline landscapes hinges on accurate mapping and understanding of water and soil salinity distributions. The salinity of Nile water exhibits significant spatial variation, with levels around 150 ppm in Aswan, approximately 200 ppm at the Delta Barrage and up to 350 ppm near the Delta's end. Agricultural drainage water salinity is managed through stringent government policies that ensure official reuse remains below 1200 ppm (1.0 - 2.0 dS/m). Over the past four decades, officially reused drainage water has steadily increased to meet rising water demands. However, unofficial reuse, estimated between 3-5 billion cubic meters (BCM) annually, averages 3200 ppm (5 dS/m), with salinity levels increasing northward in the Nile Delta, thereby exacerbating soil salinity issues. Groundwater salinity across the Nile Delta ranges from 0.35 to 24.0 dS/m (227 to 15,264 ppm), with salinity levels increasing with depth. In some northern Delta areas, salinity reaches as high as 70 dS/m (45,000 ppm) due to seawater intrusion. Groundwater used for irrigation typically has salinity levels between 0.93 dS/m and 3.7 dS/m (596 to 2,351 ppm), though variations exist based on specific locations and depths. Figures illustrating the evolution of official drainage water reuse, drainage water flowing to the sea and groundwater salinity at various depths provide visual insights into the salinity dynamics over time.

The 2024 national salinity assessment offers a detailed map of soil salinity across Egypt, covering cultivated regions within and beyond the Nile Valley and Delta, as well as the Eastern and Western Deserts, the Sinai Peninsula and the Fayoum Depression. Non-saline soils (<2 dS/m) cover 32% of the total area, predominantly in the Nile Valley and South Delta. Slightly saline soils (2-4 dS/m) occupy 22%, primarily in the Nile Valley and southern Middle Delta. Moderately saline soils (4-8 dS/m) constitute 18%, located in the northern Middle Delta and reclaimed fringes of old lands. Strongly saline soils (8-16 dS/m) represent 25%, mainly in the North Delta, the Fayoum Governorate, Siwa and newly reclaimed areas. Extremely saline soils (>16 dS/m) account for 3%, found in the far North Delta, the Fayoum Governorate, Siwa and North Sinai. The national remote sensing soil salinity map and temporal changes in salt-affected areas across the South, Middle and North Delta indicate that while some regions are experiencing increased salinity due to inadequate reclamation efforts, others show improvement thanks to local initiatives and effective management practices.

A thorough water salinity analysis involved collecting 180 water samples from four governorates—Qalyoubia, Ismailia, Fayoum and Kafr El-Sheikh—during the 2022-2024 summer and winter seasons. The analysis aimed to evaluate salinity levels across different water sources used for irrigation. In Qalyoubia, canal water is predominantly non-saline (<0.7 dS/m) and shallow groundwater wells range from non-saline to slightly saline (0.7-2.0 dS/m). Ismailia's canal water remains non-saline in both seasons, with mostly non-saline groundwater wells in winter, except for slight salinity in northern areas and Qantra. Fayoum's canals maintain non-saline water (0.23 to 0.73 dS/m), while drainage water salinity increases from 2.0 dS/m at drain starts to 6.82 dS/m near Lake Qaroun due to drainage from salt-affected soils. In Kafr El-Sheikh, canal water is mostly fresh, with some canals receiving saline drainage, exhibiting slight salinity in summer (1.61 dS/m and 0.98 dS/m) and moderate salinity in winter (1.81 dS/m and 1.32 dS/m).

The soil salinity analysis encompassed 564 soil samples collected from 51 locations across the four governorates over four seasons: summer, post-summer, post-Nili and winter. The samples were analyzed at three soil depths: 0-30 cm, 30-60 cm and 60-90 cm. In Qalyoubia, soils are predominantly non-saline (0-2 dS/m) across most locations and depths. Ismailia exhibits soil salinity ranging from non-saline (0-2 dS/m) to slightly saline (2-4 dS/m), with notable salinity near Qantra Drain at the surface layer (4-8 dS/m). Fayoum's soils are mostly moderately saline (4-8 dS/m), with highly saline soils (>8 dS/m) near Lake Qaroun due to salt accumulation. Kafr El-Sheikh shows a mix, with approximately 50% of samples being non-saline or slightly saline, while significant saline soil presence (4-8 dS/m) is observed in regions like Zawia, Sidi Salem, Hamool and Biala.

Soil salinity not only impacts agricultural yields but also has profound socio-economic implications for farmers and rural communities. Crop selection is significantly influenced by soil salinity, with farmers favoring salt-tolerant crops to ensure optimal yields and economic viability. During the 2022-2023 season, wheat remained the dominant crop in saline areas, particularly in Fayoum (63.9%) and Qalyubia (26%), while perennial clover and sugar beet also demonstrated adaptability to saline conditions. In the summer season, rice and cotton were prevalent in non-saline areas, whereas maize and summer vegetables dominated moderately saline regions. Perennial orchards showed high percentages in Fayoum and Ismailia, indicating their suitability to saline soils. This strategic crop selection underscores farmers' efforts to balance economic returns with environmental constraints, thereby mitigating the adverse effects of soil salinity.

The economic viability of crop production in saline soils is a critical determinant for farmers. Comparative analysis reveals that production costs in saline soils are consistently higher than in non-saline soils across all governorates, primarily due to additional inputs such as increased irrigation for leaching salts and soil amendments. For instance, wheat in Qalyubia shows a net return ratio of 102.3% in non-saline soils, while in Fayoum, the same crop reaches an impressive 212.9%. Similarly, summer crops follow this pattern, with higher production costs in saline environments leading to better economic returns in non-saline areas. Visual representations of relative production costs and net returns highlight the economic strain imposed by salinity on farmers, emphasizing the necessity for effective salinity management practices to alleviate financial burdens and sustain agricultural productivity.

Farmers operating in saline landscapes face a multitude of challenges that impede their agricultural productivity and economic stability. Survey data from four governorates reveal that soil quality deterioration is a primary concern, with 78% of farmers in Kafr El-Sheikh, 70% in Fayoum, 56% in Ismailia and 36% in Qalyubia, reporting significant soil quality issues. Shallow groundwater levels further exacerbate these challenges, affecting 72% of farmers in Kafr El-Sheikh, 66% in Fayoum, 40% in Ismailia and 30% in Qalyubia. Irrigation water scarcity is another critical issue, with the highest dissatisfaction reported in Kafr El-Sheikh (84%) and significant concerns in Fayoum (64%), Ismailia (40%) and Qalyubia (26%). Poor drainage is identified as a major problem by 61.5% of farmers overall, with Kafr El-Sheikh leading at 76%, followed by Fayoum (60%), Qalyubia (56%) and Ismailia (54%). Additionally, limited access to modern technology and the high cost of technological methods present substantial barriers, particularly in Kafr El-Sheikh and Fayoum, where 58% and 60% of farmers, respectively, report on these issues. Furthermore, approximately 71.5% of farmers face difficulties in conducting water and soil analyses, underscoring the need for accessible testing services. Although fertilizer use poses the least concern at around 14%, the cumulative impact of these challenges necessitates integrated solutions addressing both environmental and economic barriers to enhance agricultural productivity and ensure the sustainability of farming communities in saline landscapes.

In response to the adverse effects of soil salinity, farmers have developed and adopted various strategies to manage and mitigate salinity, aiming to sustain agricultural productivity. These practices are categorized into three main groups: crop choices, agricultural practices and agricultural procedures. Farmers prioritize reclamation of crops like rice, salt-tolerant crops such as wheat, sugar beets and perennial orchards, and dry crops that require less water to reduce salt accumulation. Agricultural practices include deep plowing and tillage to enhance soil aeration and promote salt leaching, regular maintenance of irrigation canals and drainage systems to prevent salt buildup, seasonal cleaning of branch drains to ensure efficient water flow, digging farm drain ditches to remove saline water and continuous subsurface drain maintenance to manage soil moisture and salinity effectively. Agricultural procedures encompass regular gypsum application to displace sodium ions and improve soil structure, soil leaching through excess irrigation to flush salts from the soil profile, halting cultivation during high-salinity periods to prevent salt accumulation, using treated drainage water for irrigation, communicating with extension services for guidance on best practices and practicing reciprocal irrigation to balance salinity levels. These mitigation practices demonstrate farmers' resilience and adaptability in managing saline landscapes. However, their effectiveness is contingent upon access to resources, knowledge and support from agricultural institutions. Enhancing farmer education, providing access to affordable technologies and ensuring robust extension services, are critical to maximizing the efficacy of these practices.

Effective governance is pivotal for the sustainable management of saline landscapes. Egypt has instituted several policies aimed at controlling soil salinity and enhancing agricultural productivity. The Subsurface Drainage Policy, initiated in 1970, aims to mitigate rising water tables caused by continuous irrigation through the installation of subsurface drainage networks in old agricultural lands. This policy has achieved nearly 100% coverage of Egypt's irrigated old lands with drainage systems, leading to yield increases of up to 20% for major crops and a shift towards higher-value crops (Ritzema and Abdel-Dayem, 2011; World Bank, 2008). The Land Improvement Policy of 1971, spearheaded by the Ministry of Agriculture and Land Reclamation (MALR), focuses on reclaiming salt-affected soils and enhancing the productivity of saline-sodic soils, particularly in the Northern Delta characterized by heavy clay soils. Strategies under this policy include soil amendments, crop rotation and the introduction of salt-tolerant crop varieties. Additionally, the Sustainable Drainage Water Reuse Policy launched in the late 1970s by the Ministry of Water Resources and Irrigation (MWRI), ensures the sustainable reuse of drainage water for irrigation by monitoring both quantity and quality. Currently, approximately 13 BCM of drainage water is officially reused for irrigation in El-Fayoum, the Nile Valley and the Delta.

Despite these robust policies, challenges persist in policy implementation, particularly in regions with unofficial water reuse practices. Securing adequate financial resources for large-scale drainage and reclamation projects remains a significant hurdle, as does the integration of advanced technologies for monitoring and managing soil and water salinity. Additional initiatives, such as Integrated Water Resources Management (IWRM) and continuous research and development programs, aim to optimize water resource use and innovate salinity management techniques. Effective governance also involves a myriad of actors, both primary and secondary, including governmental bodies like the Egyptian Public Authority for Drainage Projects (EPADP) and the Drainage Research Institute (DRI), research institutions such as the Soil, Water and Environment Research Institutes (SWERI) and the farming community as end-users. Secondary actors include the Irrigation Sector (IS), Department of Extension and Agricultural Management (DEAM), Drainage Collectors Associations (DCAs), and various research and development organizations. Collaborative efforts through Public-Private Partnerships (PPPs), research collaborations and community engagement ensure a coordinated approach to saline landscape management. These collaborative efforts are essential for resource sharing, joint initiatives, and aligning policies and practices with on-the-ground realities, thereby enhancing the overall effectiveness of salinity management strategies.

To ensure sustainable management of saline landscapes and maintain agricultural productivity, a strategic roadmap has been developed. **This roadmap outlines a phased approach, integrating assessment, pilot projects, scaling and continuous improvement, with active involvement from all stakeholders.**

- **Phase 1, spanning Year 1,** focuses on comprehensive assessment and stakeholder engagement. Detailed assessments of water and soil salinity across all affected regions will be conducted using remote sensing and ground-truthing methods to ensure accurate and up-to-date data. Concurrently, continuous dialogue with stakeholders, including farmers, government agencies, research institutions, and international partners, will incorporate diverse perspectives and expertise. Integrating salinity data with national development strategies will inform targeted interventions.
- **Phase 2, covering Years 1 to 3,** involves the implementation of pilot projects and capacity building. Pilot initiatives will test and demonstrate best practices in saline landscape management, such as advanced irrigation techniques, soil amendments and crop rotation strategies. Capacity building efforts will train farmers and local authorities on effective salinity management practices through workshops, training programs, and extension services. Additionally, the promotion of innovative solutions will encourage the adoption of technologies and practices that enhance water use efficiency and soil health.
- **Phase 3, spanning Years 3 to 5,** focuses on scaling up and policy integration. Successful pilot projects will be expanded to larger areas based on their success and adaptability, ensuring broader implementation of effective salinity management strategies. Policy reforms will integrate successful practices and lessons learned into national policies and guidelines to ensure widespread adoption and institutionalization of best practices. Infrastructure development will invest in enhancements to irrigation systems, drainage networks and storage facilities to support large-scale implementation.
- **Phase 4, commencing in Year 5 and beyond,** emphasizes monitoring, evaluation and adaptation. Robust monitoring and evaluation frameworks will be developed to continuously assess soil and water quality, agricultural productivity, and the effectiveness of implemented practices. Feedback mechanisms will create loops to incorporate findings from monitoring activities into ongoing management strategies, ensuring adaptive management in response to emerging challenges and opportunities. Adaptive management will

involve modifying strategies based on monitoring results, emerging research and changing environmental conditions to ensure long-term sustainability.

Key strategies underpinning this roadmap include promoting best practices in saline landscape management through dissemination via extension services and farmer cooperatives, encouraging the adoption of resilient crop varieties and demonstrating the effectiveness of innovative solutions through pilot projects and demonstration farms. Improving water use efficiency through precision irrigation technologies and water-saving practices such as drip irrigation and alternate wetting and drying is also crucial. Cultivating salt-tolerant crops by developing and introducing enhanced varieties through research and breeding programs and providing incentives for farmers to adopt these crops will bolster resilience against salinity. Infrastructure development will focus on enhancing irrigation and drainage systems and investing in storage facilities to manage water resources effectively during dry seasons. Strengthening institutional structures to manage irrigation and drainage systems efficiently and enhancing coordination among government agencies and stakeholders will support effective salinity management.

Enhancing service delivery by improving access to agricultural extension services, technical support and financial resources for farmers is vital. Facilitating access to affordable soil and water testing services will enable informed decision-making. Empowering farming communities by involving them in decision-making processes ensures that management strategies are aligned with their needs and traditional knowledge. Fostering community-led initiatives and peer-to-peer learning will enhance collective action against soil salinity. Lastly, fostering partnerships and collaborations by leveraging expertise, technologies and resources from national and international entities through strategic partnerships will drive innovation and investment in salinity management.

In conclusion, the roadmap for managing saline landscapes in Egypt emphasizes a holistic and phased approach, integrating assessment, pilot testing, scaling and continuous improvement. By fostering collaboration among stakeholders, promoting best practices and investing in infrastructure and capacity building, Egypt can effectively mitigate the impacts of soil salinity and ensure sustainable agricultural productivity. Active involvement of farming communities and strategic partnerships will be pivotal in achieving long-term success and resilience in the face of salinity challenges.

# 1. Introduction

Soil salinity affects 10% of the world's total arable land and poses a significant threat to feeding the rapidly growing population. It is estimated that about 20% of irrigated land globally is affected by salt to varying degrees (FAO, 2021; Shrivastava and Kumar, 2015). Numerous studies have revealed that extensive areas across more than 180 countries experience different levels of soil salinization. The Food and Agriculture Organization (FAO) estimates that there are more than 833 million hectares of salt-affected soils around the globe (FAO, 2021). The annual economic loss globally due to reduced productivity on salinized lands or migration from salt-affected regions is estimated at USD 27.3 million (Mishra et al. 2023). Over two-thirds of salt-affected soils are located in arid and semi-arid climatic zones, including the Middle East, North Africa and Central Asia, making these regions critical global hotspots for salinity issues with serious environmental challenges.

Saline landscapes can develop due to natural and environmental factors, such as the drying of lakes or seas or their proximity to areas where underground saline water rises to the surface (salinization or saltwater upwelling). Salinity can also be caused by inappropriate land-water-crop management practices, including inefficient irrigation, the use of low-quality water, excessive application of chemical fertilizers and inadequate drainage systems. Soil salinization leads to decreased soil fertility, reduced plant growth and lower crop yields. This, in turn, has far-reaching implications for land degradation, food security, rural livelihoods, the national economy and ecosystem health (Shahid et al. 2013; Agrawal et al. 2015; Gorji et al. 2017).

In Egypt, the agriculture sector plays a crucial role in the national economy, contributing approximately 14.5% of GDP and employing 28% of the workforce (Ministry of International Cooperation). Strategic development initiatives have been implemented to boost agricultural production by 30% by 2024, focusing on both horizontal and vertical expansion strategies (Egypt Forward, 2021). However, the sector faces several challenges, including water scarcity, fragmented land ownership, and most critically, rising levels of water and soil salinity.

Egypt has been combatting salinity for a long time, but the increasing salinity levels have raised concerns for the government, farmers and the research community. Reports suggest that approximately 30 to 40% of the Nile Delta soils are affected by varying levels of salinity (SALAD, 2022). To effectively address this issue, Egypt must enhance its understanding of the current salinity risk and integrate adaptive measures into its development strategies. These steps are essential to overcome, cope with or mitigate the inevitable impacts of salinity. This effort should include early-stage monitoring and mapping of soil salinity; to facilitate the scaling up and implementation of effective soil reclamation programs aimed at reducing or preventing future increases in soil salinity (Allbed and Kumar, 2013).

Several studies conducted in Egypt have focused on monitoring and mapping soil salinity and its impact on productivity (Nahry et al. 2015; Mahmoud and Mahmoud, 2020; Hammam and Mohamed, 2018). Salinity maps for the Nile Delta that encompass the majority of Egypt's old agricultural land (5.24 million feddans), were produced by the Ministry of Water Resources and Irrigation (MWRI) in 1989 and by the National Authority for Remote Sensing and Space Sciences (NARSS) in 1998. However, these assessments have primarily focused on the technical aspects of salinity, particularly crop salt tolerance, while often overlooking the adverse socio-economic effects, such as food access and availability (De Vos et al. 2016). A recent unpublished study by the International Food Policy Research Institute (IFPRI) reported significant impacts of salinity on commodity prices, cost of living, food insecurity and internal migration between governorates in Egypt (IFPRI, unpublished paper).

The ongoing project, "*Maintaining the Productivity of Saline Landscapes in Egypt*," is a multidimensional initiative that maps soil salinity and addresses social, environmental and economic aspects at technical, institutional and policy levels. The study identifies best practices for managing saline landscapes in Egypt within specific regions. At the national level, a recently developed remote sensing-based salinity map is being used to pinpoint priority areas for intervention, evaluate current salt-affected areas in comparison to historical records and forecast the future extent of the salinity issue. This map will function as an early warning system to guide planning and decision-making for salinity management and control. The approach combines a bottom-up strategy at the farm/watershed level, with a top-down strategy that engages various stakeholders from different governmental entities.

## 2. Methodology

The methodology for this study combined field data collection, laboratory analysis, remote sensing, socio-economic surveys and stakeholder engagement, to comprehensively assess soil and water salinity and their impacts on agricultural productivity in Egypt. The approach was designed to provide both spatial and temporal insights into salinity patterns and to inform actionable interventions for sustainable saline landscape management.

### 2.1 Study Area

The research focused on four governorates representing major saline-affected regions in the Nile Delta (Figure 1): Qalyoubia, Ismailia, Fayoum, and Kafr El-Sheikh. These areas were selected to capture a representative spectrum of salinity conditions across the Nile Delta, the Nile Valley and reclaimed lands. The study also incorporated data from national assessments covering the Eastern and Western Deserts, the Sinai Peninsula and the Fayoum Depression.


**Figure 1.** Map of Nile Delta governorate

*Source:* El-Agha, 2015

### 2.2 Water Sampling and Analysis

A total of 180 water samples were collected across the four governorates during both summer and winter seasons from 2022 to 2024. Sampling locations included canals, drainage systems and groundwater wells. Salinity levels were measured using standard electrical conductivity methods (dS/m) and spatial variations were mapped using GIS techniques. Analyses focused on identifying trends in canal water, drainage water and groundwater salinity, and their implications for irrigation suitability.

### 2.3 Soil Sampling and Analysis

Soil salinity assessment involved 564 soil samples collected from 51 locations across the four governorates over four seasons: summer, post-summer, post-Nili, and winter. Samples were analyzed at three depths: 0 -30 cm, 30 - 60 cm and 60 - 90 cm. Laboratory analyses measured electrical conductivity (EC) to classify soils into non-saline, slightly saline, moderately saline, strongly saline and extremely saline categories. Spatial distribution maps were generated using GIS and remote sensing data, integrating historical trends and current conditions.

### 2.4 Socio-Economic Survey

A structured socio-economic survey was conducted to capture farmers' perceptions, cropping patterns, production costs, and adaptive strategies in saline landscapes. The survey targeted representative farmers in each governorate and included questions on soil and water challenges, crop selection, agricultural practices and access to services and technologies. Statistical analyses were performed to quantify the impact of salinity on yields, production costs and net returns, and to identify correlations between salinity levels and socio-economic outcomes.

### 2.5 Stakeholder Engagement

To ensure practical relevance and policy alignment, the study engaged key stakeholders, including government agencies, research institutions, CGIAR centers and farmer cooperatives. Workshops and focus group discussions were conducted to validate field and survey findings, gather local knowledge and inform the development of a strategic roadmap for saline landscape management.

### 2.6 Remote Sensing and GIS Analysis

National and regional salinity patterns were mapped using remote sensing datasets combined with ground-truthing measurements. GIS was used to integrate soil and water salinity data, monitor temporal changes and generate detailed spatial representations of salinity distribution. These analyses facilitated the identification of hotspots and priority areas for intervention.

### 2.7 Roadmap Development

The study's findings informed the design of a phased roadmap for managing saline landscapes, integrating assessment, pilot interventions, scaling and continuous monitoring. The roadmap was developed in consultation with stakeholders and incorporated best practices in irrigation management, soil reclamation, crop selection, institutional coordination and capacity building.

### 2.8 Data Analysis

Quantitative data from water and soil analyses, as well as socio-economic surveys, were processed using standard statistical methods to evaluate trends, correlations and economic implications. Qualitative data from stakeholder consultations and focus groups were thematically analyzed to capture perceptions, challenges and local knowledge on salinity management. The combined analysis enabled evidence-based recommendations for policy, institutional interventions and on-farm practices.

## 3. Salinity of Soil, Water and Crop Response

### 3.1 Classification of Saline Soils

Salt-affected soils are classified based on their electrical conductivity (EC), sodium adsorption ratio (SAR) and pH levels, which are essential to determine the extent and type of salinity or sodicity. There are three main types of salt-affected soils, each linked to specific plant characteristics, soil properties and plant growth relationships: saline, saline-sodic and sodic soils (Ayers and Westcot, 1985; Zamora Re et al. 2022; Mishra et al. 2023), as illustrated in Table 1.

**Table 1.** Characteristics of saline, sodic and saline–sodic soils

| Type of salt-affected soil | Electrical conductivity Ece (dSm-1) | Exchangeable Sodium Percentage (ESP) (%) | Sodium Adsorption Ratio (SAR) | Dominant Anion | Presence of cation sodium (Na+) in soil | pH |
|---|---|---|---|---|---|---|
| Saline soils | >4 | <15 | <13 | CL-, SO4-- | Ionic phase in solution | <8.8 |
| Sodic soils | <4 | >15 | >13 | HCO3-, CO3-- | Colloidal phase on clay exchange | 8.5-10.5 |
| Saline-sodic soils | >4 | >15 | Variable | Anions of both kind of soils | Both ionic and colloidal | >8.8 |

*Source:* Author's creation

These three groups of salt-affected soils differ in their physical and chemical properties.

*a- Saline soils*

In saline soils, the predominant exchangeable cations are calcium and magnesium. This soil is typically characterized by irregular plant growth and the presence of white, salty crusts on the surface. Saline soils maintain overall normal physical conditions, characterized by good structure and permeability, as most salts in the soil solution actually enhance soil structure and facilitate water infiltration. Consequently, water penetration is not a major concern in saline soils. However, the presence of salts in the root zone can negatively impact crop yields by restricting the ability of roots to absorb water due to osmotic stress. This stress limits the potential spread of roots and their ability to take up soil solution, causing water to move from areas of lower salt concentration (the plant tissue) to regions with higher salt concentration in the soil. As a result, plants may wilt even when soil moisture is adequate.

*b- Sodic soils*

Sodic soils are characterized by high levels of exchangeable sodium (>15%), elevated pH levels (8.5 to 10.5) and low concentrations of calcium and magnesium. These conditions lead to the dispersion of soil particles, causing them to act independently. This dispersion destroys soil structure and clogs pore spaces, which hinders water movement into and through the soil. Sodic soils often appear black due to the dispersion of organic matter and may have a greasy or oily-looking surface, resulting in little or no vegetative growth. These soils are sometimes referred to as "black alkali" or "slick spots" (Gangwar et al. 2020).

