سلسلة أوراق عمل
معهد التخطيط القومي

Spatial Modeling to Assess Sectorial Climate Challenges in Egypt Using Remote Sensing and Geographic Information Systems: Applying on Delta Region

Eng. Asmaa Hamdy

ورقة عمل رقم (6 - 2025)
يناير 2025

WWW.INP.EDU.EG

سلسلة أوراق عمل

Spatial Modeling to Assess Sectorial Climate Challenges in Egypt Using Remote Sensing and Geographic Information Systems: Applying on Delta Region

م. أسماء حمدى

مدرس التخطيط البيئي المساعد - مركز التخطيط والتنمية البيئية - معهد التخطيط القومى

Asmaa.hamdy@inp.edu.eg

ورقة عمل رقم 6-2025

تم النشر لأول مرة في عام 2025 بواسطة معهد التخطيط القومي.

سلسلة أوراق عمل معهد التخطيط القومي: تستهدف هذه السلسلة عرض بعض النتائج الأولية للبحوث التي يجريها معهد التخطيط القومي بقصد مناقشتها من جانب المعنيين من داخل المعهد وخارجه تمهيدا لتطوير هذه النتائج والارتقاء بمستوي البحث العلمي بالمعهد، وأعادة نشر الورقة في وعاء نشر محكم محلياً أو إقليمياً أو دولياً.

WWW.INP.EDU.EG

جمهورية مصر العربية - طريق صلاح سالم - مدينة نصر - القاهرة - مكتب بريد رقم 11765

A.R.E SALAH SALEM ST. NASR CITY, CAIRO P.O.BOX: 11765

سلسلة أوراق عمل - معهد التخطيط القومي

Spatial Modeling to Assess Sectorial Climate Challenges in Egypt Using Remote Sensing and Geographic Information Systems: Applying on Delta Region

النمذجة المكانية لتقييم التحديات المناخية القطاعية في مصر باستخدام الاستشعار عن بعد ونظم المعلومات الجغرافية بالتطبيق علي منطقة الدلتا

م. أسماء حمدى
مدرس التخطيط البيئي المساعد - مركز التخطيط والتنمية البيئية
معهد التخطيط القومى
Asmaa.hamdy@inp.edu.eg

Abstract

Climate change poses a significant threat to various sectors in Egypt, particularly the Nile Delta. This study leverages spatial modeling, integrating remote sensing (RS) and geographic information systems (GIS), to assess the vulnerability of the Nile Delta to climate change. By analyzing factors such as salinization, reduced Nile flow, extreme weather events, sea-level rise, and coastal erosion, this research aims to quantify sectorial vulnerabilities and inform decision-making. Spatial models will be utilized to identify areas most vulnerable to these impacts, enabling policymakers to prioritize investments, target vulnerable areas, and develop effective adaptation plans. The paper included that assess vulnerability quantitatively, used a composite index approach, combined multiple indicators. Some potential indicators include (Exposure indicators, Sensitivity indicators and Adaptive capacity indicators) By employing a vulnerability assessment framework and utilizing various data sources and techniques, it's possible to identify areas with high vulnerability to specific climate change impacts in the Nile Delta.

Key words:

Climate change - Remote sensing (RS) - Geographic information systems (GIS) - Spatial modeling

ملخص:

يشكل تغير المناخ تهديدًا كبيرًا لمختلف القطاعات في مصر، وخاصة دلتا النيل حيث تواجه منطقة دلتا النيل، وهي منطقة حيوية بالنسبة لمصر، تحديات مناخية كبيرة بما في ذلك ارتفاع درجات الحرارة، وتغير أنماط هطول الأمطار، وارتفاع مستوى سطح البحر. وهذا يتطلب تقييمات قوية لفهم نقاط الضعف القطاعية وإبلاغ استراتيجيات التكيف.

تستفيد هذه الدراسة من النمذجة المكانية، ودمج الاستشعار عن بعد (RS) ونظم المعلومات الجغرافية (GIS)، لتقييم مدى تعرض دلتا النيل لتغير المناخ. من خلال تحليل عوامل مثل التملح، وانخفاض تدفق النيل، والأحداث الجوية المتطرفة، وارتفاع مستوى سطح البحر، وتآكل السواحل، يهدف هذا البحث إلى تحديد نقاط الضعف القطاعية وإبلاغ عملية صنع القرار. سيتم استخدام النماذج المكانية لتحديد المناطق الأكثر عرضة لهذه التأثيرات، وتمكين صناع السياسات من إعطاء الأولوية للاستثمارات، واستهداف المناطق المعرضة للخطر، ووضع خطط تكيف فعالة.