*c- Saline-sodic soils*

Saline-sodic soils, characterized by electrical conductivity (ECe) greater than 4 dS/m and exchangeable sodium percentage (ESP) exceeding 15, typically maintain good soil structure and permit adequate water movement through the soil profile. As long as soluble salts are present in excess, the physical properties of these soils remain favorable. Although high sodium levels can cause clay particles to swell, the presence of calcium and magnesium helps keep soil pores open, ensuring proper soil structure is maintained.

## 3.2 Water Salinity Classification

Table 2 provides guidelines for water salinity classification based on electrical conductivity (EC, in ds/m) and corresponding parts per million (ppm) (FAO, 1999; Ayer and Westcot, 1985). The FAO guidelines classify water quality for irrigation according to salinity restrictions into three classes: Class 1: EC<0.7 dS/m "*No Problem*", Class 2: EC 0.7 - 3.0 dS/m "*Slight to Moderate*" and Class 3: EC > 3.0 dS/m "*Severe Problems*."

**Table 2.** Water salinity classification based on soil salinity

| Water Salinity Classification | EC (dS/m) | ppm | Type of water |
|---|---|---|---|
| Non-saline | < 0.7 | 500 | Drinking water |
| Slightly saline | 0.7 – 2.0 | 500 - 1500 | Irrigation Water |
| Moderately saline | 2..0 – 10.0 | 1500 - 7000 | Primary drainage water and groundwater |
| Highly saline | 10.0 – 25.0 | 7000 - 15000 | Secondary drainage water and groundwater |
| Very highly saline | 25.0 – 45.0 | 15000 - 35000 | Very saline groundwater |
| Brine | > 45.0 | > 35000 | Sea water |

*Source:* FAO, 1999

### 3.3 Crop Tolerance to Salinity

Crops can maintain 100% yield potential when salinity levels are at or below a specific concentration (ECe) known as the "threshold value." Each crop has its own threshold value, based on its tolerance to salinity. When salinity rises above this threshold, crop yields decline linearly at varying rates for different crops (Figure 2). As soil salinity levels increase beyond the threshold, both the growth rate and final size of plants progressively diminish. However, not all plants respond to salinity in the same way; some can achieve acceptable yields at much higher salinity levels than others. The FAO Irrigation and Drainage Paper 29 (Rev.) provides lists of threshold salinity values for various crops (Ayers and Westcot, 1985).

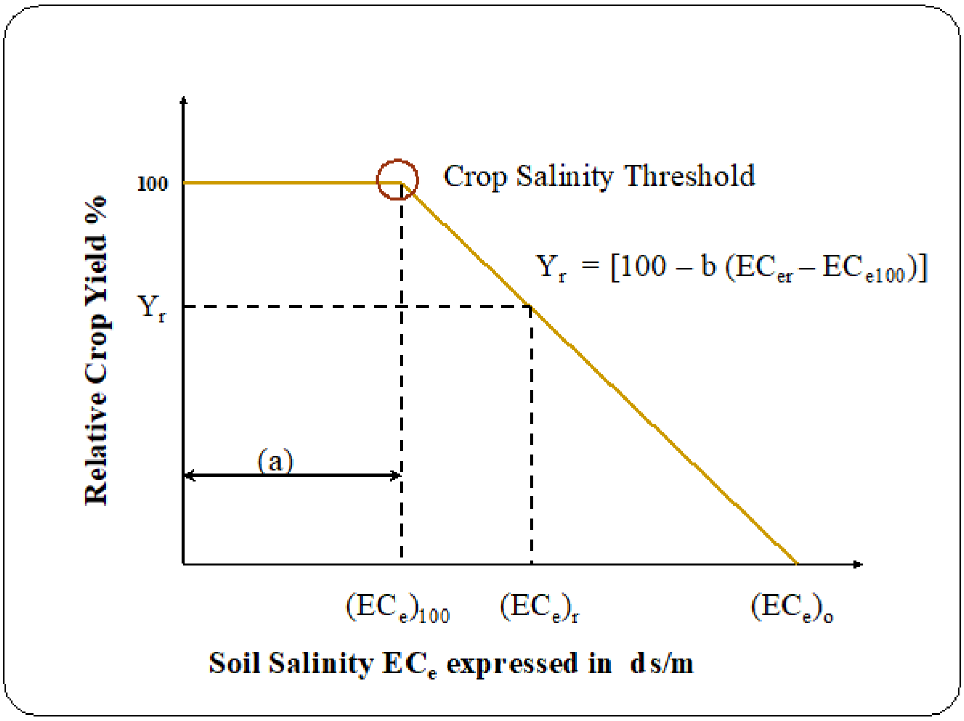


**Figure 2.** Salinity–crop yield relationship

*Source:* Ayers and Westcot, 1985

Table 3 presents a general classification of crops based on their salinity tolerance levels (Brown et al. 1954). Based on this table, the yields of many crops are expected to decline or suffer varying degrees of loss when salinity levels go beyond 4 dS/m.

**Table 3.** Agronomic classification of soil salinity based on EC

| Soil salinity class | EC (in ds/m) | Effect on crop yield |
|---|---|---|
| Non-saline soils | 0-2 | Salinity effects are negligible |
| Slightly saline soils | 2-4 | sensitive crops |
| Moderately saline soils | 4-8 | mildly sensitive crops |
| Strongly saline soils | 8-16 | mildly resistant crops |
| Extremely saline soils | >16 | resistant crops |

*Source:* Brown et al. 1954

In practical field conditions, the salinity levels that restrict crop yield can be influenced by interactions between salinity and various soil, water and climatic factors. For example, soils with poor structure or impermeable layers can restrict root growth and affect water and salt distribution in the soil. Surface crusting acts as a physical barrier for emerging seedlings. Climatic conditions have a significant influence on plant response to salinity. Most crops can tolerate higher salt-related stress in cool, humid weather compared to hot, dry conditions. The combined effects of salinity and high evaporative demand—caused by high temperatures, low humidity, wind or drought—are more stressful than salinity alone. Figure 3 illustrates the soil characteristics in the Nile Delta that could influence these conditions.

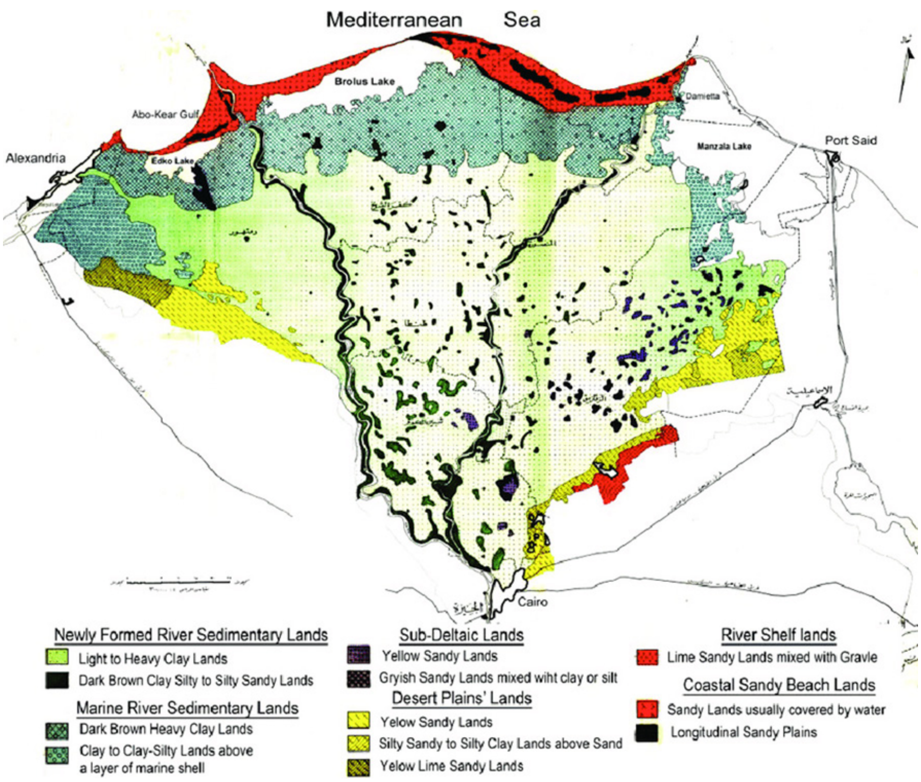


**Figure 3.** Nile Delta surface soil classification
*Source:* Alfiky et al. 2012

Additionally, factors such as water availability, ultraviolet radiation and the use of pesticides and fertilizers can adversely affect crop growth (Suchánková and Bezděkovská, 2012). Climate change also poses a significant threat to crop production and food security by affecting monthly rainfall, irrigation water availability, temperature and other climatic variables which can greatly influence yield.

# 4. Mapping Water and Soil Salinity in Egypt

## 4.1 Mapping Agricultural Water Salinity

Due to its highly arid climate, Egypt's agriculture relies entirely on irrigation. The country receives an annual allocation of 55.5 billion cubic meters (BCM) from the Nile River, accounting for about 98% of its freshwater resources. Additional water sources include seasonal rainfall along the North Coast (1.3 BCM), deep non-renewable groundwater (2.4 BCM) and desalination (0.4 BCM), bringing the total available freshwater to 59.5 BCM per year. However, the total annual water demand is 80.5 BCM, resulting in a significant deficit. To address this shortfall, Egypt relies on reusing drainage water and extracting groundwater from the shallow Nile aquifer, both of which involve the use of Nile water. As water travels from Aswan to the Mediterranean Sea, drainage water is reused multiple times for irrigation. Each of these water sources has different salinity levels:

*Nile Water*

The salinity of the Nile River varies significantly, measuring approximately 150 ppm around Aswan, 200 ppm at the Delta Barrage and around 350 ppm at the tail end of the two Nile branches.

*Agricultural Drainage Water Salinity*

Agricultural drainage water is becoming increasingly vital in bridging the gap between water resource supply and demand. In Upper Egypt, agricultural drainage water is typically discharged into the main stem of the Nile, with the exception of the El-Rahawy drain, which directs its effluent into the upstream reach of the Rosetta Branch. In the Delta region, drainage effluent is discharged into the Northern Lakes or the Mediterranean Sea. The quantity and quality of drainage water from the Delta drains are monitored continuously throughout the year.

The salinity of drainage water used for irrigation varies based on its location and the nature of its reuse, whether official or unofficial (random). Official reuse follows government policies and standards, which require direct reuse or mixing with fresh canal water, to maintain salinity levels below 1200 ppm or at approximately 1.0 - 2.0 dS/m. Over the past 40 years, the volume of officially reused drainage water has gradually increased due to rising water demands, while available resources have remained relatively constant (Figure 4).

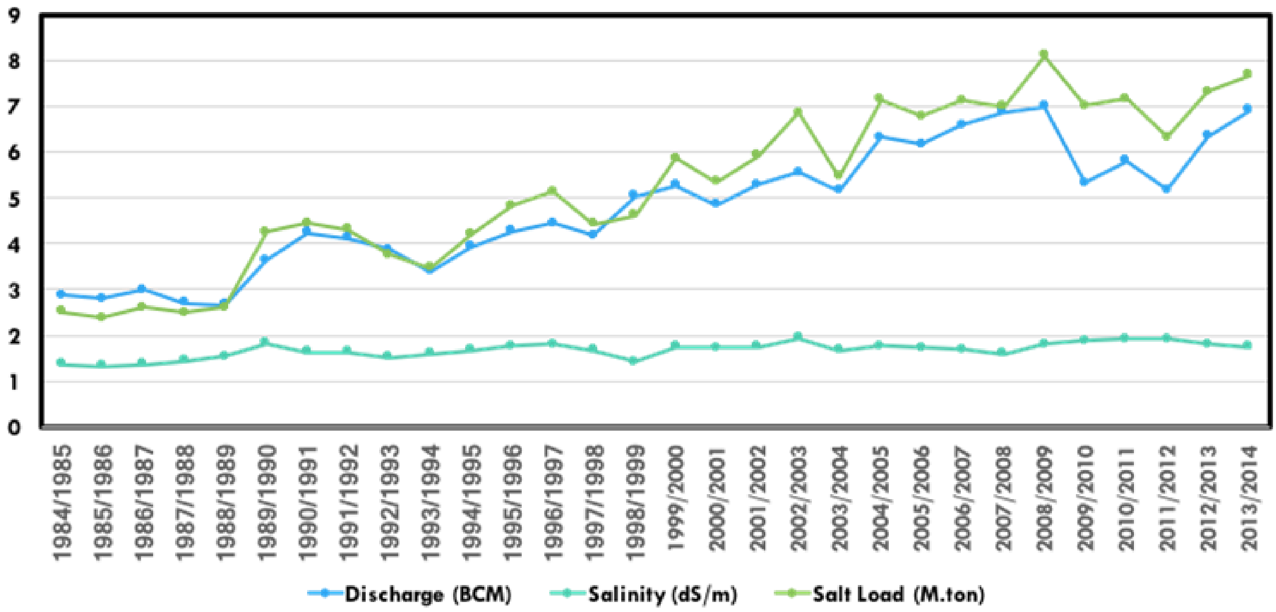


**Figure 4.** Evolution of official drainage water reuse in the Nile Delta from 1984 to 2014
*Source:* DRI Database

Unofficial reuse occurs when farmers pump drainage water, regardless of its salinity, directly from drains onto their fields, especially during shortages of fresh canal water. While the exact annual volume of unofficially reused drainage water is not precisely determined, it is estimated to be between 3 and 5 BCM.

The salinity of drainage water in the Delta increases as it moves northward for several reasons. First, the drainage water is reused multiple times along its route to the outlet. Second, soil salinity in the agricultural lands rises towards the north of the Delta and will be further detailed in the section on soil salinity mapping. Lastly, drainage water in the north is affected by seawater intrusion. Figure 5 illustrates the volume, salinity and salt load of drainage water flowing to the sea from 1984 to 2014. The average salinity of this drainage water is less than 5 dS/m or 3200 ppm.

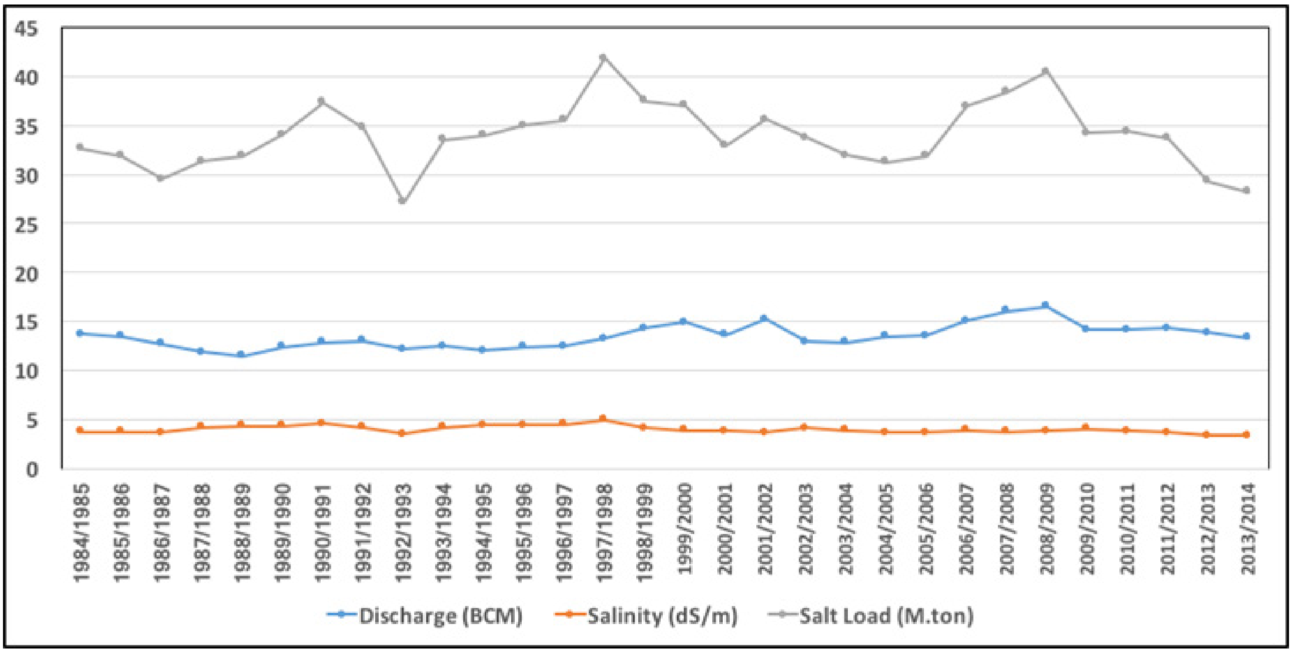


**Figure 5.** Drainage water flowing to the sea from 1984 to 2014
*Source:* DRI Database

In the northern part of the Delta, the salinity of drainage water varies spatially. In the eastern part of the North Delta, salinity can reach up to 3.9 dS/m (2,500 ppm). This increases to between 5.5 and 8.6 dS/m (3,500 to 5,500 ppm) in the central and western parts of the North Delta (Abd Elgawad et al. 2013). In the middle and southern sections of the Delta, the salinity of drainage water increases from south to north due to repeated reuse, reaching levels between 1,500 and 2,000 ppm (DRI, 1989).

Although this project's discussion focuses on salt concentration, it is important to recognize that agricultural drainage water contains other pollutants. Agricultural drains frequently receive domestic and industrial wastewater, and those with high levels of pollution have been excluded from the official reuse program.

The government is working on several national initiatives, including the "Hayat Karima", to enhance the collection and treatment of sanitary and industrial wastewater. Two large treatment plants have been completed in the East Delta (Al-Mahsama and Bahr El-Baqar) for the tertiary treatment of polluted drainage water before redirecting it for irrigation in new lands in Sinai. Another large treatment plant (El-Hammam) is currently under construction to support irrigation for new lands west of the Delta. When completed, these three plants will provide approximately 5 BCM per year of additional irrigation water that was previously wasted and flowed into the sea.

*Groundwater Salinity:*

The shallow groundwater aquifer in the Nile Delta is hydraulically connected to surface water from the Nile River's branches, irrigation canals and the drainage network. This connection allows the aquifer to be continuously replenished by percolating water, which leaches soluble salts from the topsoil.

Groundwater salinity in the Nile Delta varies from 0.35 to 24.0 dS/m (227 to 15,264 ppm) as one moves from the south to the north (Atta, 1979). Additionally, salinity levels increase with groundwater depth (Figure 6). In the northern part of the Delta, groundwater is highly saline due to seawater intrusion, with salinity levels reaching up to 70 dS/m (45,000 ppm) (Farid, 1985; Farid and Tuinhof, 1991).

Farmers in the Delta drill and maintain private or community wells for irrigation purposes. These wells are usually between 50 and 90 meters deep, with the water table located 4 to 15 meters below the surface (El-Agha et al. 2015). The salinity of the groundwater used for irrigation varies significantly, ranging from 0.93 dS/m to 3.7 dS/m (596 to 2,351 ppm).

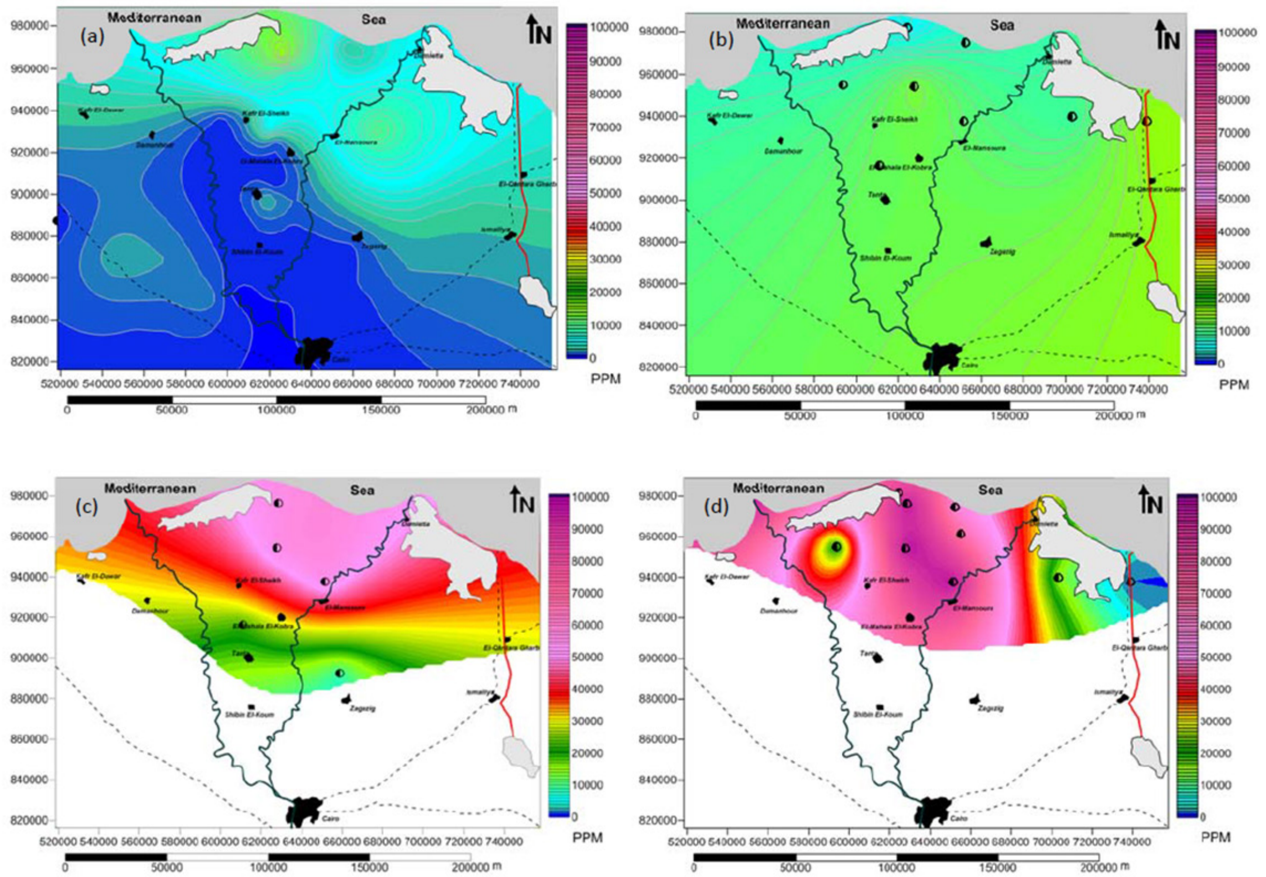


**Figure 6.** Groundwater salinity at depths: (a) <100m, (b) 200m, (c) 400m and (d) 600m below ground surface
*Source:* Research Institute for Groundwater (RIGW)

## 4.2 Historical Soil Salinity Mapping in Egypt

Given the detrimental effects of soil salinity on agricultural productivity, mapping soil salinity levels is essential for addressing this environmental challenge and improving agricultural output and food security in Egypt (Fadl et al. 2023). The history of soil salinity mapping in Egypt dates back to the early 1960s during the construction of the Aswan High Dam, which included a semi-detailed soil survey of the Nile Delta. This focus on Nile Delta's soils arose from the shift to year-round irrigation and concerns about rising water tables, which could result in salt accumulation in the topsoil.

Two important soil salinity maps for the Nile Delta region were developed at different times. The first map, shown in Figure 7, was published by the DRI in 1989. The second map, displayed in Figure 8, was created by NARSS in 1998, a decade later. Furthermore, specific area salinity maps have been generated through various research projects using remote sensing techniques (Mohamed et al. 2011; Ali and Mahmoud, 2020; Hammam and Mohamed, 2018).

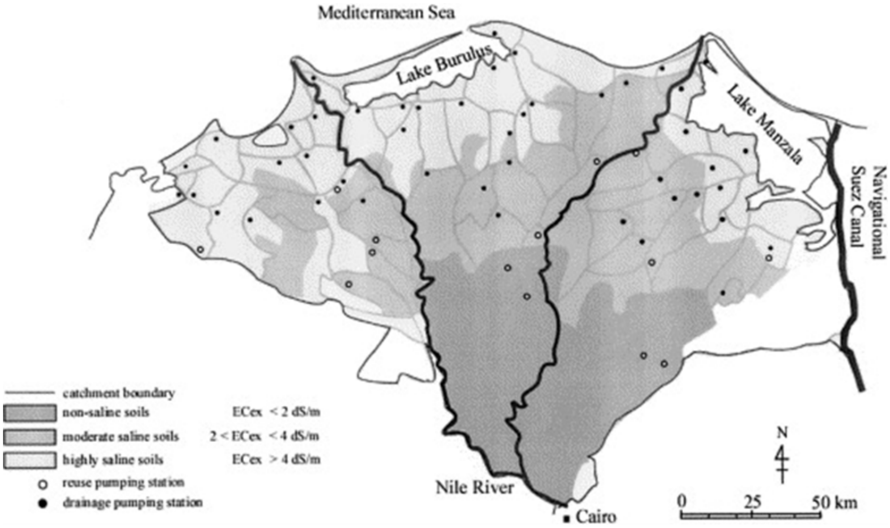


**Figure 7.** Soil salinity map of the Nile Delta
*Source:* MWRI-DRI, 1989

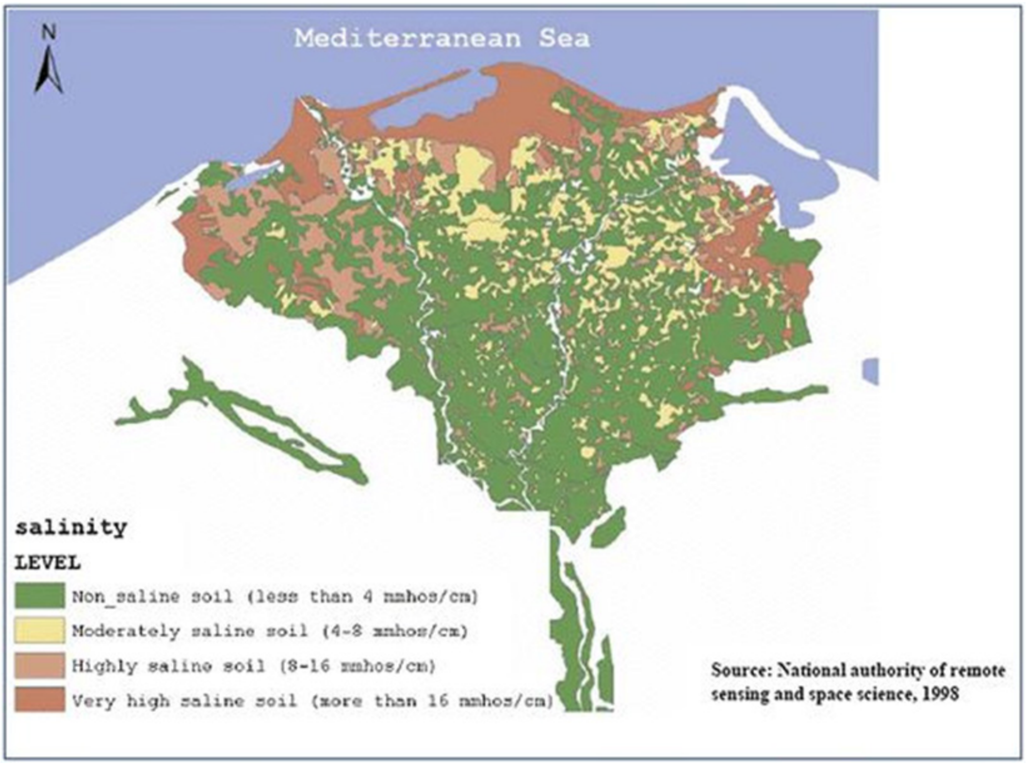


**Figure 8.** Soil salinity map of the Nile Delta
*Source:* NARSS, 1998

The two maps in Figures 7 and 8 show an identical distribution pattern of salt-affected soils in Egypt's Nile Delta, indicating an increase in soil salinity from south to north. These maps delineate three distinct salinity zones: the northern zone, characterized by very high to moderate soil salinity; the central zone, exhibiting moderately saline soil; and the southern zone of the Delta, which predominantly features non-saline soil.

## 4.3 Recent Mapping of the National Saline Landscapes

Component 1 of this project conducted a comprehensive assessment of soil salinity across approximately 4.03 million hectares of agricultural land in Egypt, utilizing satellite data collected from January 2022 to May 2023. The study employed satellite platforms like Moderate Resolution Imaging Spectroradiometer (MODIS) and

Landsat, which offer differing spatial resolutions for various assessment scales. Landsat 8 and 9data delivered detailed soil salinity mapping at the governorate level, allowing for land cover classification, agricultural analysis and environmental monitoring (Mohamed et al. 2011; Singh, 2023; Zeineddine et al. 2023). Meanwhile, MODIS data was used for a more extensive national-level assessment, providing higher-resolution information.

To ground-truth the remote sensing estimates, 584 soil samples were collected from field surveys. To evaluate the accuracy of these remote sensing measurements, statistical analyses, including the calculation of root mean square error (RMSE), were performed.

To develop the national-level salinity map (Figure 9), a methodology incorporating several key indices was employed. The Normalized Difference Vegetation Index (NDVI) was used to evaluate land cover and assess vegetation health, while the Land Surface Temperature (LST) helped analyze thermal characteristics. The Normalized Difference Salinity Index (NDSI) was specifically designed to determine salinity levels. Additionally, a Digital Elevation Model (DEM) was utilized to identify areas where surface slope contributes to water retention, which in turn influences salinity levels.

The regional salinity classes shown in Figure 8 should not be viewed as uniform salinity values across the entire area. Instead, smaller localized zones with varying soil salinity levels frequently overlap within these marked classes. Factors contributing to salinity differences within the same region include geographical location, soil geomorphology, surface and groundwater quality, climatic conditions, irrigation and drainage practices, and land improvement efforts. Additionally, the individual practices of farmers to manage soil salinity play a crucial role and these factors can change over time.

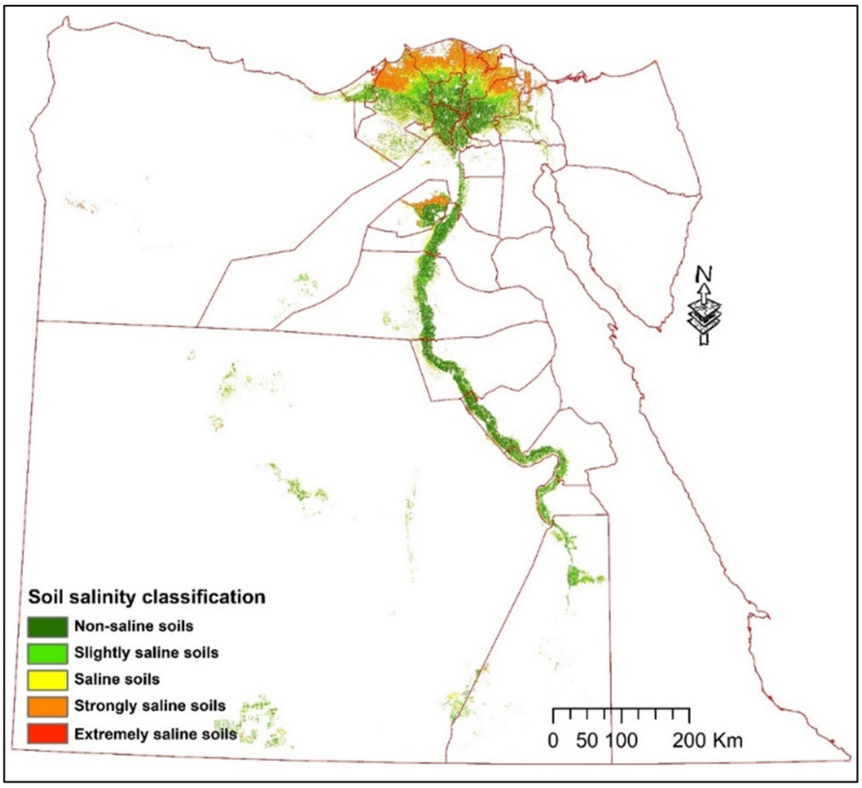


**Figure 9.** The developed national remote sensing soil salinity map of Egypt
*Source:* Author’s creation

The 2023 national assessment salinity map (Figure 8) covers all cultivated areas within and outside the Nile Valley and Delta, including the Eastern and Western Deserts, the Sinai Peninsula and the Fayoum Depression. Each geographic region has unique soil physical characteristics, climatic conditions and prevailing levels of soil salinity. Soil salinity typically develops over time under various natural and management conditions and is often site-specific. Below is a brief description of these regions' soil and salinity conditions.

*The Nile Delta*

The 2023 map depicts soil salinity, which is consistent with the distribution observed in the 1989 and 1998 salinity maps. It is divided into three distinct salinity level zones, ranging from the North to the South (Figure 10).

- **In the North Delta**, higher salinity levels prevail due to the influence of shallow saline groundwater, the proximity to the Mediterranean Sea and low land elevations. The soils in this region are predominantly dark brown heavy clay, classified as saline-sodic soils. The northernmost areas, particularly around the coastal regions and northern lakes, consist of marine river sediment deposits that contain natural salt deposits (primary salinity) from evaporated seawater (Figure 3). The soil in this zone is characterized by low permeability and infiltration rates due to sodicity. Furthermore, because the northern region is situated at the end of the irrigation system, frequent shortages of canal freshwater force farmers to rely more on the relatively saline drainage water for irrigation, which results in secondary salinization. Additionally, the North Delta area faces a significant threat from sea levels associated with climate change, which could substantially impact the soils by 2050 (Mohamed, 2016).

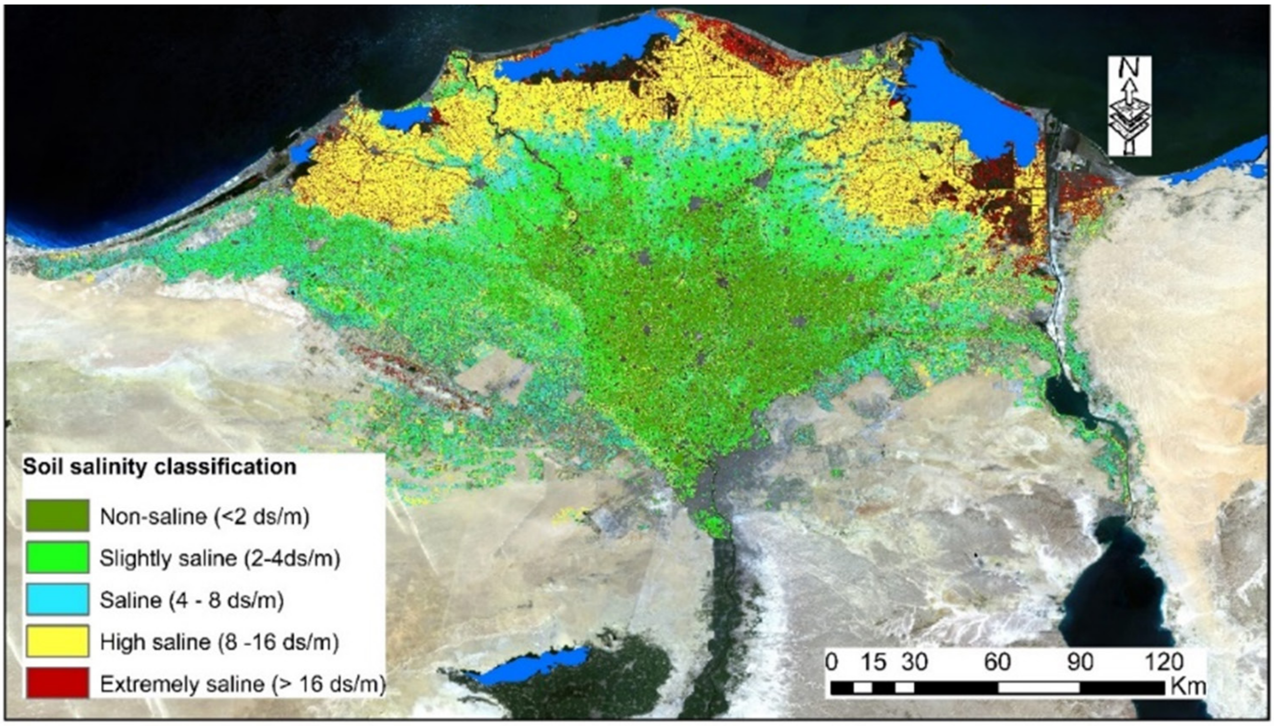


**Figure 10.** Nile Delta soil salinity map – enlarged part of map 9

Source: Author's creation

- **The Middle Delta** region is 100-150 km from the coast and serves as a transition zone between the high salinity and sodicity of the North Delta and the low soil salinity of the Southern Delta region. In this area, moderate saline soils are predominant. The water table in the Middle Delta is not as shallow as it is in the northern part and the soil texture is primarily silt-clay, with a high active capillary rise that can lead to secondary salinization if leaching and drainage are insufficient. Additionally, separate, non-continuous saline-sodic patches can be found on the soil surface, particularly towards the northern part of this zone. In the Middle Delta, Nile water, groundwater and drainage water are all reused for irrigation.

- **The South Delta** is known for having the most fertile and light-textured alluvial soils and a deeper water table than other areas of the Nile Delta. It is located on the upstream side of the irrigation canal system and benefits from higher-quality water. This region is predominantly characterized by non-saline soils and is renowned for producing high-value cash crops, such as vegetables and fruits, which supply the greater Cairo area. Saline soils in the South Delta account for no more than 24% of the total area (Mohamed, 2016).

Most of the Nile Delta's agricultural land has a subsurface drainage system (Abdel-Dayem et al. 2007).

### *The Eastern Desert*

The Eastern Desert has limited cultivated land due to its arid climate, scarce water resources, geological formations and low population density. The sedimentary rocks and sandstone formations in this region restrict the accumulation of salt deposits. However, localized saline conditions can arise in wadis with seasonal shallow groundwater tables or in coastal areas affected by seawater intrusion.

### *The Western Desert*

The soils of the Western Desert are predominantly non-saline due to the arid conditions and the lack of water necessary to mobilize salts to the surface. However, soils can become saline or saline-sodic in oasis where groundwater is used for irrigation, particularly when the groundwater has a high sodium adsorption ratio (SAR). This problem is exacerbated by ineffective groundwater management and poor drainage conditions, especially in the Siwa oasis (Figure 11), which features a complex geological formation and saline groundwater (ranging from 2.28 to 5.45 dS/m). In Siwa, saline agricultural areas have expanded from 28 km² in 1992 to 88 km² in 2015. Additionally, salt-affected soils grew from 17 km² to 64 km² and waterlogged areas increased from 19 km² to 51 km² during the same period (Elnaggar et al. 2017).

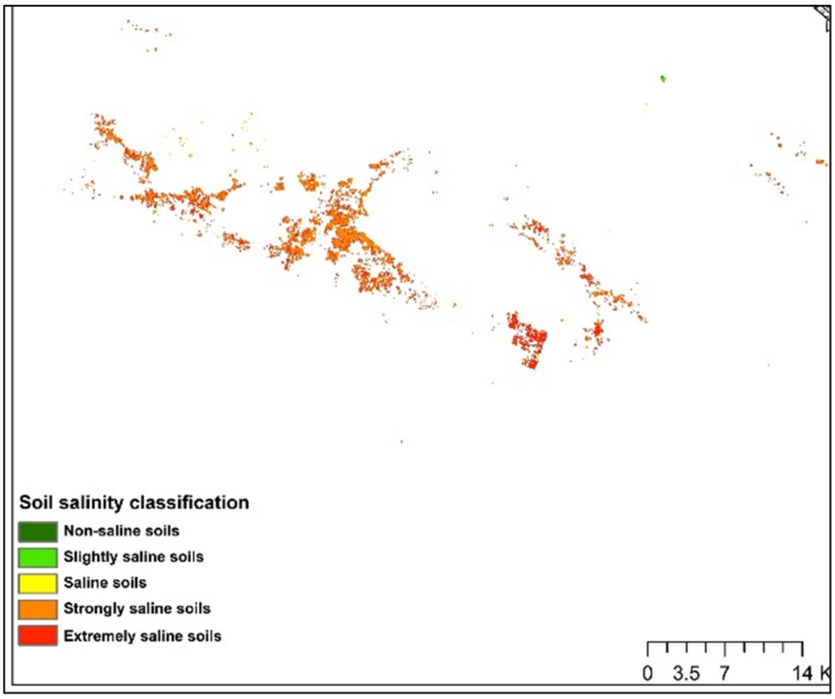


**Figure 11.** Siwa soil salinity map – enlarged part of map 9

Source: Author's creation

### *Fayoum Governorate*

The Fayoum Governorate is another significant area with considerable salt-affected soil (Figure 12). Located in a depression in the northern part of Upper Egypt, Fayoum features a land surface that slopes steeply from south to north towards Lake Qarun, with an average gradient of 2 m/km. Most of the governorate's land (93%) is irrigated by gravity-fed water from the Bahr-Youssef Canal. As a closed basin, all drainage water remains within the region, ultimately flowing into either Lake Qarun or Wadi Al Rayan Lakes (Ali and Mahmoud, 2020).

Salt-affected soils in Fayoum are concentrated in the low-lying areas south of Lake Qarun. This prevalence is attributed to a combination of primary salinity from land previously inundated by lake water and secondary salinization resulting from a shallow water table and irrigation with saline drainage water. Strongly to extremely saline soils are prevalent in this area (Abd-Elgawad et al. 2013).

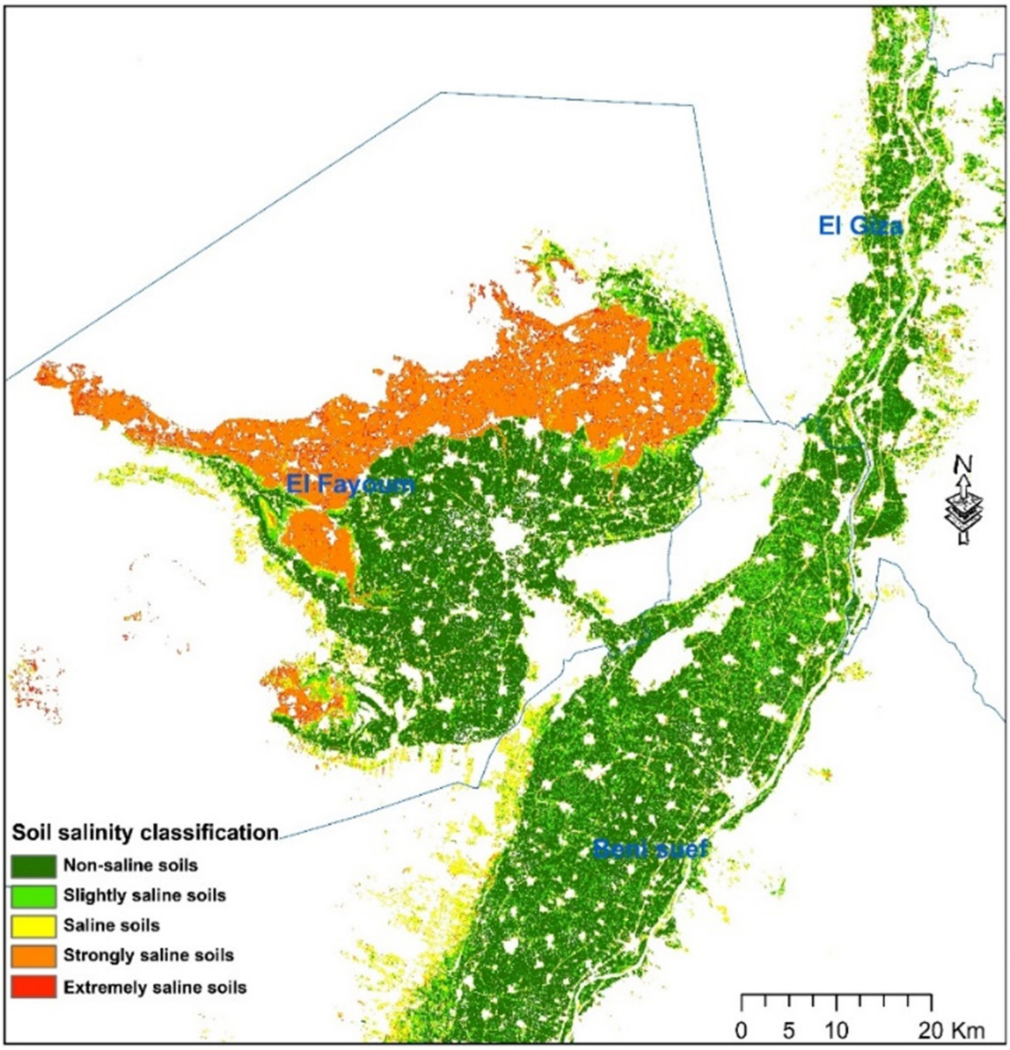


**Figure 12.** Fayoum Governorate soil salinity map – enlarged part of map 9
*Source:* Author's creation

## 4.4 Current Shares of Soil Salinity Classes

Based on data collected in 2023 through the remote sensing assessment, as shown in Table 4 the percentage of different soil salinity classes within the total agricultural area covered by the study. According to Table 4, 54% of the farming lands are either non-saline or slightly saline, which means that almost all crops can grow safely in these areas. Moderately saline soils account for 18% of Egypt's total agricultural land and are primarily located in the central part of the Delta and some newly reclaimed lands along its fringes. A wide range of crops can be cultivated in these areas with proper water management and smart agricultural practices.

Only salt-tolerant crops can thrive in strong saline soils. However, the salinity range of 8 dS/m to 16 dS/m is broad enough to support a variety of crops, depending on their sensitivity to salinity. With proper soil and water management practices, these crops can be highly productive. Extremely salt-affected soils comprise about 3% of the total cultivated land, equivalent to 288,000 feddans. These soils, including saline and saline-sodic types, require reclamation and soil improvement.

**Table 4.** Distribution of soil salinity classes in Egypt in 2023

| Type of soil salinity | Salinity threshold dS/m | % of area | Notes |
|---|---|---|---|
| Non-saline soils | <2 | 32 | Most areas of the Nile Valley and South Delta |
| Slightly saline soils | 2-4 | 22 | Nile Valley and the southern part of Middle Delta |
| Moderately saline soils | 4-8 | 18 | Northern part of Middle Delta and reclaimed areas along the fringes of the old lands. |
| Strongly saline soils | 8-16 | 25 | Mainly in North and East Delta, Fayoum Governorate, Siwa and newly reclaimed areas along the fringes of the old lands. |
| Extremely saline soils | >16 | 3 | Mainly in the far North Delta, Fayoum Governorate, Siwa and newly reclaimed areas along the fringes of the old lands and in North Sinai. |

*Source:* Author's creation

## 4.5 Temporal and Spatial Changes of Salinity

The figures presented in Table 4 highlight the extent of the salinity challenge in 2023, reflecting the health of cultivated land in Egypt from a soil salinity perspective. A critical question is how current soil salinity levels compare to those from previous years. By comparing the 2023 soil map of the Nile Delta (Figure 10) with the salinity maps from 1989 (Figure 7) and 1998 (Figure 8), we can gain insights into changes over the past 24 years. Notably, the geographical distribution of soil salinity zones has remained consistent, with low salinity found in the south, moderate salinity in the middle and high salinity in the north. However, detectable changes in the extent of each salinity class have occurred over time.

For comparison purposes, the five soil salinity classes have been consolidated into two categories: soils with salinity equal to or below 4 dS/m and soils with salinity above 4 dS/m. It is assumed that at salinity levels below 4 dS/m, most crops remain unaffected, aside from those particularly sensitive to salinity. Figure 13 illustrates the temporal changes in soil salinity in the south, middle and north Delta based on the available salinity maps from 1989, 1998, and 2023, respectively.