إن النمذجة المكانية، التي تستفيد من الاستشعار عن بعد ونظم المعلومات الجغرافية، تقدم حلاً قوياً حيث يمكن لهذا النهج رسم خرائط نقاط الضعف والتنبؤ بالتأثيرات عبر القطاعات الحيوية مثل الزراعة، وموارد المياه، والمناطق الساحلية.

إن تطوير نماذج خاصة بالقطاعات ومصممة خصيصًا للزراعة وإدارة المياه وحماية السواحل أمر بالغ الأهمية. يمكن للتقييمات القائمة على السيناريوهات تقييم التأثيرات المحتملة في ظل توقعات مختلفة لتغير المناخ.تضمنت الدراسة تقييم الضعف كميًا، واستخدام نهج المؤشر المركب، والجمع بين مؤشرات متعددة. تشمل بعض المؤشرات المحتملة (مؤشرات التعرض، ومؤشرات الحساسية، ومؤشرات القدرة على التكيف). من خلال استخدام إطار تقييم الضعف والاستفادة من مصادر البيانات والتقنيات المختلفة، من الممكن تحديد المناطق ذات التعرض العالي لتأثيرات تغير المناخ المحددة في دلتا النيل.

الكلمات الدالة: التغييرات المناخيه - الاستشعار عن بعد - نظم المعلومات الجغرافية - النمذجة المكانية

1 Introduction

Climate change poses a significant threat to various sectors in Egypt, particularly the Nile Delta. Spatial modeling, a powerful tool integrating remote sensing (RS) and geographic information systems (GIS), offers valuable insights into assessing climate challenges and developing targeted adaptation strategies.

The Nile Delta, a vital agricultural hub and densely populated region, faces numerous climate threats such as Salinization, Reduced Nile Flow, Extreme weather events, Sea level rise and Coastal erosion. Spatial modeling allows scientists and policymakers to assess climate challenges and their impacts on different sectors. This approach combines two key technologies (RS) Provides data about Earth's surface from satellites and aerial platforms and (GIS) Integrates, analyzes, and visualizes geospatial data to create maps and models.

This research aims to leverage spatial modeling, integrating remote sensing (RS) and geographic information systems (GIS), to assess the vulnerability of various sectors in the Nile Delta to climate change, Quantify Sectorial Vulnerabilities , Spatial Risk Assessment (Utilize spatial models to identify areas within the Nile Delta that are most vulnerable to various climate change impacts. This will inform decision-making on resource allocation and implementation strategies), Enhance Decision-Making (Provide policymakers with data-driven insights and spatial visualizations to inform decision-making regarding climate change adaptation strategies in the Nile Delta. These tools can help prioritize investments, target vulnerable areas, and develop effective adaptation plans).

By applying spatial modeling in the Nile Delta, researchers can Identify areas most vulnerable to salinization and saltwater intrusion, Model the impact of reduced Nile flow on agricultural productivity, Assess the risk of coastal erosion and inundation under various sea-level rise scenarios and Develop targeted adaptation strategies to enhance resilience in different sectors.

2 Literature review

The Nile Delta, Egypt's lifeblood, faces significant threats from climate change. Assessing the vulnerability of various sectors within the Delta is crucial for developing effective adaptation strategies. This review explores how Geographic Information Systems (GIS) and Remote Sensing (RS) are utilized to evaluate climate change impacts on the Delta's diverse sectors.

The Nile Delta, a vital agricultural and economic hub, is increasingly vulnerable to climate change impacts. Numerous models have been developed to assess these challenges, but many have faced criticism due to their ineffectiveness or discrepancies with real-world conditions. This paper show to evaluate these controversial models, focusing on their applications in the Delta region.

From Model Types that have been developed based on previous literature and tools that have sparked controversy due to their ineffectiveness or a gap between their results and the current situation:

- GCM-based models: General Circulation Models often struggle to accurately represent regional climate processes, especially in complex terrains like the Delta.
- Statistical models: While efficient, these models may underrepresent physical processes and struggle to capture extreme events.
- Hydrological models: These models can be sensitive to input data quality and may not adequately represent groundwater dynamics.

We assessed sectorial climate challenges in Egypt using remote sensing and geographic information systems for many reasons:

- Model performance: Accuracy in simulating temperature, precipitation, and other climate variables.
- Spatial resolution: Ability to capture regional and local climate patterns.
- Temporal resolution: Adequacy in representing short-term and long-term climate variability.
- Sectoral relevance: Applicability of model outputs to specific sectors (agriculture, water resources, etc.).
- Uncertainty assessment: Quantification of model uncertainties and their impact on results.

Traditional methods for assessing climate change impacts often lack the spatial detail required for effective adaptation planning. Therefore, a critical need exists to develop a comprehensive understanding of the Nile Delta's vulnerability to climate change across various sectors. This research proposes to address this gap by employing spatial modeling techniques utilizing (RS) and (GIS), Table (1) shows Impacts and vulnerabilities in Egypt in sectors.