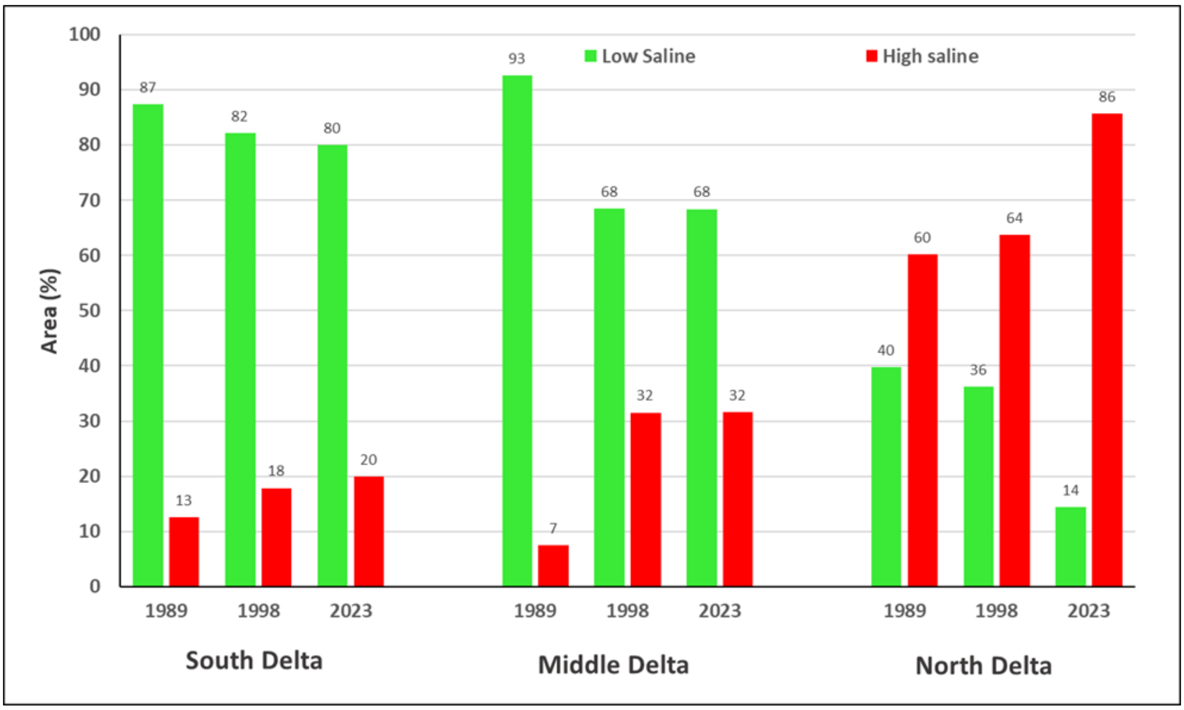


**Figure 13.** Temporal changes of salt-affected areas in south, middle and north Delta
*Source:* Author's creation

Overall, there has been an increase in high-saline areas at the expense of low-saline areas. Low-saline areas have gradually declined in the South Delta from 1998 to 2023. In the Middle Delta, there was a significant increase in high-saline areas by 1998, which remained stable through 2023. The year 1989 also marked an increase in the reuse of drainage water for irrigation (see Fig. 3). A study by (DRI) in 1997 showed a correlation between average soil salinity and the salinity of irrigation water, indicating that salt accumulation occurs in areas where drainage water is used as the primary irrigation source. Consequently, soil salinity in the South and Middle Delta reached a near-equilibrium state between 1998 and 2023.

The North Delta has the highest concentration of high-salinity areas, steadily increasing from 60% in 1989 to 86% in 2023. As previously mentioned, this region experiences challenging water and soil conditions due to a shallow saline water table, seawater intrusion, a shortage of fresh irrigation water and a reliance on drainage water for irrigation with relatively high salinity content. As a result, the North Delta is recognized as a high-risk salinity area within the Nile Delta.

Unfortunately, no similar analysis has been conducted for Fayoum, the second-highest salinity risk area. However, a study in the Sinnuris District assessed and monitored salinity changes before and after the construction of a subsurface drainage system covering 20,650 ha (Ali and Mahmoud, 2020). The Sinnuris District, bordering the southern and eastern shores of Lake Qarun, is among the areas most affected by soil salinization in Fayoum. The results indicated significant improvements in soil salinity levels: the area of non-saline soils (< 2 dS/m) increased from 1.3 ha in 2009 to 9,119 ha in 2018, while the area of high-saline soils (>16 dS/m) decreased from 3,031.36 ha in 2009 to 7.7 ha in 2018. These impressive results are attributed to the construction of subsurface drainage systems which began in 2007.

The discussion above illustrates that while certain areas experience significant and growing deterioration, others within the same region may improve due to local reclamation and remediation efforts. This was evident in a remote sensing (RS) study on soil degradation in the North Delta between 1983 and 2003, which assessed the increase, decrease, and stability of waterlogged and salt-affected areas during this period (El Nahry et al. 2015).

The study revealed that waterlogged areas increased by 52% of the study area, decreased by 10.1%, and stayed the same by 37.7%. For salt-affected areas, 31.4% increased, while 43% decreased and 25.2% showed no change. These findings suggest that when evaluating soil salinity on a regional scale, it is important to consider both the causes of deterioration and the remedial actions taken, as these factors can result in increases, decreases or stability in salinity levels.

### 4.6 Projection of Future Salinity Changes

Monitoring and assessing soil salinity reveals its complex and dynamic nature, highlighting the influence of both natural and human factors that can increase, decrease or maintain salinity levels over time. Inefficient water management and poor farming practices are the primary human contributors to soil salinization. In parallel, rising temperatures and saline water intrusion are key issues that emphasize the intricate relationship between climate change and soil salinity in the Nile Delta. These factors can adversely affect crop productivity, soil quality and biodiversity, thereby posing a significant threat to the livelihoods of rural communities.

Component 1 of the project attempted to predict future salinity changes in the Nile Delta through linear modeling based on annual temperature data. The results revealed a significant correlation between rising temperatures and increasing soil salinity. Elevated temperatures lead to higher evaporation rates, which reduce soil moisture levels and accelerate salinization processes. The outcomes of this simulation indicate that the region is particularly vulnerable to temperature increases.

However, the study also acknowledges the inherent limitations of predicting future scenarios, especially in complex systems like the Nile Delta. Changes in crop water requirements, irrigation water quantity and quality, crop patterns, land use and water management practices may all occur due to climate change adaptation. Despite these uncertainties, the study emphasizes the urgency of implementing immediate and adaptive measures to safeguard the agricultural and ecological systems of the Nile Delta as climate change continues to evolve.

The study did not investigate potential future increases in soil salinity resulting from sea level rise; however, it recommended continuous monitoring changes to assess changes in soil and water salinity under ever changing natural conditions and management practices. Updated salinity maps could be instrumental in formulating mitigation and adaptation strategies to reduce the soil salinity's impact on ecosystems and agricultural production. Additionally, ongoing research and innovations can enhance predictive models by incorporating new factors and improving overall accuracy.

Two man-made developments under consideration could significantly impact future soil salinity changes. First, the government plans to implement pressurized drip and sprinkler irrigation systems in Egypt's old agricultural lands. Some farmers have already adopted these methods to enhance crop yields; however, these irrigation techniques also pose risks regarding soil and crop salinity. Second, there is a proposal to divert large quantities of drainage water from the East and West Delta to irrigate newly reclaimed lands in Sinai and the new North-West Delta. The salt load carried by this drainage water could have long-term effects on soil salinity. Similarly, the use of brackish groundwater for irrigation may also influence soil salinity levels. These potential issues highlight the need for further monitoring and research.

## 5. Field-Level Analyses of Water and Soil Salinity

Component 2 of the project focused on detailed analyses, to map soil and water salinity and assess their impact on crop productivity at selected key sites across the northern, southern, eastern and western regions of the Nile Delta. The study was conducted in four benchmark governorates in Egypt: Qalyoubia, characterized by low levels of water and soil salinity; Ismailia, representing the eastern fringes of the Nile Delta; Fayoum, known for its unique topography that contributes to salt accumulation; and Kafr El-Sheikh, located in the North Nile Delta, where high levels of water and soil salinity are prevalent. The primary objective was to analyze and evaluate soil and water salinity in these benchmark areas and investigate their boundary conditions.

Sampling locations were marked on a Google Earth map using different color codes: red for soil samples, light blue for surface water samples and green for well water samples (Figure 14).

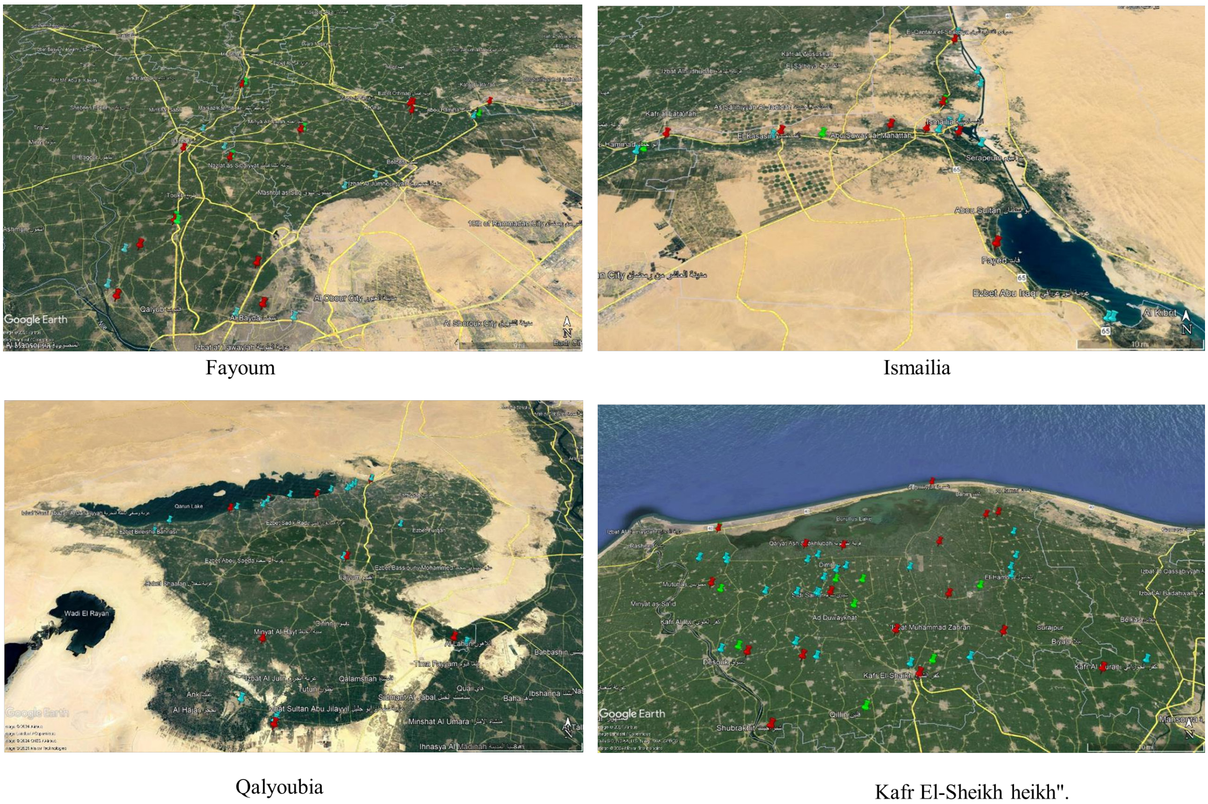


**Figure 14.** Location of soil and water sampling sites in the four benchmark governorates
*Source:* Author's creation

## 5.1 Water Salinity Analysis

A total of 180 water samples were collected from the four governorates during two seasons (summer and winter), representing the upstream, middle and downstream sections of canals and drains. This collection aimed to assess location-based and seasonal variations in water salinity and validate historical remote sensing maps. Water quality, including its salinity in canals and drains, is influenced by agricultural, domestic, and industrial activities along their courses from upstream to downstream. A monitoring plan was established to collect water samples at specific points where the boundaries of the governorates intersect with canals and drains. The classification of water salinity used in the following analysis follows FAO guidelines, as outlined in Section 3 and summarized in Table 3.

In the Qalyoubia Governorate (Figure 15, top left), canal water is classified as non-saline (< 0.7 dS/m), while the salinity of groundwater wells ranges from non-saline to slightly saline (0.7-2.0 dS/m). An increase in groundwater salinity is observed in wells located near industrial zones, particularly around Tokh. Generally, drainage water is classified as non-saline to slightly saline, except for the Belbas Drain, which receives domestic wastewater from residential areas. Overall, the salinity of water sources is higher in winter than in summer, mainly due to reduced irrigation activity and the absence of high-water-demand crops like rice and sugarcane, which in summer contribute to diluting salt concentrations in canals and drainage water. Notably, canal water remains consistently non-saline throughout both seasons. In contrast, groundwater and drainage water transition from non-saline to slightly saline, in various locations during winter. In the Belbas Drain, water salinity reaches moderately saline levels (2.47 dS/m) near residential areas in winter, but it returns to slightly saline downstream, due to dilution from additional drainage water from adjoining branch drains.

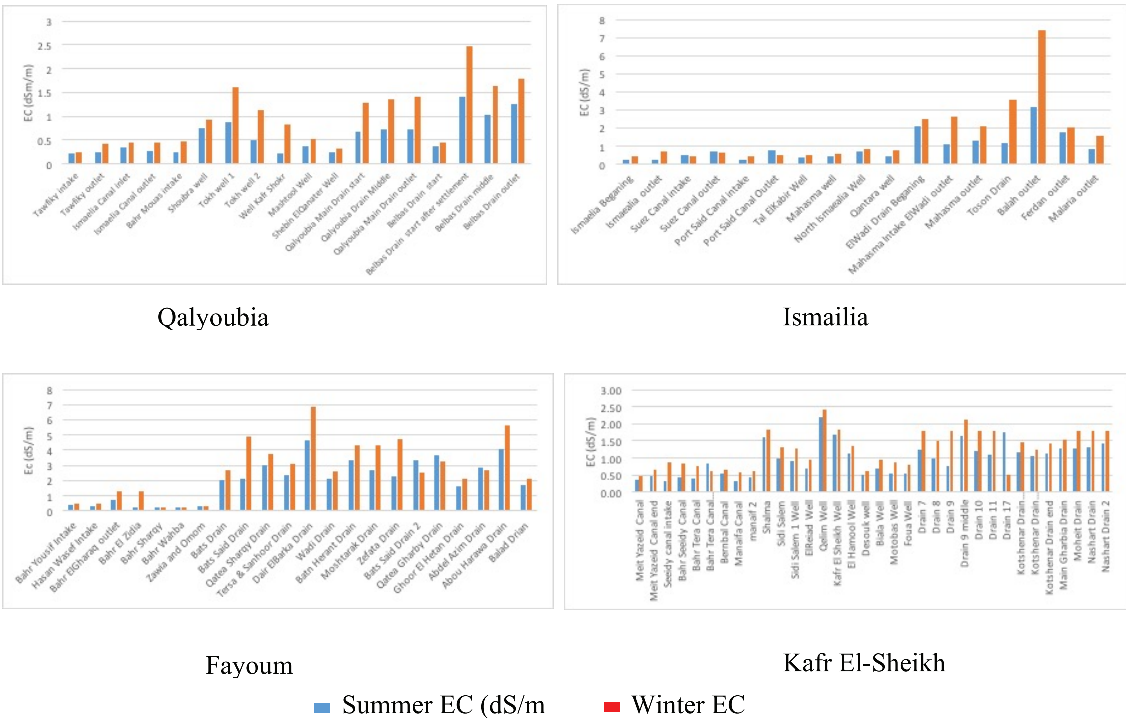


**Figure 15.** Salinity of canals water, groundwater, wells and drains in four governorates: Qalyoubia (top left); Ismailia (top right); Fayoum (bottom left) and Kafr el-sheikh (bottom right)

*Source:* Author's creation

In the Ismailia Governorate (Figure 15, top right), the primary irrigation artery is the Ismailia Canal, which branches off into the Suez and Port Said Canals. The irrigation system also includes several branch canals, *mesqas* and numerous wells. The main drainage channel is the Mahsama Drain, supplemented by several branch drains - including Balaah, Malaria, Toson, Ferdan, Sarapiom and Shohada. During summer and winter, water salinity at the intake and outlet points of the canals remains non-saline. Most shallow groundwater wells are classified as non-saline in winter, except those in north Ismailia and Qantra, which have slightly saline water.

The salinity of drainage water in the Ismailia Governorate is particularly relevant, as it supplies the newly constructed El Mahsama treatment plant with drainage water for irrigating newly reclaimed arable lands in Sinai. At the beginning of the Elwadi Drain, the drainage water is moderately saline during summer and winter (2.11 and 2.517 dS/m, respectively). However, the drainage water at its outlet becomes slightly saline in summer (1.12 dS/m) and moderately saline in winter (2.6 dS/m) as it flows into the Mahsama Drain. The water in the Mahsama Drain is slightly saline in summer (1.3 dS/m) and moderately saline in winter (2.07 dS/m) at its outlet.

Toson and Ferdan Drains show a similar pattern at their outlets, being non-saline in summer and moderately saline in winter. In contrast, water in Balaah Drain remains moderately saline year-round, with higher salinity levels compared to the other drains (3.15 dS/m in summer and 7.41 dS/m in winter). The water in the Malaria Drain retains slightly saline characteristics throughout the year.

In the Fayoum Governorate, the Bahr Yousef Canal serves as the primary irrigation source, supplying water to major canals such as Bahr Hassan Wasif, Bahr El Gharaq and Bahr El Nazla. Various small, medium and large drains collect drainage water from Fayoum and direct it to Qaroun and Wadi El Rayan Lakes. Essential drains in the governorate include Moshtarak, Bats, Wadi and Tersa, among others. Nile water of good quality is the sole resource for all agricultural and domestic uses. Water salinity in the primary and branch canals (Figure 15, bottom left) ranges between 0.23 to 0.73 dS/m, indicating non-saline water. With a few exceptions, the salinity of canal water remains consistent between summer and winter.

In the Fayoum Governorate, drainage water salinity varies from 2.0 dS/m at the starting points of the drains to 6.82 dS/m (moderately saline) near Lake Qaroun. This increase is influenced by drainage from the salt-affected soils around the lake. Due to Fayoum's unique topography, Lake Qaroun has historically served as the final destination for all drainage water in the governorate. The expansion of cultivated areas and low irrigation efficiency have occasionally caused the lake's water level to rise, flooding adjacent agricultural lands. Typically, drainage water salinity is significantly higher in winter than in summer. However, the Bats Drain is an exception, with drainage water salinity at 3.34 dS/m in summer and dropping to 2.55 dS/m in winter, remaining moderately saline throughout the year.

In the Kafr El-Sheikh Governorate, canal water is predominantly fresh; however, some canals, such as the Shalma and Sidi Salem canals, are supplemented by legal and illegal drainage water which affects salinity levels. During the summer, these canals exhibit slightly saline water (1.61 dS/m and 0.98 dS/m, respectively) and moderate salinity during the winter (1.81 dS/m and 1.32 dS/m, respectively).

Despite the MWRI imposing restrictions on drilling groundwater wells in Kafr El-Sheikh, several wells have been identified near Sidi Salem, El-Reiad, El-Hamool, Dosouk and Biala. The groundwater in this region is susceptible to salt intrusion from the sea, regardless of proximity to the Mediterranean. Salinity levels in the groundwater range from 0.49 dS/m to 2.19 dS/m during the summer and from 0.63 dS/m to 2.43 dS/m in the winter. Notably, wells closer to the sea display higher salinity due to the encroachment of saline water.

The dynamics of drainage water salinity experience significant changes throughout the year, influenced mainly by the high soil salinity and the presence of a saline shallow water table in the North Delta. During summer, the volume of drainage water increases considerably due to rice cultivation, which helps dilute salt concentration. In contrast, winter sees an increase in salt attributable to soil leaching and limited water flow in the drains. Most drains contain slightly saline water in summer, with salinity levels ranging from 0.75 dS/m and 1.77 dS/m, while in winter, the water typically ranges from slightly to moderately saline

## 5.2 Soil Salinity Analysis

A total of 564 soil samples were collected at various depths (0-30, 30-60, and 60-90 cm) from 51 locations in the four benchmark governorates across four seasons: summer, post-summer, post-Nili and winter. Some samples were intentionally gathered near lakes, the sea, shallow groundwater wells, as well as irrigation and drainage canals. The soil salinity classification used in the subsequent analyses follows the guidelines outlined in Table 4, based on electrical conductivity (EC) (Brown et al. 1954).

In Qalyoubia Governorate, soil samples were collected from eight irrigation districts, including areas that utilize shallow groundwater wells for irrigation, such as Shoubra, Qalyoub and Tokh. Here, water quality ranges from slightly saline to moderately saline. Figure 16 illustrates the soil extract (EC) salinity for the samples, measured in dS/m, across the three soil layers during the four crop seasons at various locations.

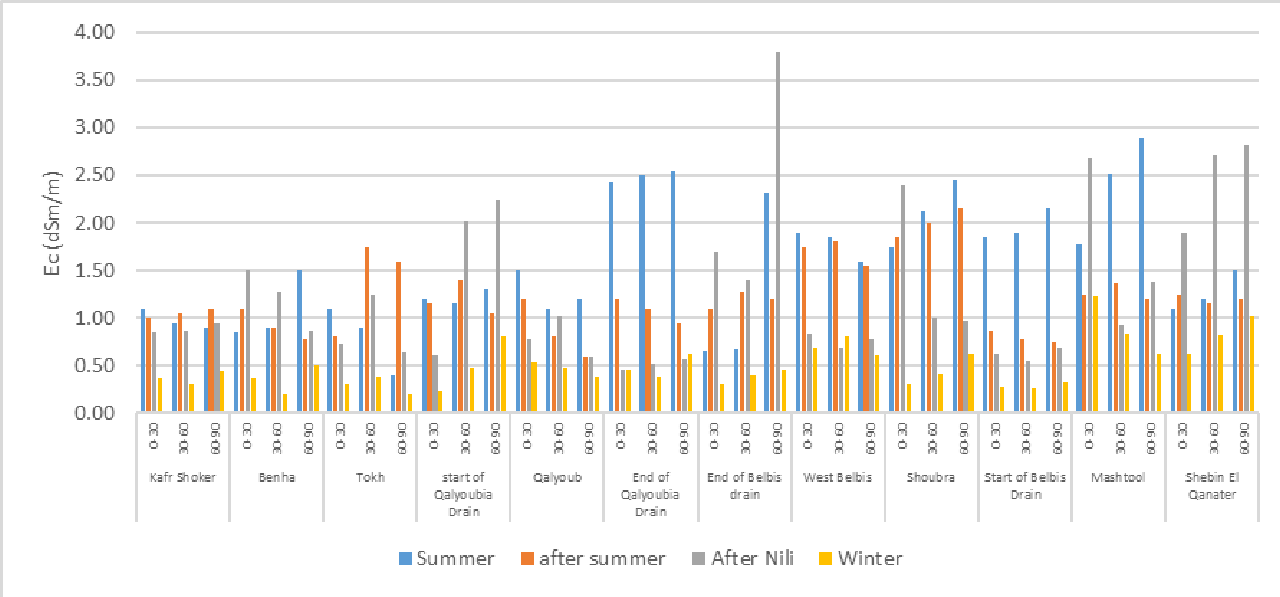


**Figure 16.** Soil salinity at various locations in Qalyoubia Governorate
*Source:* Author's creation

In the Qalyoubia Governorate, most soil samples are classified as non-saline (0-2 dS/m), consistent with the national assessment. However, slightly saline soil samples (2-4 dS/m) were found near the Qalyoubia and Belbas drains, as well as in areas irrigated with shallow groundwater wells. Furthermore, areas near industrial zones showed minimal salinity (4-8 dS/m). The irrigation water sources in the region include canal water from Qalyoub, Benha, Belbis and Kafr Shokr, groundwater from wells in Tokh and around the Qalyoubia Main Drain, and a combination of canal and groundwater in Shobra, Mashtoul, and near the tail end of Belbis Drain.

Salt movement through the soil profile is limited, typically occurring where there are small differences in salinity between the soil layers. However, there is a tendency for salt to accumulate in the topsoil during the summer season, which is then leached away during the following winter. In Shebin El Qanater, farmers plant Nili crops immediately after the summer season without any land preparation, leading to ongoing salt accumulation during the Nili season. Subsequent leaching and land preparation activities help reduce salinity levels to non-saline conditions. Therefore, land preparation and post-season leaching are crucial for preserving soil quality.

Six irrigation districts in the Ismailia Governorate feature diverse soil types and varying water quality used for irrigation. Soil samples were collected from these districts—Eltal El-Kabir, ElQassasin, Abou Sewar, Ismailia, Fayed and Qantara—as well as from areas near drains with high salt levels. Additionally, samples were taken from locations that rely on well water for irrigation or a combination of well and canal water. Two additional soil samples were collected from areas near the Malaria and Qantara Drains.

Soil salinity in the Ismailia Governorate ranges from non-saline (0-2 dS/m) to slightly saline (2-4 dS/m) across most locations (Figure 17). However, near the start of the Wadi Drain, close to residential areas, soil salinity approaches the upper limit of slightly saline (4 dS/m) in both the surface and subsurface layers following the Nili season. In Qantra Gharb, salinity increases with depth during and after the summer but significantly decreases after the Nili and winter seasons. Soil samples near the Qantra Drain reveal notably saline conditions at the surface layer (4-8 dS/m) following the summer and Nili seasons at 0-30 cm depth, indicating salt accumulation in the topsoil.