Table (1)
Impacts and vulnerabilities in Egypt in sectors.

Impacts and vulnerabilities in delta region in sectors		
Sector	Impact of Climate Change	Vulnerability
Agriculture	• Sea level rise leading to salinization of freshwater and loss of arable land. • Changes in precipitation patterns affecting irrigation water availability and crop yields. • Increased temperatures impacting crop growth and heat stress.	• Low-lying coastal areas most susceptible to salinization [1]. • Areas dependent on rain-fed agriculture more vulnerable to drought [2]. • Certain crops less adaptable to temperature extremes [3].
Water Resources	• Sea level rise causing saltwater intrusion into coastal aquifers. • Changes in precipitation patterns affecting river flows and groundwater recharge.	• Coastal aquifers most at risk of contamination [4]. • Areas with limited water storage capacity more vulnerable to droughts [5].
Coastal Infrastructure	• Sea level rise causing inundation of coastal areas and damage to infrastructure (roads, buildings, etc.). • Increased storm intensity leading to coastal erosion.	• Low-lying coastal zones with high infrastructure density most vulnerable [6]. • Areas with weak infrastructure less able to withstand extreme weather events [7].
Human Settlements	• Sea level rise displacing coastal communities. • Increased frequency and intensity of floods impacting settlements in floodplains.	• Densely populated coastal areas most at risk of displacement. • Settlements in floodplains with limited evacuation routes more vulnerable.
Ecosystems	• Sea level rise causing wetland loss and saltwater intrusion into estuaries. • Changes in temperature and precipitation affecting plant and animal life.	• Coastal wetlands and ecosystems dependent on specific salinity levels most at risk [8]. • Unique and fragile ecosystems less adaptable to rapid environmental change.

Spatial modeling provides a powerful tool to assess these challenges and inform adaptation strategies. This response outlines potential research hypotheses, considering the region's specific vulnerabilities and data availability, Table (2) shows Key Sectors and Potential Hypotheses [9].

Table (2)

Key Sectors and Potential Hypotheses

Key Sectors	Hypothesis 1	Hypothesis 2	Hypothesis 3
Agriculture	Increased sea level rise will directly correlate with a reduction in agricultural land area in the Nile Delta, leading to decreased crop yields and food security challenges.	Changes in precipitation patterns, particularly extreme rainfall events, will increase soil erosion and nutrient loss, negatively impacting agricultural productivity.	The spatial distribution of saline intrusion will exacerbate soil salinity levels, reducing crop suitability and agricultural income in specific Delta regions.
Water Resources	The combination of rising sea levels and reduced Nile River flow will intensify saltwater intrusion into the Delta's freshwater aquifers, compromising water quality for both agricultural and domestic use.	Climate change-induced changes in temperature and evaporation rates will increase water demand for irrigation, leading to water scarcity in certain Delta regions.	The spatial distribution of flood-prone areas in the Delta will change due to sea level rise and altered river flow patterns, impacting water management infrastructure and flood risk.
Coastal Zones	Sea level rise will accelerate coastal erosion rates, leading to increased property damage and loss of coastal protection infrastructure in the Delta.	Changes in storm patterns and intensity will increase the frequency and severity of coastal flooding, impactin human settlements and economic activities.	The spatial distribution of coastal wetlands will change due to sea level rise and human activities, affecting ecosystem services and coastal resilience.

Key Threats and Impacts:

Sea Level Rise (SLR): Studies by El-Banna [10]and El-Ganzori [11]highlight the vulnerability of the Nile Delta's low-lying coast to SLR. They use GIS to map inundation zones and assess potential impacts on infrastructure and coastal communities.

Water Scarcity: Fouda [12] emphasizes the use of RS data for monitoring water availability and agricultural water use. Hereher [13]employs GIS to assess vulnerability to water scarcity under climate change scenarios.

Desertification: Several studies, including El-Nahry et al. [14]and Solyman & Monem [15], utilize RS data like NDVI to map land degradation and assess desertification risks within the Delta.

Applications of GIS and Remote Sensing:

- Spatial Modeling: GIS allows for integrating various data sources (e.g., elevation, precipitation, land cover) to create spatial models that predict climate change impacts on specific sectors. Hereher [13] demonstrates the use of GIS for vulnerability assessment of SLR on the Nile Delta coast.
- Data Analysis and Visualization: Remote sensing data provides valuable insights into land cover changes, soil moisture levels, and crop health. Fouda [12] exemplifies the use of RS data to monitor water availability for agricultural practices.
- Scenario Planning: By incorporating climate projections into GIS models, researchers can simulate future scenarios of climate change impacts and assess potential vulnerabilities across different sectors. Solyman & Monem [6]demonstrate this approach for assessing SLR impacts on the Nile Delta.