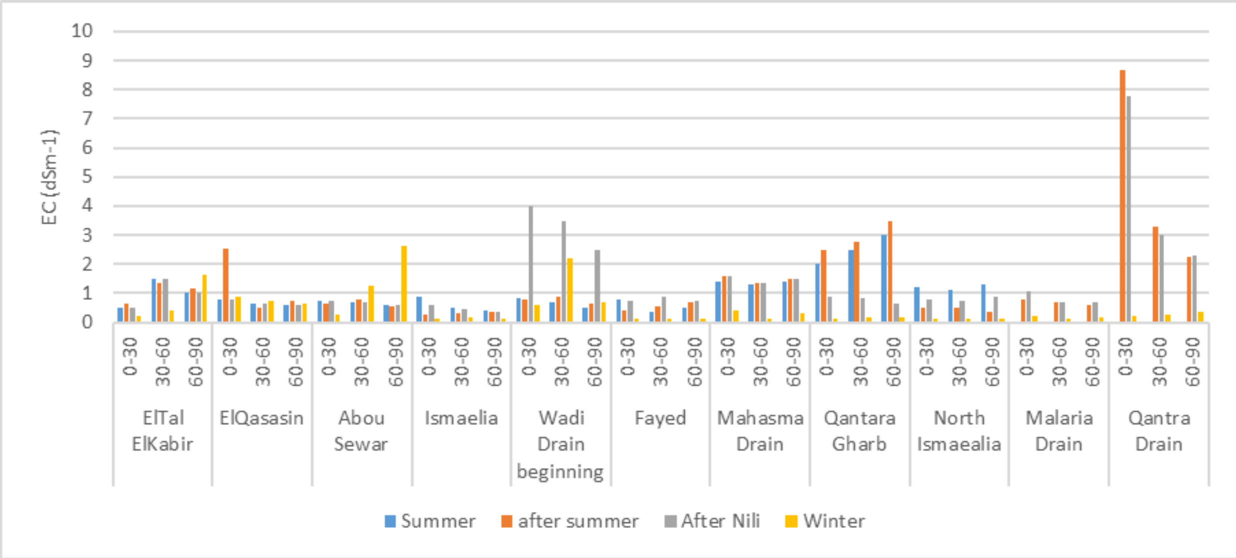


**Figure 17.** Soil salinity at various locations in Ismailia Governorate
*Source:* Author's creation

During winter, the combination of sandy soils and rainfall enhances leaching, substantially reducing soil salinity. In some areas near the Qantara Drain, farmers replace the top 0.5 meters of soil with fresh sand after the Nili and summer seasons, leading to a significant decrease in salinity from 8.7 to 0.23 dS/m. Irrigation water sources in the monitored locations include groundwater in El Qassasen, areas near the Qantra Drain, North Ismailia and West Qantra. In Abo Sower and upstream Wadi Drain, both canal and well water are utilized for irrigation, while the remaining locations predominantly use canal water.

The Fayoum Governorate consists of six irrigation districts, each characterized by diverse soil types and water quality. Soil samples were collected during various cropping seasons for soil salinity analyses. These samples were taken from the six irrigation districts as well as from areas near Lake Qaroun and other locations with elevated salt concentrations.

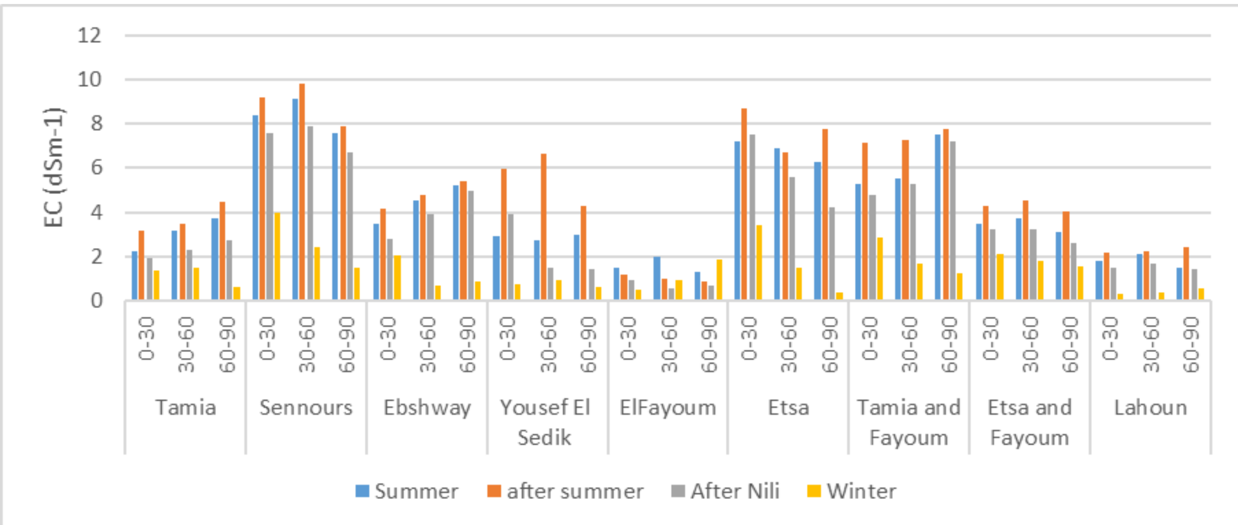


**Figure 18.** Soil salinity at various locations in Fayoum Governorate
*Source:* Author's creation

Soil analysis was conducted four times throughout the year (summer, post-summer, after Nili and winter) as shown in Figure 18. Saline soils (4-8 dS/m) dominate most districts in Fayoum, with salinity levels increasing to highly saline (>8 dS/m) near Lake Qaroun. Geographical location and irrigation water quality play crucial roles in soil salinity. Drainage water is the primary irrigation source in Sennours, Tamia and Youssef El-Sedik. The remaining districts and other monitored locations are irrigated with canal water.

Lahoun and Fayoum districts exhibit the lowest soil salinity, likely due to their proximity to the fresh waters of Bahr Youssef and Hassan Wasef. In contrast, Sennoures records the highest salinity, attributable to its location near Lake Qaroun and its dependence on the Bats Drain for water supply. Although Ebshway is also close to Lake Qaroun, it displays lower soil salinity levels because the Bahr El Zidia Canal irrigates it. Notably, the topsoil layer in Sennoures has the highest salinity due to ongoing salinization processes. In Ebshway, however, the lower soil layer exhibits higher salinity due to leaching. Salt accumulation peaks during the summer when elevated temperatures drive increased evaporation. Soil salinity is influenced not only by proximity to lakes and canals but also by the quality of irrigation water, climate factors and the types of soil and crops, as observed in Etsa, Tamia and Fayoum.

In the Kafr El-Sheikh Governorate, soil samples were collected from ten irrigation districts, including areas near the drain outlets leading to Lake Burulous and locations irrigated by groundwater. The sampling process considered variations in irrigation water sources—such as canals, drains, mixed water sources and wells—and differences in soil textures (light and heavy soils) and the types of crops cultivated in these areas.

In Figure 19, approximately half of the samples are classified as non-saline or slightly saline. However, significant areas exhibit saline soil (4-8 dS/m), particularly in Zawia, Sidi Salem, parts of Hamool and Biala. Strongly saline soils (8-16 dS/m) are found in Village 71 and Demro, while extremely saline soils (>16 dS/m) are present in certain parts of Hamool. Following the winter season, the leaching process—driven by rainfall and water availability in canals—alters soil salinity, transforming it into non-saline, slightly saline or saline conditions based on the summer salinity levels.

Districts irrigated with a mix of fresh and drainage water include Sidi Salem and Village 71, while those relying exclusively on drainage water include El-Hamool, Biala, Demro, Sidi Salem and El Zawia. Farmers in the region employ various techniques to combat soil salinity effectively, such as mole drains, open drains, subsurface drains with closely spaced laterals and the application of gypsum and organic fertilizers. Additionally, rice cultivation is common in Kafr El-Sheikh, serving as a reclamation crop to enhance soil leaching.

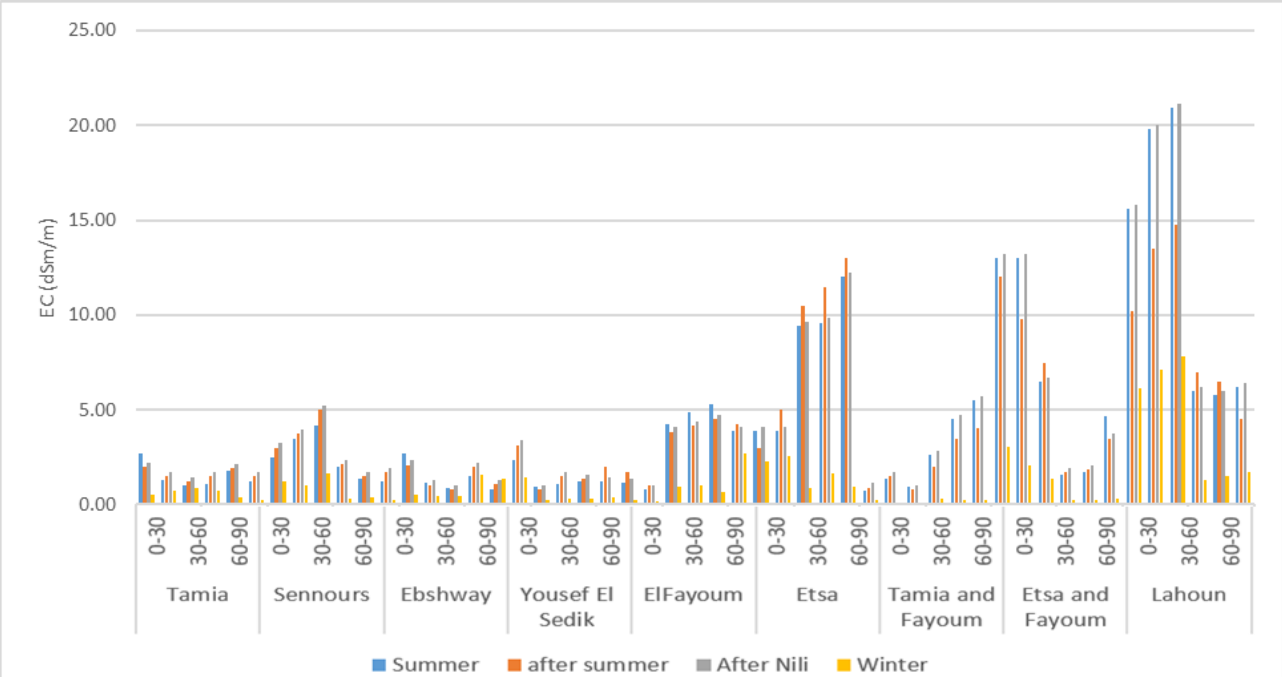


**Figure 19.** Soil salinity at various locations in Kafr el-sheikh Governorate

*Source:* Author’s creation

# 6. Socio-Economic Aspects of Saline Soil Crop Production

Component 3 of the project focused on studying common practices and indigenous solutions for maintaining and enhancing saline landscapes' productivity, based on surveys conducted with farmers in the four benchmark governorates: Qalyoubia, Ismailia, Fayoum and Kafr El-Sheikh. These governorates were also considered in the farm-level soil and water salinity assessment (Component 2). The study analyzed the impacts of soil salinity on the social and economic livelihoods of farmers in these regions. Fieldwork was conducted during the winter crop season of 2022/2023 and the summer season of 2023.

Component 3 of the study employed several indicators to analyze the impact of salinity on agricultural production in each area. The indicators included crop patterns influenced by soil salinity, production input costs, irrigation expenses and productivity per unit of land area. A comparative analysis of economic indicators was conducted between crop production in saline and non-saline lands. The study also factored in the relative location along the canal—whether upstream, middle or at the tail end—taking into account variations in water availability and quality for irrigation.

Key economic indicators, such as average variable costs and net acre returns, were analyzed across various geographical locations (governorates). The objective was to identify the most significant challenges facing crop production in different saline landscapes and to pinpoint the key practices and techniques used by farmers to adapt to or mitigate the adverse impacts of salinity.

The study used descriptive and quantitative research methods to identify patterns, trends and relationships between indicators. Analyses were conducted using arithmetic averages and simple regression methods to gain insight into farmers' perceptions, understandings, capabilities and indigenous solutions for addressing soil salinity. To achieve this, the study adopted a comprehensive approach that combined primary data collection with integrating published and unpublished secondary data from various sources, including relevant studies and research.

The study also examined how farmers utilize saline lands in the selected governorates and assessed the relative importance of cultivated crop areas during the 2022-2023 productive season. Additionally, it evaluated the impact of soil salinity on crop yield, based on agronomic classifications, providing insights into how soil salinity affects crop growth. This information contributes to the development of sustainable agricultural practices in Egypt.

The study involved two groups of farmers. The first group consisted of 200 farmers, with 50 selected from each of the four governorates. These farmers were chosen using a stratified sampling method based on their geographical distribution along the irrigation canal. The second group included farmers participating in a series of Focus Group Discussions (FGDs) held in each governorate, with a total number of 139 farmers participating in FGDs (40 from Kafr El-Sheikh, 28 from Qalyubia, 40 from Ismailia and 31 from Fayoum). In both cases, the selection of farmers considered social and economic factors, including land tenure types (owner or renter) and gender. The FGDs aimed to validate the interview results, identify knowledge gaps and develop solutions. Other relevant stakeholders, including extension agents and experts, were consulted.

## 6.1 Influence of Soil Salinity on Crop Choices

Understanding crop patterns—specifically, the types of crops grown in a season—and crop intensity, which refers to the percentage of each crop within the overall crop pattern is essential background information. This data offers valuable insight into farmers’ choices and preferences for crop production in saline landscapes. Table 5 presents the winter and summer crop patterns and intensities in the four governorates during the 2022-2023 season. Crop intensities vary across the governorates to accommodate the local water, soil and climate conditions.

It is evident that salt tolerance significantly influences farmers’ crop choices. In the winter, wheat and sugar beets are commonly grown in Kafr-El-Sheikh, while wheat is the predominant crop in Fayoum. During the summer, farmers in Kafr El-Sheikh grow clover (berseem), despite its sensitivity to salt, as it serves as an important fodder crop for cattle and can be sold at a high price in the local market. In contrast, Qalyoubia and Ismailia focus on high-value cash crops, primarily fruits. Qalyoubia grows citrus, grapes and strawberries, whereas Ismailia specializes in mango cultivation. In Kafr El-Sheikh, cotton and rice dominate the summer crop pattern. Although rice is relatively sensitive to salt, it plays a crucial role in leaching salt from the soil. Its constant irrigation promotes downward seepage and facilitates salt leaching.

**Table 5.** Crop percentage in the crop pattern during the 2022–2023 season[1]

| Season | Crop pattern | Salinity tolerance EC (dS/m) | Crop intensity (%) | | | |
|---|---|---|---|---|---|---|
| | | | Kafr El-Sheikh | Qalyoubia | Fayoum | Ismailia |
| Winter | Wheat | 6.0 | 41.1 | 26 | 63.9 | 10.7 |
| | Perennial clover | 1.5 | 23.3 | 31 | 17 | 15.4 |
| | Sugar beet | 7.0 | 20.7 | 0.2 | 11.2 | 3 |
| | Short clover | 1.5 | 5.7 | 3.2 | 1.7 | - |
| | Beans | 1.0 | 1.9 | - | 0.2 | 0.3 |
| | Onion | 1.2 | 0.7 | 8 | 3.1 | 0.3 |
| | Winter vegetables | 1.0- 2.5 | 3.0 | 2.4 | 2.3 | 19.0 |
| | Perennial orchards | 1.5- 1.8 | - | 23.9 | - | 49.0 |
| | Other | | 4.3 | 13.3 | 3.7 | 2.3 |
| | % | | 100 | 100 | 100 | 100 |
| Summer | Cotton | 7.7 | 20.6 | 0.1 | 5.2 | 0.4 |
| | Rice | 3.0 | 46.7 | 7.1 | 1.7 | 1.9 |
| | Maize | 1.7 | 9.1 | 32.2 | 21.8 | - |
| | Summer vegetables | 1.0-2.5 | 7.3 | 11.2 | 6.2 | 7.5 |
| | Corn derawa | 1.8 | 3.7 | - | 27.7 | 0.1 |
| | Yellow corn | 2.0 | 3.1 | 6.4 | 1.4 | 10.6 |
| | Others | | 9.6 | 19.1 | 36.0 | 8.7 |
| | Perennial orchards | 1.5- 1.8 | - | 23.9 | - | 48.8 |
| | Under cultivation | - | - | - | - | 21.9 |
| | % | | 100 | 100 | 100 | 100 |
| Total cultivated area in the governorate (one thousand acres) | | | 523.09 | 157.388 | 325.493 | 473.053 |

*Source:* Author's creation

## 6.2 Average Variable Cost of Production and Net Return

*Absolute Cost and Net Return Values*

Using the soil salinity assessment data generated by Component 2 of the project, as presented in Section 5, Component 3 analyzed the absolute values of the variable cost of crop production and the net return for selected crops during both the winter season (Table 6) and the summer season (Table 7). This analysis includes comparisons for both saline and non-saline soils across the four benchmark governorates.

In winter crops, the cost of production in saline soils (S) generally exceeds that in non-saline soils (N) across all governorates. The absolute average cost of crop production (Table 6) was highest for wheat, followed by sugar beet and clover (*berseem*). This discrepancy can be attributed to each crop's varying agricultural input requirements. Geographically, the absolute average cost of production for all crops was highest in Kafr El-Sheikh (North Delta), where saline soils are more prevalent, possibly due to the additional watering needed

[1] Other crops could include ornament and medical crops.

for leaching salts. Conversely, the lowest absolute average cost of crop production was in Qalyoubia, where non-saline soils are more predominant compared to the other three governorates.

The absolute value of net return among the three winter crops (Table 6) was generally higher in non-saline soils for all crops across all governorates. Clover (*berseem*) produced the highest net return in both non-saline and saline soils, which may explain its popularity among farmers. Notably, the net return from clover in saline soil was significantly higher in Qalyoubia than in Kafr El-Sheikh and Fayoum, likely due to the higher salinity levels in these governorates.

Despite its strong tolerance to salinity, wheat – identified as the costliest crop in Kafr El-Sheikh – yielded the lowest net return. Similarly, sugar beet, another salt-tolerant crop, exhibited the lowest net return in Ismailia. The low net returns for these salt-tolerant crops cannot be solely attributed to salinity; other factors, such as soil type or climate conditions, may also influence the results, although this could not be definitively confirmed.

The average variable cost for growing clover in saline soil is 8% higher in Qalyoubia and 58% higher in Fayoum compared to non-saline soils. This difference is mainly due to the higher salinity levels in Fayoum compared to Qalyoubia. In Fayoum, production costs were higher than those in Kafr El-Sheikh for all crops, even though both areas were classified as having higher saline soil. On the other hand, Qalyoubia has the lowest costs for all crops, as it only has a limited area of saline soil.

**Table 6.** Total production cost and net return per feddan for selected winter crops in the four benchmark governorates

| Crop | Governorate | Total Variable Cost (EGP 1000) | | Net Return (EGP 1000) | |
|---|---|---|---|---|---|
| | | Non-Saline (N) | Saline (S) | Non-Saline (N) | Saline (S) |
| Wheat | Kafr El-Sheikh | 11.1 | 13.2 | 2.7 | 1.4 |
| | Fayoum | 7.3 | 10.8 | 6.6 | 3.1 |
| | Qalyoubia | 10.8 | 11.4 | 4.5 | 4.4 |
| | Ismailia | 8.6 | 10.5 | 5.6 | 4.7 |
| Beat | Kafr El-Sheikh | 8.9 | 10.5 | 5.3 | 5 |
| | Fayoum | 8.6 | 10.6 | 4.9 | 3.7 |
| | Ismailia | 6.5 | 7.4 | 2.1 | 1.8 |
| Clover | Kafr El-Sheikh | 5.7 | 7.5 | 16.9 | 10.8 |
| | Fayoum | 4.5 | 7.1 | 17.2 | 12.3 |
| | Qalyoubia | 3.8 | 4.1 | 17.2 | 16.3 |

*Source:* Author's creation

Summer crops and winter crops show a similar pattern of crop production and net return, as indicated in Table 6. It is worth noting that the cost of rice production in Qalyoubia, where soils are primarily non-saline, is higher than in Kafr El-Sheikh, despite yielding the lowest net return in both saline and non-saline soils. This increased cost may be attributed to the greater irrigation needs of Qalyoubia's lighter soils, where high downward seepage requires extra water to maintain standing water levels. However, it is important to mention that rice cultivation in Qalyoubia is prohibited by the government and is considered a legal violation. This explains the low intensity of rice cultivation in Qalyoubia's summer crop pattern (7%) compared to Kafr El-Sheikh (46.7%) in the North (Table 7). The significantly lower cost of cotton production in Qalyoubia, approximately 50% less than in Fayoum and Kafr El-Sheikh, remains difficult to explain.

The net return from cotton in Qalyoubia is meager, even in non-saline soils, although it exceeds the net return in saline soils by more than twofold. It appears that, aside from corn, growing field crops during the summer is not an economically viable choice for farmers in Qalyoubia (Table 7).

**Table 7.** Total production cost and net return (egp 1000) per feddan for selected summer crops in the four benchmark governorates

| Crop | Governorate | Total Variable Cost (EGP 1000) | | Net Return (EGP 1000) | |
|---|---|---|---|---|---|
| | | Non-saline (N) | Saline (S) | Non-saline (N) | Saline (S) |
| Rice | Kafr El-Sheikh | 12.8 | 16.3 | 7.4 | 5.3 |
| | Qalyoubia | 14.9 | 18.5 | 0.7 | 0.4 |
| Corn | Kafr El-Sheikh | 9.8 | 12 | 4.2 | 2.3 |
| | Fayoum | 11.9 | 13 | 2.4 | 1.7 |
| | Qalyoubia | 9.3 | 10.4 | 4.4 | 3.9 |
| | Ismailia | 9 | 12.1 | 2.7 | 1.9 |
| Cotton | Kafr El-Sheikh | 16.2 | 19.1 | 4.5 | 3.2 |
| | Fayoum | 14.6 | 17.3 | 9.1 | 10.3 |
| | Qalyoubia | 6.2 | 7.3 | 1.7 | 0.7 |

*Source:* Author's creation

### Relative Costs and Net Returns

This report includes relative cost and revenue values to standardize the comparison between the average variable costs of crop production and the net returns under saline and non-saline soil conditions. The following relative parameters have been calculated:

1. The ratio of average variable cost in non-saline soil to those in saline soil.
2. The ratio of net returns in non-saline soil to those in saline soil.
3. The ratio of net returns to average variable cost in non-saline soil.
4. The ratio of net returns to average variable cost in saline soil.

For winter crops, net returns were consistently higher in non-saline soils than in saline soils. The ratio of net return for wheat varied significantly, with a minimum ratio of 102.3% in Qalyoubia and a maximum of 212.9% in Fayoum (Figure 20). In Kafr El-Sheikh, the net return ratio for wheat was also notably high at 199.9%. In Ismailia, however, the net return for wheat was lower at 119.1%. While wheat is recognized as a salt-tolerant crop, these variations in net returns suggest that factors beyond salinity – such as soil type, agricultural inputs, labor costs and market prices – substantially impact profitability.

Relatively high net returns from clover were observed in Kafr El-Sheikh (156.5%) and Fayoum (139.85%). In contrast, Qalyoubia showed a lower net return ratio of only 105.5%. These results underscore the importance of selecting crops based on geographical location and considering soil salinity along with other factors that influence crop production.

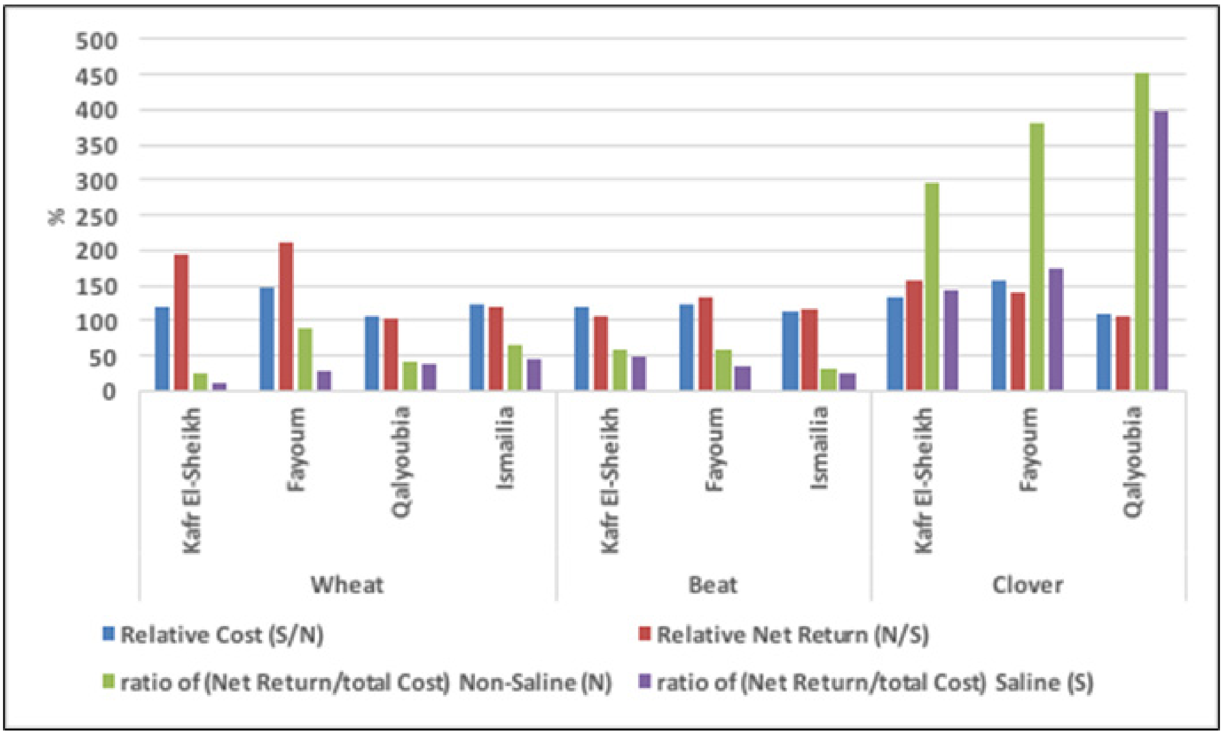


**Figure 20**. Relative production costs and relative net return of winter crops

*Source:* Author's creation

The ratio of net return to average variable cost in non-saline soils is generally higher than in saline soils (Figure 20). For clover, this ratio is notably high in non-saline soils, with values of 296.5%, 382.2%, and 452.6% in Kafr El-Sheikh, Fayoum and Qalyoubia, respectively. Even in saline soils, clover maintains significant ratios of 144.0%, 173.24%, and 397.6% in these governorates. This trend explains why growing berseem is more popular among farmers than wheat, indicating that potential revenues are a more decisive influence on crop choice than soil salinity. Despite clover being a salt-sensitive crop, farmers mitigate soil salinity through heavy irrigation before and during the growing season, contributing to higher cultivation costs. For all other crops across the governorate, the ratio of net return to average variable cost ranges from 24.4% to 59.6% in non-saline soils and from 10.6% and 47.6% in saline soils. Therefore, high market prices encourage farmers to adopt practices and techniques that help mitigate soil salinity.

The calculated relative parameters for summer crops are presented in Figure 21. The ratio of the relative cost of rice production in non-saline soil compared to saline soil is similar in both Kafr El-Sheikh (127.3%) and Qalyoubia (124.3%) governorates. However, the ratio of the net return for rice in non-saline soil is higher in Qalyoubia (175%) than in Kafr El-Sheikh (139.52%). This difference indicates that soil salinity restricts potential profits from rice due to its detrimental impact on yield. In Kafr El-Sheikh, the ratio of net return for rice to total variable cost is 57.8% in non-saline soil compared to just 32.5% in saline soils. In Qalyoubia, these ratios are even lower, at 4.7% and 2.2%, respectively, underscoring the unprofitability of rice in this region—even at low levels of soil salinity.

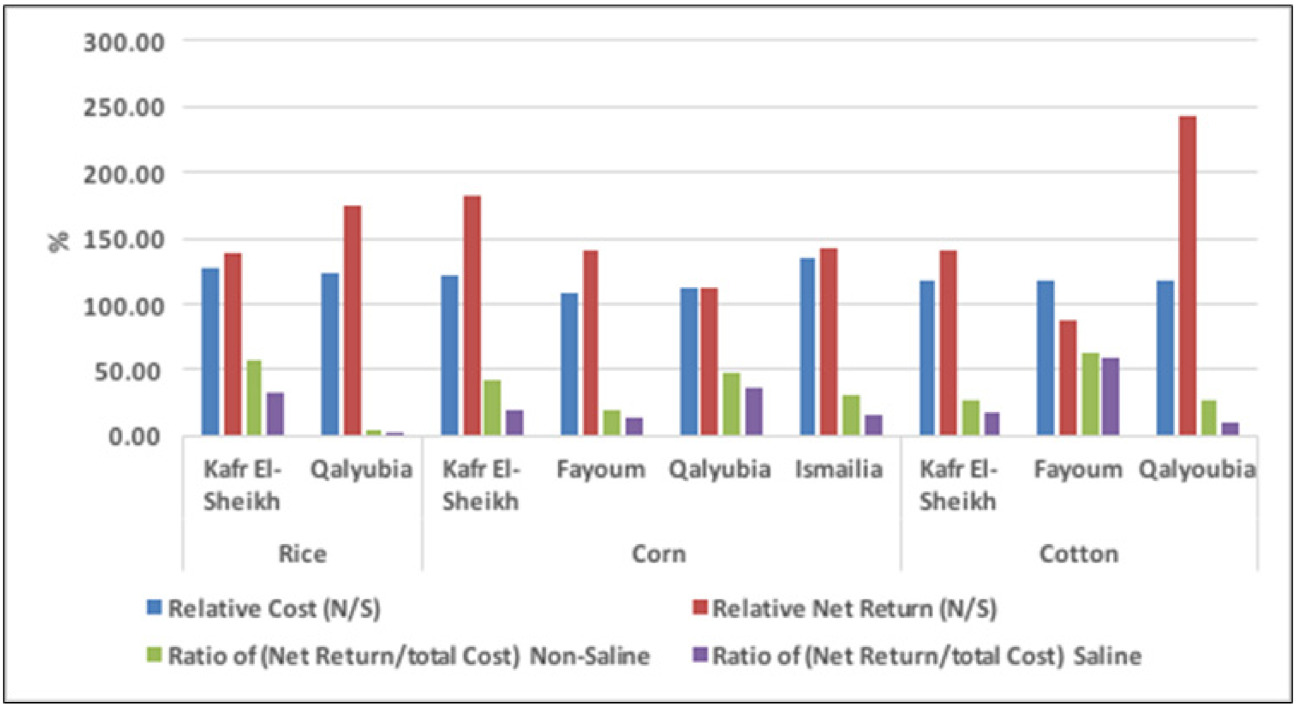


**Figure 21.** Relative production costs and relative net return of summer crops

*Source:* Author's creation

With the exception of the Fayoum Governorate, corn performed well across all relative parameters. The ratio of net return to variable costs for corn in non-saline soils was 42.9% in Kafr El-Sheikh, 47.3% in Qalyoubia and 30% in Ismailia. These ratios were 19.2%, 13.1%, and 15.7% in saline soils, respectively. In Fayoum, the ratios were lower, at 20.2% in non-saline soils and 13.1% in saline soils. This demonstrates the significant impact of salinity on corn yield, as corn is known to be sensitive to salinity.

In contrast, the ratio of net return to average variable cost for cotton was notably high in Fayoum, at 62.3% for non-saline soils and 59.5% for saline soils. That ratio was lower in Kafr El-Sheik, measured at 27.8% for non-saline soils and 27.4% for saline soils. Even lower values were observed in Qalyoubia, where the ratios were 16.8% in non-saline soil and 9.6% in saline soil.

The economic analysis above indicates that soil salinity increases the production costs of both winter and summer crops, while reducing net revenues compared to non-saline or low-salinity soils. However, the cost differences between these conditions are influenced by the crops' tolerance to salinity and water, and soil management practices (such as choosing drought- resilient crops, crop rotation strategies, deep plowing, regular tillage and adding gypsum and organic fertilizers) implemented to mitigate the effects of salinity (Choukr-Allah et al. 2023). Additionally, the microclimate of each governorate plays a significant role in these dynamics. Furthermore, high market prices affect the absolute net return and serve as a crucial factor in farmers' crop choices, often outweighing the influence of soil salinity.

## 6.3 Salinity-Related Challenges Facing Farmers

The challenges associated with salinity in agriculture are multifaceted and involve various factors. According to the surveyed farmers, the key challenges they face across the four governorates are similar, albeit varying in significance. These challenges include soil quality, groundwater levels, land surface elevation, irrigation water quality and availability, and land drainage status. In unfavorable conditions, these challenges can lead to soil deterioration, shallow groundwater levels, surface flooding, low water quality, drought and poor drainage. Additionally, farmers encounter difficulties in adopting modern technology and obtaining proper guidance.

According to farmers' perceptions, soil quality deterioration is most significant in Kafr El-Sheikh, with approximately 78% of farmers reporting this issue. This is followed by Fayoum at 70%, Ismailia at 56% and Qalyoubia at 36%. The challenge of shallow groundwater levels was reported by 72% of farmers in Kafr El-Sheikh, 66% in Fayoum, 40% in Ismailia and 30% in Qalyoubia. Farmers believe that proximity to bodies of water, such as the Mediterranean Sea, Lake Burullus, and Lake Qarun, contributes to the high groundwater levels in these areas.

Irrigation water scarcity is a significant issue across all four governorates. Kafr El-Sheikh experiences the highest level of discontent, with approximately 84% of farmers expressing concern, followed by Fayoum at 64%, Ismailia at 40% and Qalyoubia at 26%. This problem can be attributed to many factors, including excessive withdrawals of canal water by upstream users, inefficient irrigation methods, high irrigation costs driven by increased energy prices and elevated evapotranspiration rates, particularly during the summer.

Challenges related to irrigation water quality differ, depending on the farm's location along the irrigation canal. Factors such as mixing irrigation water with poor-quality drainage, insufficient canal maintenance and pollution, contribute to the deterioration of the water as it progresses from the canal's head to the tail. In Kafr El-Sheikh, farmers report significant water quality issues, with 88% indicating problems. This is followed by Fayoum at 52%, Qalyoubia at 44% and Ismailia at 38%.

Poor drainage is the most critical issue identified by farmers, with 61.5% of the respondents mentioning this problem. Kafr El-Sheikh has the highest rate of complaints at approximately 76%, followed by Fayoum at 60%, Qalyoubia at 56% and Ismailia at 54%. Farmers cited several reasons for the poor performance of the drainage systems, including inefficient maintenance and a lack of cleaning of open drains. Component 2 of the project reported that the investigated sites were predominantly served by open drainage systems[2].

The limited use of modern technology in agriculture is primarily attributed to high costs, insufficient funding, operational difficulties and a general lack of awareness of state-of-the-art treatment methods. Some governorates suffer from this more than others. For instance, approximately 58% of farmers in Kafr El-Sheikh reported not using modern technologies, as did 60% in Fayoum, 22% in Qalyoubia and 24% in Ismailia. Additionally, the cost of adopting modern tools is a significant concern. Around 40% of farmers in Kafr El-Sheikh, 50% in Fayoum, 20% in Qalyoubia and 18% in Ismailia reported this problem.

Furthermore, difficulty obtaining funding, excessive use of fertilizers and resistance to changing crop patterns are other prevalent challenges across the surveyed areas. These issues were encountered with various severity in the four governorates, highlighting the diverse challenges faced in addressing salinity in agricultural lands.

The main issue identified by individual farmers was the difficulty in conducting water and soil analyses, with about 71.5% of the total sample reporting that concern. Barriers include prohibitive costs, the remoteness of testing facilities and a lack of understanding of these results' significance. On the other hand, farmers ranked excessive fertilizer use as the least concerning challenge, with only 14% of surveyed farmers rating it as an issue.

## 6.4 Practices Used by Farmers to Mitigate Soil Salinity

Farmers in the sampled governorates reported adopting key practices to limit, control or mitigate soil salinity, which can be categorized into three main groups:

1. *Crop Choices:* Selecting reclamation crops (e.g., rice), salt-tolerant and drought resilient crops.
2. *Agricultural Practices:* Practicing deep plowing, regular tillage, cleaning canals and drains, seasonal maintenance of branch drains, excavating farm drainage ditches, and ongoing upkeep of subsurface drains.
3. *Agricultural Procedures:* Regularly adding gypsum, conducting continuous soil leaching, deep plowing, halting cultivation in some seasons, using drainage water, communicating with extension services and practicing reciprocal irrigation.

The relative importance of these practices, as reported by farmers, is illustrated in Figure 22. These practices highlight the need for research and development to effectively address the issue of soil salinity. However, farmers indicated that financial constraints limit their ability to adopt these practices. As a result, they are calling for governmental or community assistance to manage soil and water salinity, conduct regular cleaning of canals and drains, and install effective drainage systems. They also seek support from the Egyptian Authority for Land Improvement Projects (EALIP) to help halt soil deterioration and implement awareness campaigns.

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2 Already, more than 95% of the agricultural land of the Nile Delta is provided with subsurface drainage systems.

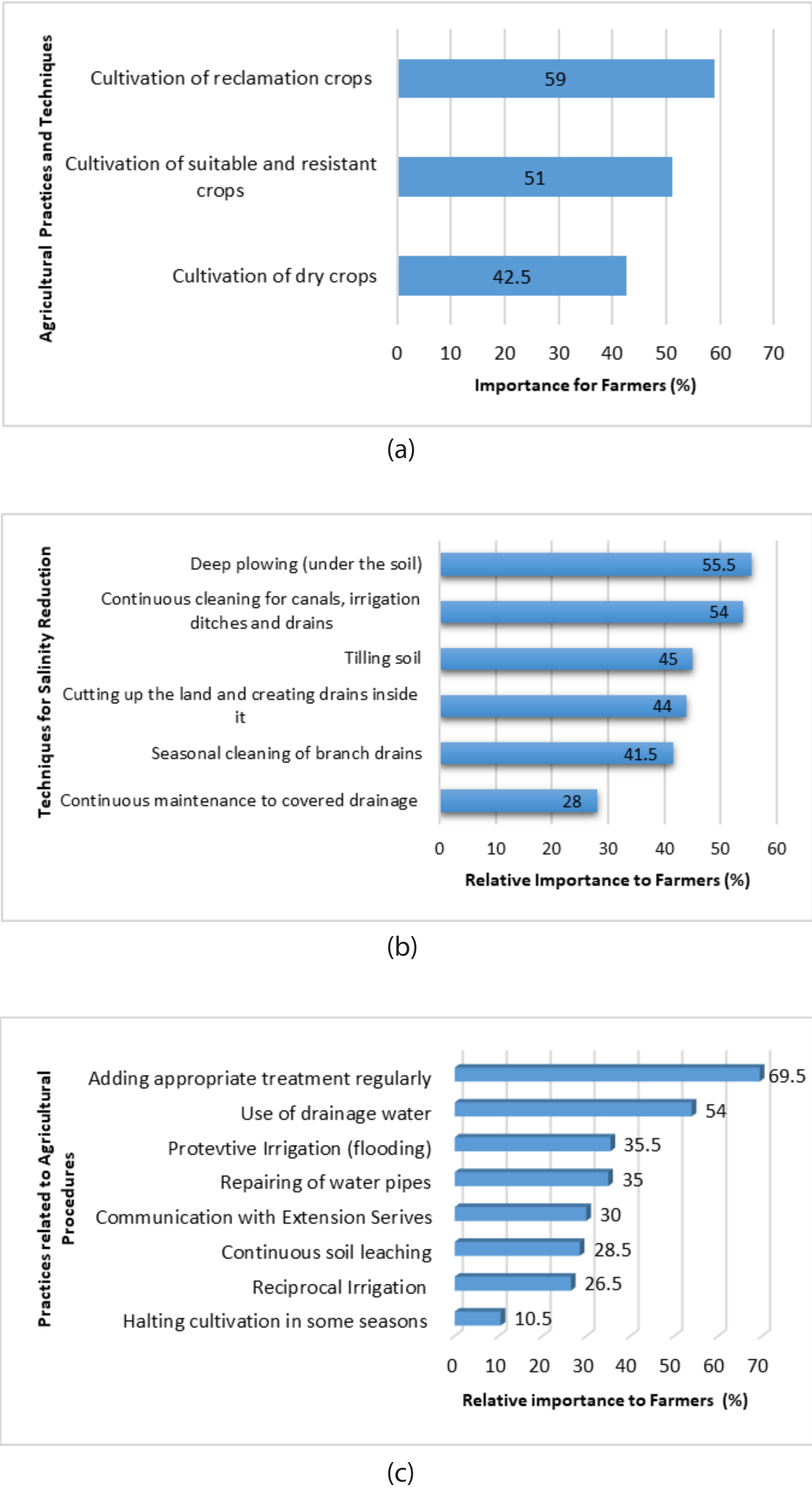


**Figure 22.** The relative importance of some agricultural practices and techniques used by farmers to reduce soil salinity

*Source:* Author's creation

Farmers in the four studied governorates employ various crop cultivation practices to combat soil salinization. The most common practice is the cultivation of reclamation crops, favored by 59% of farmers. The second most prevalent one involves growing salinity-resistant crops, particularly in the Qalyoubia governorate, where it is more widely adopted than cultivating dry crops. As shown in Figure 22-a, cultivating dry crops is the least prioritized measure for addressing soil salinity.

In the overall sample, deep plowing emerges as the most important agricultural practice (Figure 22-b). In contrast, continuous maintenance of subsurface drains ranked lowest, with only 28% of farmers considering it essential. Notably, in Qalyoubia, consistent maintenance of subsurface drains is highly valued – and 70% of farmers consider it necessary. Interestingly, farmers in Ismailia place less emphasis on deep plowing, tilling soil and continuous maintenance of covered irrigation, with only 12-24% viewing them essential. However, a whopping 76% of farmers among Ismailia's farmers highlight the continuous cleaning of canals, irrigation ditches and drains as a crucial practice.

Farmers employ a variety of agricultural practices to combat soil salinization, including protective irrigation—also known as flooding.  This practice varies significantly across the four governorates: it is used by 54% in Kafr El-Sheikh, 18% in Fayoum, 22% in Qalyoubia and 48% in Ismailia. These differences highlight how farmers from different regions tackle soil salinization. Continuous soil leaching is commonly practiced in Fayoum and Kafr El-Sheikh but is less frequent in Qalyoubia and Ismailia. In contrast, halting cultivation in specific seasons is the least favored approach, with no reports of this practice in Kafr El-Sheikh and only up to 18% in the other governorates. 69.5% of farmers rated regularly adding appropriate chemical treatments, such as gypsum amendments, as the most important practice, a popularity closely followed by drainage water use at 54%. Communication with extension services is less popular among farmers (Figure 22-c).

## 6.5 Economic and Social Aspects of Drainage and Land Improvement

Egypt's drainage policy adopts a cost recovery approach with a social dimension. It allows farmers to repay the investment cost over 20 years with no interest and includes a 3-year grace period following the installation of subsurface drains. This grace period enables farmers to reap the benefits of improved drainage before they start repayments. This effectively reduces their financial burden to about half of the investment cost.

The cost recovery policy for subsurface drainage is based on a study conducted in 1984 by the Agricultural Economic Research Institute of the MALR, in collaboration with the Egyptian Public Authority for Drainage Projects (EPADP). The study assessed farmers' economic ability to pay for subsurface drains in (Kotb et al. 2000). It revealed that the net income from improved crop production was 11-14% higher in tile-drained farms compared to non-drained farms in the Nile Delta and 9-16% higher in Upper Egypt.

An investigation into the socio-economic advantages of implementing subsurface drains in 2001 found that net annual farm income on traditional farms rose by approximately USD 200 to USD 350 per hectare, representing a 25% to 40% increase. Gross production values also improved, increasing by USD 500 to USD 550 per hectare based on actual yield and farm-gate prices for primary and secondary products over successive years. The same study estimated that the annual GDP contribution of drainage in Egypt is 1.3%, amounting to USD 0.9 billion (Ali et al. 2001).

Another significant social and economic benefit of installing subsurface drains is the provision of immediate compensation to farmers if their planted fields are damaged during the construction phase. This compensation is determined based on the market price of the harvested product and the cost is included in the investment recovery cost, which is repaid by all beneficiaries in installments (Abdel-Dayem et al. 2007). Additionally, land improvement activities led by the Egyptian Authority for Land Improvement Projects (EALIP) have resulted in an increase in crop yield by 10-12% due to the reduction in soil salinity by 18.5-60%, decrease in soil sodicity by 9.7-25.5%, lowering of soil compaction by 10-40% and breaking sub-soil hard pans[3].

[3] EALIP website at https://ealip.weebly.com/15711606158815911577-157516041607161015741577.html

## 6.6 Development of Crop Yield During 1989 – 2022

A key question from the analyses of Components 1, 2 and 3 is: How has the change in soil salinity over the past 24 years affected crop yields, considering the interventions by the State and farmers to control soil salinity? Data on the yields of four strategic crops—rice, maize, wheat and cotton—were collected for the years 1987, 1998, 2018 and 2022 from the Department of Statistics of the Directorate of Agriculture in the four governorates, as presented in Tables 8 through 11. These crops vary in their tolerance to salinity, with maize being sensitive to salt and cotton being more tolerant. The tables group the governorates based on their location in the East, Middle or West Delta, with relevant historical data on crops' yields, from which a trend analysis for each governorate could be derived.

**Table 8.** Historical records of corn (maize) yield in different governorates

| Region | Governorate | Salinity Tolerance dS/m | 1989 | 1998 | 2018 | 2022 |
|---|---|---|---|---|---|---|
| East Delta | Daqahliya | | 3.81 | 3.90 | 3.42 | 2.63 |
| | Sharqiya | | 3.47 | 3.49 | 3.18 | 1.95 |
| Middle Delta | Kafr El-Shekh | $EC_e$ =1.7 | 3.32 | 3.30 | 3.02 | 2.13 |
| | Gharbia | $EC_w$ =1.1 | 3.32 | 3.30 | 3.29 | 2.22 |
| | Monofiya | | 3.41 | 3.37 | 3.48 | 2.01 |
| West Delta | Behayra | | 3.58 | 3.42 | 3.56 | 2.40 |

$EC_e$ = salinity of saturated soil extract, $EC_w$ = salinity of irrigation water

*Source:* Agricultural Economics Research Institute database

**Table 9.** Historical records of rice yield in different governorates

| Region | Governorate | Salinity Tolerance dS/m | 1987 | 1998 | 2018 | 2022 |
|---|---|---|---|---|---|---|
| East Delta | Daqahliya | | 2.16 | 3.70 | 3.64 | 3.80 |
| | Sharqiya | | 2.54 | 3.70 | 3.38 | 3.33 |
| Middle Delta | Kafr El-Shekh | $EC_e$ =3.0 | 2.30 | 3.52 | 3.99 | 3.98 |
| | Gharbia | $EC_w$ =2.0 | 2.84 | 3.60 | 3.71 | 3.77 |
| | Monofiya | | 3.03 | NA | NA | 3.13 |
| West Delta | Behayra | | 2.85 | 3.70 | 3.08 | 2.89 |

*Source:* Agricultural Economics Research Institute database

**Table 10.** Historical records of wheat yield in different governorates

| Region | Governorate | Salinity Tolerance dS/m | 1989 | 1998 | 2018 | 2022 |
|---|---|---|---|---|---|---|
| East Delta | Daqahliya | | 2.23 | 3.02 | 2.53 | 2.50 |
| | Sharqiya | | 1.68 | 2.71 | 2.49 | 2.77 |
| Middle Delta | Kafr El-Shekh | $EC_e$ =6.0 | 2.01 | 2.86 | 2.53 | 2.50 |
| | Gharbia | $EC_w$ =4.0 | 2.04 | 2.74 | 2.52 | 2.50 |
| | Monofiya | | 2.28 | 2.73 | 3.08 | 3.01 |
| West Delta | Behayra | | 1.89 | 2.77 | 2.75 | 2.83 |

*Source:* Agricultural Economics Research Institute database

**Table 11.** Historical records of cotton yield in different governorates

| Region | Governorate | Salinity Tolerance dS/m | 1987 | 1998 | 2018 | 2022 |
|---|---|---|---|---|---|---|
| East Delta | Daqahliya | | 6.68 | 3.77 | 9.56 | 9.08 |
| | Sharqiya | | 6.41 | 4.58 | 8.88 | 8.53 |
| Middle Delta | Kafr El-Shekh | $EC_e$ =7.7 | 5.94 | 4.55 | 7.12 | 7.56 |
| | Gharbia | $EC_w$ =5.1 | 7.28 | 4.85 | 8.94 | 8.66 |
| | Monofiya | | 7.23 | 6.00 | 9.24 | 10.28 |
| West Delta | Behayra | 2.85 | 6.23 | 6.00 | 9.24 | 10.28 |

*Source:* Agricultural Economics Research Institute database

The data in Tables 8 to 11 reveal an increase in crop yield across various geographical locations of the Nile Delta from 1989 to 2022. With the exception of cotton, the yield of all crops has increased since 1998, regardless of the soil and water salinity levels reported in national and field-level assessments—even in the northern governorates of the Delta. Cotton yield performance was notably different in 1998, which was a poor year for cotton production; however, this decline was not due to soil salinity, as cotton yields improved in 2018 and 2022. The lack of a significant impact from soil and water salinity on crop yields can be attributed to several factors:

- Most of the water used for irrigation has a salinity level below the threshold value established by the FAO (1985) crop tolerance guidelines, which defines the electrical conductivity (ECe) limit for achieving 100% relative crop yield.
- The salinity of canal water is sufficiently low to effectively leach residual salts left from supplementary irrigation using drainage water or groundwater.
- Excess irrigation water that percolates through the soil profile, using conventional irrigation methods (e.g., basin or furrow irrigation) often satisfies the leaching requirements for the cultivated crops.
- All old lands of the Delta and Nile Valley are equipped with subsurface field drainage systems that effectively control water table depth, promote a well-aerated root zone and remove leached salts from the soil profile.
- Farmers routinely engage in effective soil improvement activities, such as plowing, land leveling and adding gypsum, particularly in areas with saline-sodic soils. These activities are well coordinated with the drainage program.
- Dynamic agricultural research in Egypt over the past 50 years has led to the development of new salt-tolerant crop varieties and the introduction of effective agricultural practices adapted for salinity control, such as elevated beds.
- Egyptian farmers have inherited great farming skills, turning challenges into opportunities to increase crop yields and better support their livelihoods. They have adapted to salinity by managing water applications in small basins, including heavy water applications before sowing crop seeds.
- According to the FAO database, Egypt's grain crop yield per unit area is among the highest in the world, particularly for rice, wheat, and maize.
- The yield data for the northern governorates' aggregate yields across the entire governorate, which may mask lower crop yields at the district or local levels, particularly in areas with extreme soil salinity.

The crop yield data presented in Tables 8 to 11 is expected to alleviate concerns and misconceptions regarding the impact of soil salinity on crop yield and food security in Egypt, particularly given the stable levels of soil salinity in most agricultural areas (Figure 12). However, it is important to recognize the ongoing risk of increasing salinization in coastal zones around the Mediterranean, Lake Qaroun, Siwa and newly reclaimed lands, as these areas rely entirely on drainage water for irrigation. Constant monitoring and future research and development efforts are essential for these regions. Moreover, the assessment results and yield data indicate that certain localities may experience soil salinity issues due to unfavorable natural or man-made conditions.

## 7. Governance Framework of Saline Landscapes in Egypt

Good governance requires the participation and collaboration of all institutional actors to achieve their common objectives. It relies on a clear legal framework, comprehensive policies, enforceable regulations, capable and accountable institutions, effective implementation and citizen-based oversight mechanisms. Additionally, it is important to consider the connections among these entities. Therefore, evaluating the governance system should focus on formal actors in sectors such as water and agriculture, while also recognizing the role of informal actors, systems of rules, norms and traditions that influence the behavior of individuals and organizations (UN ESCAP, 2009).

Component 4 of the project focused on assessing the governance system for managing saline landscapes in Egypt. The objective was to identify potential improvements that could enhance the productivity of these areas. This analysis connects technical solutions with existing institutional, social, political and legal frameworks. Effective governance of saline landscapes requires more than just enacting policies and regulations; it necessitates a holistic approach that integrates scientific research, community involvement and the harmonization of policies across multiple sectors and levels of government.

The governance system in Egypt is characterized by a centralized authority that plays a vital role in managing saline landscapes. Component 4 analyzes this governance system through three steps: (i) assessing the water and agriculture actors involved in managing saline landscapes in Egypt, (ii) investigating the governmental approach to managing these landscapes and (iii) mapping the roles and responsibilities of key stakeholders. The study was based on a literature review, structured interviews and discussions with officials from key governmental and relevant entities. Additionally, a consultative workshop was held to present and discuss findings, as well as gather additional insight from participants.

The interplay between Egypt's political economy and governance system presents a unique set of challenges and opportunities for managing saline landscapes. Together, they influence the country's capacity to address water and soil salinity, which is critical for ensuring food security, protecting livelihoods and maintaining ecological balance. The governance system and institutional framework in Egypt play a pivotal role in managing agricultural salinity. The effectiveness of policies and salinity control initiatives largely depends on the coordination among various public agencies. While the centralization of authority in Egypt can facilitate swift policy implementation, it may also result in bottlenecks and inefficiencies if local needs and conditions are not adequately addressed.

### 7.1 Saline Landscape Management Policies

Managing saline landscapes in Egypt is a complex task influenced by several important factors. Effective management necessitates careful consideration of resource allocation, funding and the prioritization of projects aimed at controlling water and soil salinity. The country's approach to agricultural policies is primarily shaped by governmental agencies, which are responsible for enforcing regulations, conducting research and implementing large-scale projects. Despite the diversification of Egypt's economy, agriculture remains a significant sector, employing about 28% of the population and constituting a substantial part of the GDP (USAID, 2022). The sector is crucial not only for supplying food to the growing domestic population, but also as a source of export revenue from crops such as cotton, rice, vegetables, fruits, onions and potatoes. Developing new, potentially productive irrigated lands through land reclamation has become essential to meet the nation's current and future needs for food and fiber.

Agricultural lands in Egypt rely entirely on irrigation, which makes them inherently susceptible to soil salinity due to the lack of effective rainfall and high evaporation rates. The escalating water scarcity in the country places immense pressure on the agricultural sector, which consumes approximately 85% of Egypt's freshwater resources. This competition for limited water resources has led the agricultural sector to repeatedly reuse Nile water, despite the associated risk of soil salinization. Apart from the risk of secondary salinization from irrigation, some areas also contend with primary salinity due to the parent soil material. This is particularly evident in regions with marine sedimentary soil near the northern lakes and the seashore of the Delta (Figure 2).

Policies aimed at controlling the risk of secondary salinization became essential following the construction of the Aswan High Dam, which enabled a stable year-round water supply for irrigation and the reclamation of new lands. Several governmental policies have been implemented in Egypt to manage saline landscapes and mitigate the adverse effects of water and soil salinity on crop production. Three significant policies regarding salinity management emerged in Egypt. Two of these policies were introduced in the post-Aswan High Dam era, focusing on salt-affected soils in the old lands by providing drainage services and land improvement practices. The third policy was enacted when water demands began to exceed the fixed supply of Nile water, leading to the consideration of drainage water reuse as a non-conventional water resource to bridge the gap.

The anticipated rise in the water table due to continuous irrigation prompted the MWRI to launch a land drainage policy in 1970. The primary objective of this policy was to equip all old agricultural lands with subsurface drainage networks. Subsurface drainage was selected for its effectiveness in controlling the water table below the root zone, removing salts accumulated in the soil profile, preserving productive land that would otherwise be lost to open drains and requiring minimal maintenance.

The implementation of this drainage policy has been successful in protecting Egypt's fertile soil from salinity degradation (Abdel-Dayem et al. 2007). Currently, nearly 100% of Egypt’s irrigated old land is equipped with subsurface drainage systems (Ritzema and Abdel-Dayem, 2011). This initiative has resulted in yield increases of up to 20% for major crops and has encouraged many farmers to switch to higher-value crops (World Bank, 2008).

The second policy, aimed at enhancing crop productivity through land, was issued in 1971 by the MALR. Its primary objective was to reclaim salt-affected soils and improve the productivity of saline-sodic soils, particularly in the northern parts of the Delta where heavy clay soils are prevalent. The policy focused on equipping farmers with the knowledge and resources necessary to implement land improvement programs. These programs included deep plowing to break hardpans that impede water percolation and plant growth, land leveling to enhance irrigation efficiency and the addition of agricultural gypsum to replace exchangeable sodium with calcium, which facilitates the leaching of sodium out of the soil through constructed drain ditches. The impact of this policy was evident in the agricultural productivity of the Northern Delta, as reflected in the comparable crop yields of Kafr El-Sheikh with the rest of the Delta governorates, as seen in Tables 6 through 9.

In response to the growing gap between water supply and demand, the MWRI initiated a third policy in the late 1970s to promote the sustainable reuse of drainage water for irrigation (Amer and de Ridder, 1989; FAO, 1992). Since drainage water contains salts leached from cultivated land, the policy emphasized the need for thorough monitoring of both the quantity and quality of drainage water. It also called for the development of guidelines for using drainage water, either directly or after mixing with freshwater, to ensure that its salt content remains within safe levels for irrigating crops. A research program was launched to develop these reuse guidelines, using a customized simulation model “Simulation of Water Management in the Arab Republic of Egypt (SIWARE)” for the Nile Delta.

At present, El-Fayoum, the Nile Valley and the Nile Delta officially reuse approximately 13 BCM of drainage water for irrigation. However, untreated municipal and industrial wastewater discharged into open agricultural drains poses a risk to the quality of drainage water. To tackle this issue and enhance the availability of water for reclaiming newly discovered land in Sinai and the northwest Delta, three large treatment plants have recently been constructed in both the eastern and western parts of the Delta. These plants do not specifically address the salt content of the drainage water; instead, they focus on treating biological contaminants and heavy metals to a tertiary level.

## 7.2 Legislative Framework with Reference to Salinity

Legislative frameworks transform policies into governing laws. Local and federal laws cover aspects such as domestic use, resource ownership, permits and user rights (GWP, 2002). Essentially, the legal framework defines the responsibilities and rights of all parties involved, including public and private organizations. It provides prescriptive guidelines for resource management and development that promote the public interest (GWP, 2002).

The aforementioned policies for managing saline landscapes—specifically the Agricultural Land Drainage Policy, Land Improvement Policy and Drainage Water Reuse Policy—have been translated into laws and regulations. A summary of these laws is provided in Table 12.

**Table 12.** Laws governing saline landscapes management

| Law No. and Date | Law – objectives and consequences |
|---|---|
| Law 178 of 1952 | The Land Reform law has led to the fragmentation of agricultural land ownership, creating challenges in the distribution of irrigation water at the farm level (Agrarian Reform Organization, 1957). |
| Law for subsurface drainage, execution year 1956 | A law was enacted assigning responsibility for the implementation of field drainage to the government. This change was necessary to facilitate the execution of subsurface drainage systems (SSD), as field irrigation and drainage fall under the farmer's responsibility (World Bank, 1983). |
| Law 12 of 1984 | This law served as the principal piece of legislation governing irrigation and drainage in Egypt until the issuance of Law No. 147 of 2021[4]. https://www.fao.org/faolex/results/details/en/c/LEX-FAOC121428 |
| Law 213 of 1994 | This law establishes the legal framework for farmers' participation in irrigation management at the *Mesqa* (tertiary canals) and farm levels through the formation of Water User Associations (WUAs). It also amends certain provisions of the Irrigation and Drainage Law No.12 of 1984[5]. https://www.ecolex.org/details/legislation/law-no213-of-1994-amending-some-provisions-of-the-irrigation-and-drainage-law-no12-of-1984-lex-faoc170699/ |
| Law 147 of 2012 (Water Management Law) | An updated law that replaced Laws No. 213 of 1994 and Law No. 12 of 1984 with the goal of establishing efficient irrigation, drainage, administration and distribution systems for water. It places greater emphasis on groundwater use regulations and enhances the ability to form water user organizations at the branch canal, district, governorate and national levels, including the establishment of the Water User Federation[6]. |
| Law 48 of 1982 | This law protects the water channels and the Nile River from pollution by prohibiting discharges into the Nile, canals, drains, and groundwater without a license issued by the MWRI[7]. |
| Ministerial Decree No. 8 of 1982 | This decree establishes standards for effluents discharged into water bodies and imposes fines for violators[8]. |
| Ministerial Decree No. 92 of 2013 | This decree amends Ministerial Decree No. 8 of 1982, which pertains to the executive regulations of Law No. 48 of 1982[9] https://www.ecolex.org/details/legislation/ministerial-decree-no-92-of-2013-amending-the-ministerial-decree-no-8-of-1982-on-the-executive-regulations-of-law-no-48-of-1982-concerning-the-protection-of-the-nile-river-and-water-channels-from-pollution-lex-faoc122154/?. |

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[4] Food and Agriculture Organization, "Ministerial Decree No. 92 of 2013 (amending Ministerial Decree No. 8 of 1982) – Protection of the Nile River and Water Channels from Pollution," FAOLEX, accessed December 8, 2025, https://www.fao.org/faolex/results/details/en/c/LEX-FAOC121428

[5] Law No. 213 of 1994, amending some provisions of the Irrigation and Drainage Law No. 12 of 1984, "Law No. 213 of 1994 — Amending Some Provisions of the Irrigation and Drainage Law No. 12 of 1984," accessed December 8, 2025, https://www.ecolex.org/details/legislation/law-no213-of-1994-amending-some-provisions-of-the-irrigation-and-drainage-law-no12-of-1984-lex-faoc170699/

[6] Egypt, Law No. 147 of 2021, FAOLEX, accessed December 8, 2025, https://www.fao.org/faolex/results/details/en/c/LEX-FAOC212586

[7] Egypt, Law No. 48 of 1982 (PDF), FAOLEX, accessed December 8, 2025, https://faolex.fao.org/docs/pdf/egy18642.pdf

[8] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC121620/

[9] Ministerial Decree No. 92 of 2013 (amending Ministerial Decree No. 8 of 1982), Protection of the Nile River and Water Channels from Pollution, accessed December 8, 2025, https://www.ecolex.org/…faoc122154

## 7.3 Financing and Investment for Saline Landscapes Management

It can be quite challenging to report on the number of investments in landscape management due to its complexity. Investments in this area involve a combination of multiple interventions that may be funded separately or included in the budgets of various ongoing projects. One of the main challenges is obtaining data on public investments, especially considering the limited information available regarding private investments. The Ministry of Finance provides annual budgets to the MWRI and MALR, which cover the majority of public investments.

In the 2023-2024 fiscal year, approximately 2.45 billion United States dollars (USD) were invested in the irrigation and agriculture sectors, representing a 71% increase over the previous fiscal year—with around 44% attributed to the private sector. The economic and social development plan for the fiscal year 2024/2025 estimates investments for agricultural and irrigation activities at roughly 179 billion EGP, which marks an increase of about 60% over the investments made in 2023/2024. Public investments account for approximately 90 billion EGP, making up roughly 50% of the total investments made in the sector. In the planned year, these operations are expected to contribute around 12% to the GDP[10].

Up until the year 2000, Egypt had invested approximately USD 1.15 billion in land drainage projects, according to a review of the World Bank's drainage portfolio (Abdel-Dayem, 2004). This investment covered drainage projects spanning 3,150,000 hectares, excluding costs for operation and maintenance. Public investments, allocated through successive five-year and annual plans, served as the primary funding source for the drainage program. These projects were executed in phases, funded by direct government contributions and external loans from international financial institutions, including the World Bank, the African Development Bank and the German Kreditanstalt für Wiederaufbau (KfW). Additionally, the Dutch and German governments provided grants for research, technical assistance, capacity building and institutional strengthening to the Drainage Research Institute (DRI) and the EDADP (Abdel-Dayem et al. 2007).

## 7.4 Actors Involved in Saline Landscape Management

Component 4 of the project examined the roles and responsibilities of various actors involved in managing saline landscapes in Egypt. This analysis was conducted through interviews with relevant governmental entities and a consultative multi-stakeholder workshop. The study classified the actors into state and non-state categories based on their mandates, roles and responsibilities, grouping them into four areas: policymaking, implementation, monitoring and support.

State actors are primarily responsible for developing the overarching policy and regulatory framework, building infrastructure and monitoring performance, while non-state actors focus more on providing services and advocacy. The categorization of actors is based on their levels of responsibility, interest and influence, aiming to provide a strategic framework for understanding their roles in addressing soil salinity in Egypt.

A) Actors with primary responsibilities:

-- *The Egyptian Public Authority for Drainage Projects (EPADP)*

In 1970, a public authority was established within the MWRI to implement the drainage policy, launching the first drainage project in the Nile Delta. This authority has since evolved into the EPADP, which now oversees the national drainage program. This program encompasses various projects co-financed by international financial institutions, primarily led by the World Bank. Key components of the program include the installation of subsurface drains (SSDs), deepening and widening existing main open drains and constructing drainage pump stations to service all the old, irrigated lands (Abdel-Dayem and El-Safty, 1993).

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10 Business Today Egypt, "EGP 2 TN: Egypt's overall investment structure for FY2024-2025," Business Today Egypt, accessed December 8, 2025, https://www.elbalad.news/6220369https://www.businesstodayegypt.com/Article/1/5815/EGP-2TN-Egypt%E2%80%99s-overall-investment-structure-for-FY2024-2025

-- *The Drainage Research Institute (DRI)*

The Drainage Research Institute (DRI), established in 1976 as part of the National Water Research Center (NWRC) within the Ministry of Water Resources and Irrigation (MWRI), supports the implementation of drainage projects through a dedicated research program. DRI focuses on developing design criteria for subsurface drainage systems (SSDs) and testing new drainage technologies in pilot areas. Additionally, DRI monitors and evaluates the quantity and quality of drainage water by maintaining a regional monitoring system at key points along the open drainage system in the Nile Delta. The institute has also developed guidelines for the sustainable reuse of drainage water in irrigation and conducts research to assess the long-term impacts of this reuse on soil salinity and crop yield (Roest, 1998).

-- *Drainage Collectors Associations (DCAs)*

The Drainage Collectors Associations (DCAs) were established by the EPAPD in the 1990s, in accordance with the Water Management Law (147/2021), drawing parallels with WUAs in irrigation. Although more than 3,000 DCAs have been formed with the mandate of cleaning manholes and performing minor repairs, their effectiveness has been limited by a lack of incentives and insufficient interest among farmers to work collectively in maintaining SSD systems.

-- *The Egyptian Authority for Land Improvement Projects (EALIP)*

Following the construction of the Aswan High Dam, the reclamation and improvement of saline-sodic soils, particularly in the northern Delta, became a government priority. To enhance agricultural knowledge among farmers, the government established the EALIP under the Ministry of Agriculture and Land Reclamation (MALR). EALIP's mandate includes supporting farmers by conducting field and laboratory soil analyses to assess land improvement needs and implementing soil enhancement measures such as deep plowing, subsoiling, laser land leveling, the addition of agricultural gypsum, digging drainage ditches and leaching salts. Currently, EALIP extends its services to agricultural lands across all governorates, focusing also on improvements to on-farm irrigation and the maintenance of farm open drains. The authority coordinates with the Egyptian Public Authority for Drainage Projects (EPADP) to prevent overlap and conflicts in drainage system implementation while providing awareness programs to the farming community through MALR's Agricultural Extension Service.

-- *The Soil, Water and Environment Research Institutes (SWERI)*

SWERI is part of the Agricultural Research Center (ARC) within the MALR. SWERI conducts research to support land improvement and reclamation, focusing on the development and testing of enhanced on-farm irrigation and drainage practices, as well as improving land preparation to mitigate the effects of salinity on crops. SWERI operates field experimental sites in various geographical locations, with the most notable site in Sakha, Kafr-El-Sheikh, where applied research is conducted and field staff and farmers receive training. In response to the growing challenges posed by climate change, MALR's research efforts now focus on applying sustainable practices to adapt to water scarcity by leveraging advanced agricultural science and technology.

-- *The Farming Community*

The farming community is the most crucial stakeholder in managing saline landscapes, as it is the most economically and socially impacted by water and soil salinity. Therefore, it stands to benefit the most from effective management and control efforts. Although mentioned last in this section, all the institutions listed above ultimately aim to serve and support the farming community.

B) Actors with secondary responsibilities

-- *The Irrigation Sector (IS)*

The Irrigation Sector of the MWRI is responsible for distributing and allocating irrigation water through an extensive canal network that spans from the main stem and branches of the Nile to the primary and branch canals, ultimately reaching the turnouts of *mesqas* (tertiary canals). Water allocation per unit area is determined based on plant consumptive use and leaching requirements. Additionally, the IS oversees the official reuse of drainage water.

-- *The Ground Water Sector (GWS)*

The GWS of the MWRI is responsible for monitoring and issuing permits for groundwater use, both for agricultural and domestic purposes. GWS takes into consideration water quality, including salinity and the safe yield of aquifers. The new Water Resources and Irrigation Law (Law 147/2021) give the GWS greater authority over groundwater usage and the management of various aquifers. Additionally, the law imposes strict fines on those who violate these regulations.

-- *The Irrigation Improvement Sector (IIS)*

The IIS is responsible for planning and implementing irrigation improvement and modernization projects designed to enhance irrigation efficiency. The IIS also establishes WUAs and provides training for their members. Additionally, the IIS offers technical support to MALR for the improvement of *mesqas* and *marwas*.

-- *The National Water Research Center (NWRC)*

The NWRC of the MWRI encompasses research institutes focused on salinity management. One such institute is the Research Institute for Groundwater (RIGW), which monitors groundwater levels and quality, to assess its potential and develop a hydrogeological map of the country. RIGW conducts research to create sustainable groundwater exploitation scenarios and to evaluate the extent of seawater intrusion. Another institute under NWRC is the Water Management Research Institute (WMRI), which determines the crop water requirements for all cultivated crops across Egypt's different climate zones. WMRI also introduces and tests new irrigation methods for enhancing water efficiency and effective salt leaching, while exploring the integration of renewable energy into irrigation practices.

-- *The Irrigation and Drainage Advisory Service (IDAS)*

The IDAS, established within the IIS of the MWRI, aims to enhance farmers' involvement in irrigation water management. IDAS provides training and knowledge to facilitate the adoption of modern irrigation and drainage systems.

-- *The Agricultural Research Center (ARC)*

The ARC of the MALR, through its research institutes, including the Field Crops Research Institute (FCRI) and the Agricultural Genetic Engineering Research Institute (AGERI), focuses on developing new salt and drought-tolerant crop varieties. Additionally, the ARC operates a Remote Sensing (RS) unit dedicated to mapping agricultural land use, assessing soil salinity and conducting agricultural economic research.

-- *The Department of Extension and Agricultural Management (DEAM)*

DEAM supports the farming community in areas such as crop production, marketing, distribution, and the adoption of modern farming techniques. DEAM collaborates with the Irrigation and Drainage Advisory Service (IDAS) of the MWRI to provide unified advice and support to farmers.

-- *The Desert Research Center (DRC)*

The DRC of the MALR conducts research aimed at promoting the ecological, social and economic sustainability of desert communities in Egypt. Its mission is to improve the well-being of new desert settlers through research, training and activities that focus on sustainable development in arid regions.

-- *The National Authority for Remote Sensing and Space Sciences (NARSS)*

The NARSS was established under Decree No. 1427 of 2022, within the Ministry of Higher Education and Scientific Research. Its mandate is to advance remote sensing research and innovative studies to support the government in various aspects of sustainable development.

-- *The Agriculture Cooperatives (ACs)*

ACs were established in the early 20th century as "Agricultural Cooperative Syndicates" to unite farmers, facilitate access to agricultural inputs, enhance production and support rural development. The primary goal of ACs is to provide essential agricultural services to farmers, including fertilizers, approved seed cultivars and agricultural gypsum, as well as to conduct agricultural awareness programs. Recent legislation, specifically Law 204/2014, has empowered ACs to establish shareholding companies and pursue profit-seeking projects, thereby fostering organization and funding efforts. Today, each village has an AC dedicated to serving the local farming community (Ghonem, 2019).

C) Interested actors

-- *International Funding and Development Organizations*

International institutions such as the World Bank, the African Development Bank, the Islamic Bank and the European Union play a significant role in financing Egypt's land drainage and irrigation improvement projects.

-- *Development Partners*

The Drainage Research Institute (DRI) has received support from the Dutch government for its research programs on drainage and drainage water reuse through the Egyptian-Dutch Advisory Panel on Land Drainage. Additionally, the German government, through KfW, is helping to strengthen EPADP's institutional capacity.

-- *Regional and International Research and Development Organizations*

International research organizations, such as the International Water Management Institute (IWMI), the International Center for Agricultural Research in the Dry Areas (ICARDA), the Food and Agriculture Organization (FAO) and the Mediterranean Agronomic Institute of Bari (CIHAM-Bari), actively support research and development programs for land and water management in collaboration with Egyptian institutions.

-- *National Universities and Research Centers*

Several Egyptian Universities and research centers outside the MWRI and MALR, conduct research related to water and soil salinity, particularly within their geographical regions.

-- *The Private Sector (PS)*

The private sector encompasses contractors involved in the construction and maintenance of modern irrigation and drainage systems, commercial companies and suppliers of materials and equipment and private firms engaged in agricultural production and agribusiness.

Mapping the actors involved in managing saline landscapes reveals a complex network of stakeholders at both central and local levels. At the central level, analysis, interview results and workshop discussions emphasize the dominant roles of MWRI and MALR, along with their affiliated institutions. These entities are considered the "strategic actors" due to their significant interest, influence and ability to mobilize resources, which can either support or hinder change.

The interviews and discussions also indicated that institutions such as financial bodies, international and regional organizations and the private sector are classified as "secondary actors," as they engage only when invited by the primary actors. In contrast, farmers and research institutions are considered "relevant actors" because they have a substantial interest in salinity issues and are significantly impacted by them, yet they lack the power and resources to meaningfully change the existing dynamics.

The newly established participatory water management framework under Law No. 147/ 2021, represents a real turning point in Egypt's approach to water management. It is expected to play a pivotal role in decision-making and actions aimed at tackling challenges related to water management and agricultural production, including soil salinity.

In assessing the effectiveness of the governance system for managing saline landscapes in Egypt, stakeholder discussions revealed significant gaps in both approach and implementation. Decision-making institutions only partially embrace principles of engagement, coordination, transparency and accountability. There is substantial room for improvement, particularly with respect to involving non-state actors in policy and decision-making processes. Additionally, it is also essential to ensure full transparency in data and information sharing, as well as the decision-making process. The study recommends that policymakers acknowledge the growing involvement of non-state actors in governance arrangements and emphasizes the need for the development of new accountability mechanisms.

## 8. Summary of the Main Findings of the Project

The four components discussed aimed to provide a comprehensive understanding of the current state of soil salinity, its causes and, its temporal and spatial distribution. They also assessed the impact of soil salinity on crop yield, examined the actions taken to control salinity and identified the institutions responsible for managing saline landscapes, both directly or indirectly. Before proceeding to the final step of the project, which will outline a Roadmap for the future management of saline water, it is essential to summarize the key findings of these studies.

*Outcomes of Component 1: National baseline assessment for saline landscapes in Egypt: situation analysis and prediction of salinity at the national level*

In Egypt's hyper-arid climate, agriculture relies on surface and groundwater for irrigation. The Nile River provides approximately 98% of the country's freshwater, with about 85% of it used for irrigation. As water demands increase across all sectors, freshwater resources remain constant. To bridge the gap between supply and demand, agricultural drainage water is reused for irrigation. This drainage water is officially reused directly or mixed with canal freshwater to ensure safe salinity levels for most crops. However, farmers often resort to using drainage water directly when faced with shortages of freshwater. Except in areas near the northern lakes, the Mediterranean Sea and Lake Qaroun, the salinity of drainage water generally falls within the acceptable range for irrigation, as per FAO guidelines. Additionally, groundwater from the Nile aquifer, which comes from the downward seepage of water from canals and irrigated fields, is also used for irrigation.

Over the past 24 years, soil salinity maps—including the one produced in this study—reveal a consistent pattern of soil salinity distribution in the Nile Delta. In the southern part of the Delta, soils are predominantly non-saline. Salinity gradually increases towards the north, becoming highly saline near the northern lakes and the Mediterranean Sea. The distribution of soil salinity classes within the Delta, which range from non-saline to highly saline, has changed only slightly since 1989, coinciding with a significant increase in the reuse of drainage water for irrigation. Since 1998, soil salinity in the southern and central Nile Delta has approached equilibrium, as indicated by the stable salinity distribution observed between 1998 and 2023. In contrast, the northern region continues to experience rising soil salinity, due to seawater intrusion and an increased reliance on relatively saline drainage water for irrigation.

The soil salinity map created in this study through remote sensing, is the first to extend beyond the boundaries of the Nile Delta and to provide a comprehensive overview of Egypt's soil salinity nationwide. It highlights areas at risk of salinity, including the desert fringes of the West Delta, the lowlands around Lake Qaroun in Fayoum, Siwa Oasis and North Sinai. Additionally, the map identifies the current salinity situation in the high-risk Northern Delta area. This map will be crucial for developing future salinity management plans and interventions and will facilitate the evaluation of the long-term effects of redirecting more drainage water from the Delta to irrigate new lands in Sinai and the New Delta.

The complex and dynamic nature of soil salinity highlights the impact of both natural and human factors influencing salinity levels over time. Key natural factors include increasing temperatures and rising sea levels, which reveal the intricate relationship between climate change and soil salinity in the Nile Delta. Higher temperatures will boost evaporation rates, leading to reduced soil moisture and accelerated salinization. Additionally, rising sea levels, driven by climate change, will result in land flooding, increase waterlogging, and greater seawater intrusion, which contaminate freshwater reserves in coastal aquifers.

These issues will exacerbate water scarcity and make leaching out accumulated salts all the more complicated. Continuous monitoring and the use of advanced simulation technologies are essential to effectively plan and adapt to climate change's impacts on soil salinity. However, the study also acknowledges the challenges of predicting future scenarios, particularly in complex systems like the Nile Delta, where changes in crop water requirements, irrigation quantity and quality, crop patterns, land use and water management may occur.

*Outcomes of Component 2: Situation analysis of water and soil salinity at field level: investigation of the current status of soil and water salinity in four selected governorates through a field study*

Field-level surveys of soil and water were conducted in four governorates with diverse land and water characteristics to complement the findings from the national-level study discussed in Component 1. The governorates included are:

- Qalyoubia: A Southern Delta governorate characterized by low levels of salinity in the water and the soil.
- Ismailia: Representing the Eastern Nile Delta, Ismailia is known for its light soil texture near a saline water body.
- Fayoum: Located in Middle Egypt, this governorate features a unique topography that contributes to salt accumulation in low-lying areas.
- Kafr El-Sheikh: A Northern Delta governorate with heavy-textured soils and shallow water tables, which relies heavily on drainage water for irrigation.

Soil samples were collected from various depths and locations, particularly near canals, wells and drains where irrigation water of different qualities was used.

In the Qalyoubia Governorate, soils are predominantly non-saline, with only slightly saline soils found near drains. Soils in the vicinity of industrial zones exhibit higher salinity levels, although they remain relatively low on the salinity scale. Irrigation water comes from canals, groundwater or a combination of both. While there are minimal differences in salinity levels between soil layers, salt tends to accumulate in the topsoil during the summer. Thankfully, this salt is typically washed away during the winter season.

Soil salinity in the Ismailia Governorate is similar to that of the Qalyoubia Governorate. Near residential areas, soil is slightly saline in both the surface and subsurface layers following the Nili season. In areas using drip irrigation, salinity increases with depth from the land surface during and after the summer, but it significantly decreases after the Nili and winter seasons. Winter rainfall, combined with the region's light-textured sandy soils, facilitates soil leaching, leading to a notable reduction in soil salinity. Unlike in Qalyoubia, where salts accumulated during the Nili season are leached out during land preparation for the next cropping season, some farmers in Ismailia proactively replace the top 0.5 meters of soil with fresh sand after the Nili and summer seasons, to create a non-saline root zone.

In the Fayoum Governorate, districts located on higher ground experience lower soil salinity levels due to their proximity to fresh canal waters. In contrast, low-lying districts face high soil salinity, influenced by a shallow water table near Lake Qaroun and reliance on drainage water for irrigation. Soil salinity in Fayoum is influenced by several factors, including the district's location relative to Lake Qaroun, the quality of irrigation water, climate conditions, soil composition and the types of crops grown.

While approximately 50% of the soil samples in the Kafr el-Sheik Governorate are classified as non-saline or slightly saline, there is still a non-negligible number of areas that exhibit saline and strongly saline soils. Farmlands in certain districts are irrigated with a mix of fresh and drainage water, while others rely exclusively on drainage water. Following the winter, rainfall and water availability in canals facilitate a leaching process that can alter soil conditions to non-saline, slightly saline or saline, depending on the initial salinity levels from summer. To manage soil salinity, farmers in Kafr el-Sheikh employ a range of methods, including mole drains, open drains, subsurface drains, gypsum application and organic fertilizers.

In all governorates, the quality of irrigation water when it comes to salinity, varies depending on the source—be it Nile water (typically fresh), drainage water or groundwater, which can have variable salinity levels. The predominant water source is specific to each location and directly impacts soil salinity. Salinity levels in canal water fluctuate along the stream, from the head to the tail end, possibly due to factors such as return flows, evaporation and mixing with drainage water. Generally, drainage water and shallow groundwater in most tested drains and wells are either non-saline or slightly saline. However, water near industrial or residential zones or close to saline water bodies may become moderately saline.

Rice cultivation in the North Delta plays a crucial role in managing soil salinity by flushing out salts from the soil profile. Additionally, the deep seepage from rice fields helps control seawater intrusion, making the practice of wet-foot rice cultivation a strategic choice in this region. Soil texture and local climate also significantly influence salinization levels. For example, the Baltim area, located near the Mediterranean Sea and essentially floats above seawater, maintains non-saline soils due to heavy winter rainfall. In the northern region, winter rains are crucial for leaching salt from the soil. Similarly, areas with high humidity see minimal salt accumulation, because reduced evaporation and evapotranspiration rates limit salt concentration.

In irrigated areas where untreated drainage water, a mix of fresh and drainage water or brackish groundwater is used for irrigation; salinity levels tend to be higher compared to those using Nile water. However, by using salt leaching and effective drainage, soil salinity generally stays within reasonable levels. Interestingly, drainage water salinity is typically higher in winter than in summer due to increased irrigation rates and lower irrigation efficiency, resulting in a greater volume of lower-salinity drainage water, especially in rice-growing areas. Overall, soil salinity is influenced by the quality of the irrigation water, specific soil characteristics, drainage and farming practices in each governorate.

*Outcomes of Component 3: Common practices and indigenous solutions for maintaining/improving the productivity of saline landscape: a farmers' survey in the four governorates to indicate these practices*

This study investigates the socio-economic effects of soil salinity on crop production and its impact on farmers' livelihoods in the same four benchmark governorates mentioned in Component 2. It uses a comprehensive approach that combines primary data collection and integrates both published and unpublished secondary data from various sources, including relevant studies and research. Additionally, the study explores how farmers use saline lands in these governorates and the significance of different crop varieties during the 2022-2023 production season. Farmers in each governorate participated through interviews and a series of focus group discussions. Various indicators were used to assess the impact of salinity on agricultural production, including crop patterns influenced by soil salinity, production input costs, irrigation costs and productivity per unit area of both saline and non-saline lands.

Saline soil increases production costs for all crops and reduces net revenues. Geographically, Kafr El-Sheikh recorded the highest average variable in production costs for most crops, while Qalyoubia had the lowest. Factors contributing to these differences include soil type, market access and the cost of agricultural inputs and labor. For specific crops, average variable production costs were notably higher for wheat, rice and cotton in both non-saline and saline soils. Generally, the highest net returns were for clover and rice in Kafr El-Sheikh and for cotton in Fayoum.

The ratio of net return to average variable cost is generally higher in non-saline soils compared to saline soils. This ratio is particularly favorable for clover in non-saline soils and to a lesser extent in saline soils, which may explain why *berseem* (clover) is more popular among farmers than wheat. Market prices have a significant influence on farmers' decisions about which crops to grow, even if it means they must incur higher costs to manage environmental constraints such as salinity.

When answering a questionnaire, farmers from all benchmark governorates reported facing challenges with soil salinity, though the degree of impact varied. These challenges include soil quality, groundwater levels, land surface elevation, the quality and availability of irrigation water, and the condition of land drainage systems. In particularly adverse conditions, these challenges can manifest as soil degradation, shallow groundwater levels, waterlogging, land surface flooding, poor water quality and irrigation water scarcity. Additional challenges include difficulties in obtaining loans, adopting modern technology and accessing technical guidance.

Respondents reported employing several key practices to limit, control and mitigate soil salinity. These include techniques such as salt leaching, deep plowing, tillage and land leveling. Farmers also add agricultural gypsum to the soil and allow land to rest between cropping seasons to promote aeration. To better cope with soil salinity, they cultivate crops with different levels of salt tolerance. Additionally, farmers use crop rotation and diversification as strategies to manage salinization in the root zone. Other practices mentioned include digging drainage ditches, cleaning canals and drains, performing seasonal maintenance on branch drains and maintaining subsurface drains. Furthermore, farmers expressed the need for additional government support to effectively address the causes and impacts of soil salinity.

The study also emphasized the significant impact of soil salinity on farmers' livelihoods from a socio-economic perspective. The ability to effectively manage salinity increases with the knowledge and experience gained through education, training or practical experience. Governorates with more experienced farmers, such as Fayoum and Kafr El-Sheikh, demonstrated superior salinity management even under challenging conditions. This was clearly reflected in the data on crop production across the four governorates.

Crop yields at the governorate level have remained stable since 1998, indicating that soil salinity has not led to a decline in production. This stability suggests that soil and water salinity are generally within tolerable limits for most crops, highlighting the effectiveness of both state and farmers' efforts to manage and control salinity when it exceeds acceptable thresholds. However, these interventions require significant investments in infrastructure and services, resulting in financial costs for farmers. Nonetheless, these costs are seen as justifiable as long as the harvest yields a satisfactory net return.

*Outcomes of Component 4: Assessment of the governance system for managing saline landscapes in Egypt: understanding the current governance system of saline landscapes in Egypt, in order to provide recommendations that would help in accelerating the rate of utilizing these areas and enhancing their productivity*

Egypt's governance system is characterized by a centralized authority which plays a crucial role in managing saline landscapes. Government agencies largely shape the country's agricultural policies and are responsible for enforcing regulations, conducting research, and implementing large-scale projects.

Following the construction of the Aswan High Dam, several policies were introduced to manage saline landscapes. One policy focuses on land drainage to protect agricultural land from waterlogging and salinity, while another aims to enhance the productivity of saline and saline-sodic soils. A third policy addresses the safe reuse of drainage water for irrigation, to meet growing water demands amid ongoing water scarcity. The continued implementation of these policies remains a primary strategic objective for managing saline landscapes.

Analyses of the roles and responsibilities of various actors categorized them into state and non-state actors. The mapping of these stakeholders in salinity management in Egypt reveals a complex web of duties shared among actors at the central and local levels.

Legal frameworks are created to transform policies into laws that define resource ownership, permits and user rights. Substantial investments have been made since implementing these three policies, which require a separate study to quantify the total investment to date. For example, Egypt invested approximately USD 1.15 billion in land drainage up to the year 2000, as per the World Bank’s review of its drainage portfolio. Investments in new drainage infrastructure and rehabilitation continue to this day.

Numerous institutions – public and private, formal and informal – are involved in managing saline landscapes in Egypt. Since the mid-20th century, two primary institutions have been established under the Ministry of Water Resources and Irrigation (MWRI) and the Ministry of Agriculture and Land Reclamation (MALR) with direct responsibilities for national salinity control. These institutions – the Egyptian Public Authority for Drainage Projects (EPADP) and the Egyptian Authority for Land Improvement Projects (EALIP) – continue to fulfill their mandates based on their monitoring mechanisms and the needs of farmers.

Several research institutes are tasked with developing criteria, technologies, predictions and guidelines, to support project implementation. Agricultural extension services and irrigation advisory services serve as intermediaries between government organizations and farmers. Additionally, farmer organizations and Water User Associations (WUAs) have been formed to engage farmers and delegate water management duties to end users.

Egypt's agriculture and water resource management attract interest and support from regional and international development institutions. These organizations collaborate with national entities and research institutes to conduct pilot projects, generate new knowledge, and introduce modern technologies.

While Egypt’s governance system for salinity management has several strengths, it also exhibits notable weaknesses. These include a lack of cooperation and coordination among institutions, poor communication between end-users and service providers, insufficient integration of development plans, limited transparency regarding ongoing and future programs, inadequate access to funding, a weak role for the private sector and other governance-related issues. Addressing these challenges will be essential for driving future improvements. Component 4 outlined a comprehensive set of recommendations to enhance the governance of saline landscape management in Egypt. These recommendations include improving data collection and processing systems, engaging stakeholder communities, involving the private sector and bridging the gap between science and policy. Additionally, the recommendations emphasize the importance of sharing knowledge and responsibilities, enhancing intra-ministerial coordination, increasing farmer participation and exchanging best practices both locally and internationally. The development of a coordinated monitoring system and the creation of guidelines for the sustainable management of newly reclaimed land are also key components of this initiative.

*Overall conclusion of the four components*

The salinity landscape is influenced by various causes and corresponding remedial actions designed to control salinity and mitigate its negative impact on crop yields. The interaction between these factors and their associated mitigation measures are crucial in determining the overall state of soil salinity in a given area. The Arab Organization for Agricultural Development (AOAD) study identified three distinct categories of salinity landscapes in Egypt:

1. The first category refers to the old lands in Upper Egypt, as well as the middle and southern Nile Delta. In these areas, a balance has been achieved between the factors causing salinity and the measures taken to address it. The danger of salinity resulting from irrigation with relatively saline water, is mitigated by state interventions, including subsurface drainage and soil improvement projects, in conjunction with the skills and expertise of farmers who employ effective salinity management practices.

2. The second category is found in the North Delta and around Lake Qaroun in Fayoum, where severe natural and human-made conditions prevail and are likely to worsen due to climate change. In this region, the imbalance between the causes of salinity and remedial actions has resulted in rising soil salinity levels. If these conditions persist, they could significantly reduce agricultural productivity.

3. The third category covers newly reclaimed lands, both under development or those planned for future expansion, particularly those that depend exclusively on drainage water and groundwater for irrigation. These areas are likely to face salinity challenges in the medium to long term, due to the substantial salt loads transferred to the new lands. Strengthening capacity for salinity management is therefore essential, especially as substantial investments are being directed toward treatment facilities and irrigation infrastructure in these regions.

In conclusion, these reports emphasize the need to mobilize scientific, technical, developmental and financial resources to maintain balanced salinity conditions in the old lands. It is also essential to develop policies and action plans to protect agricultural lands in the North Delta and newly reclaimed areas from salinity risks and potential productivity losses. The following section of the report presents a "Roadmap" aimed at enhancing and refining the governance system, to improve its effectiveness in managing saline landscapes in Egypt, which is critical for food security and sustainable development.

## 9. The Way Forward: A Roadmap for Managing Saline Landscapes in Egypt

This study concludes with the formulation of a "Roadmap" based on the findings from its four components. This Roadmap seeks to deepen the understanding of the salinity challenge and create a unified vision for the effective management of saline landscapes. It provides a strategic framework for developing an action plan that aims to transform Egypt's saline areas into sustainably managed, productive agricultural zones, thereby supporting food security, economic growth and environmental sustainability. Building on past successes, the Roadmap outlines four phases for future work, as depicted in Figure 23. Each phase includes specific actions, objectives, key stakeholders, required resources, coordination strategies and anticipated outcomes.

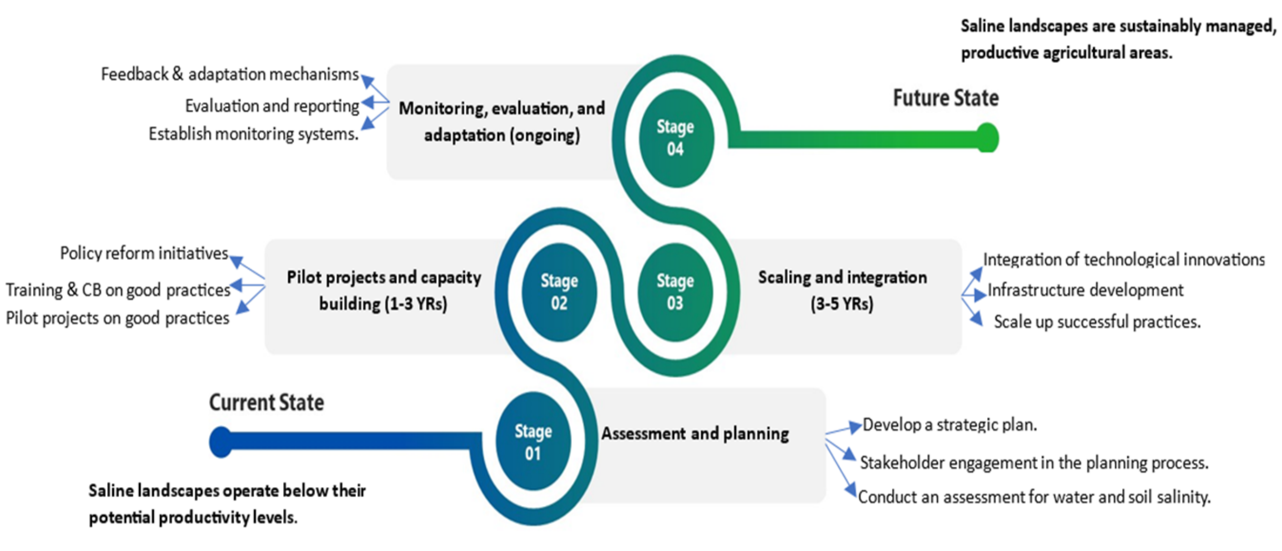


**Figure 23.** Roadmap towards sustainable management of Egypt's saline landscapes

*Source:* Author's creation

As a first step, the assessment of water and soil salinity will be continuously updated through ongoing and comprehensive dialogue with stakeholders. This will ensure that their perspectives, expertise and needs are reflected in future planning and implementation phases. A strategic plan will be developed with clear SMART objectives (Specific, Measurable, Achievable, Relevant, Time-bound) to enhance the productivity of saline landscapes.

The second step focuses on implementing pilot projects and building capacity over a period of one to three years, to promote best practices in managing saline landscapes. Specifically, the pilots aim to test and demonstrate innovative solutions for land reclamation, enhance water use efficiency, promote the cultivation of salt-tolerant crops and ultimately improve the productivity of saline landscapes in Egypt. These pilots will also provide training opportunities to strengthen key stakeholders' knowledge, skills and practices, including local farmers and community members. The outcomes of this training will support advocacy for policy reforms that create an enabling environment for the sustainable management of saline landscapes, promote best practices, restore productivity and conserve water.

The third step focuses on scaling up and integrating successful practices and policy reforms to enhance overall agricultural productivity and sustainability. Over the course of three to five years, this phase plans to expand the use of proven methods, to combat salinity identified through research and pilot programs, to broader saline landscape areas in Egypt. Additionally, this phase will include infrastructure development and the strengthening of institutional structures to support the efficient management of irrigation and drainage systems, as well as improving service delivery to end users.

In phase 4, monitoring, evaluation and adaptation systems will be established to continuously assess soil and water quality, agricultural productivity and the overall outcomes of implemented projects at both national and farm levels. The evaluation and reporting system will systematically review the effectiveness, efficiency and impact of initiatives aimed at enhancing the management and productivity of saline landscapes in Egypt. Findings, insights and recommendations will be communicated to relevant stakeholders through comprehensive reports. An adaptation mechanism will be implemented to create a dynamic and responsive framework that enables the collection of feedback from various stakeholders, ensuring their views and recommendations are incorporated into project adaptation plans and continuous improvement processes.

The successful implementation of the Roadmap hinges on strengthening the institutional framework that governs Egypt's saline landscapes. A robust financial mechanism is essential to ensure adequate resources for project execution and ongoing research. Furthermore, active involvement and empowerment of farming communities in decision-making and management processes are critical for integrating their insights, needs, and traditional knowledge into sustainable landscape management strategies. Fostering partnerships with national and international entities will also be vital to leverage external expertise, technologies and resources for effective management of the saline landscape.

As a strategic framework, the Roadmap aims to enhance the productivity of both new and existing agricultural lands in Egypt. Through phased implementation, stakeholder engagement and continuous evaluations, Egypt can sustain and boost agricultural productivity, ultimately supporting national food security and promoting economic development.

Egyptian farmers possess a wealth of time-honored expertise, passed down through generations, that once established the country as the breadbasket of Europe. The study revealed several effective practices employed by the farming community, to manage salt-affected soils and maintain agricultural productivity. Techniques such as raised beds are now commonly used to keep plant roots above saline zones. While novel water and energy-saving techniques are being adopted, they are still in their early stages. Additionally, farmers use manure, compost and crop residues in combination with deep tillage, to lower soil salinity and enrich soil organic matter. Mulching is also applied to reduce soil surface evaporation and minimize salt buildup.

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