Importance of Sectorial Analysis:

- Differential Impacts: Climate change will not affect all sectors equally. Mohameden et al. [16]emphasize the importance of sector-specific vulnerability assessments to identify areas with high vulnerability in agriculture, coastal zones, and public health.

3 Materials and Methods

3.1 Data Acquisition:

- **GIS Data:**
  - **Base Maps:** Acquire high-resolution base maps of the Nile Delta including:
  - Topography and elevation data (Digital Elevation Models (DEMs) from USGS National Elevation Program).
  - Land cover and land use maps (international datasets like USGS National Land Cover Database).
  - Soil data (Egyptian Ministry of Agriculture and Land Reclamation soil maps or FAO soil data).
  - Administrative boundaries (provinces, districts).

3.2 Remote Sensing Data:

- Select historical and future satellite imagery covering a suitable time period (Landsat archive, Sentinel-2) to monitor land cover changes and vegetation health.
- Climate data (temperature, precipitation) can be obtained from Egyptian meteorological agencies or global climate datasets.
- Socio-economic data (population density, economic activity)
- Land Use/Land Cover Mapping: (Supervised classification algorithms will be used to classify satellite imagery and identify land cover types (e.g., agricultural land, forests, and urban areas).

3.3 Pre-processing and Analysis of Geospatial Data:

- GIS Software: Utilize GIS software (Arc GIS) for data processing and analysis.
- Remote Sensing Pre-processing: Perform atmospheric correction and geometric correction on satellite imagery to ensure data accuracy as shown in fig 3.

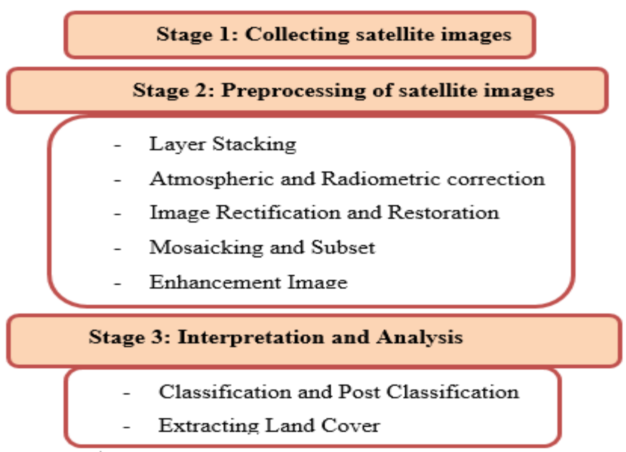


Figure (1)

flow chart of satellite image processing procedures

- Vegetation Indices: Derive vegetation indices (e.g., NDVI) from RS data to assess vegetation health and productivity over time as shown in table 3

Table (3)

data to assess vegetation health and productivity

Source	Description	Advantages	Disadvantages	Cost	Access
Landsat	Freely available multi-spectral satellite imagery with a long historical record (since 1970s). Moderate resolution (30 meters).	Long time series data allows for trend analysis. Suitable for regional-scale studies.	Lower resolution might not capture fine details of vegetation or land cover.	Free	USGS EarthExplorer https://earthobservatory.nasa.gov/ or GloVis https://glovis.usgs.gov/
Sentinel-2	Freely available high-resolution (10 meters) multi-spectral imagery with good revisit frequency (every 5 days).	Captures detailed information on vegetation and land cover changes. Suitable for local-scale studies.	Might require additional processing due to frequent data updates.	Free	ESA's Copernicus Open Access Hub [invalid URL removed]
World View	Very high-resolution (less than 1 meter) multi-spectral and hyper spectral imagery.	Provides exceptional detail for precise vegetation mapping and analysis.	Highest cost among listed options. Limited free data availability.	Varies	Digital Globe https://www.digitalglobe.com/
EOsat - Deimos-2	High-resolution (1.2 meters) multi-spectral imagery with frequent revisit capabilities.	Good alternative to World View with potentially lower cost.	Limited historical data archive compared to Landsat.	Varies	EOsat [invalid URL removed]
Egyptian Remote Sensing Authority (ERSA)	Offers high-resolution satellite imagery and aerial photography data of Egypt.	Provides the most localized and potentially highest-resolution data for the Nile Delta.	Data access might require contacting the agency directly and potentially involving fees. Limited online access information.	Varies	https://globaledge.msu.edu/global-resources/resource/10322 (Contact for information)

- Spatial Analysis: Analyze spatial relationships between climate data (temperature, precipitation), soil properties (salinity, moisture), and land cover using GIS tools as shows in fig 4 and fig 5.

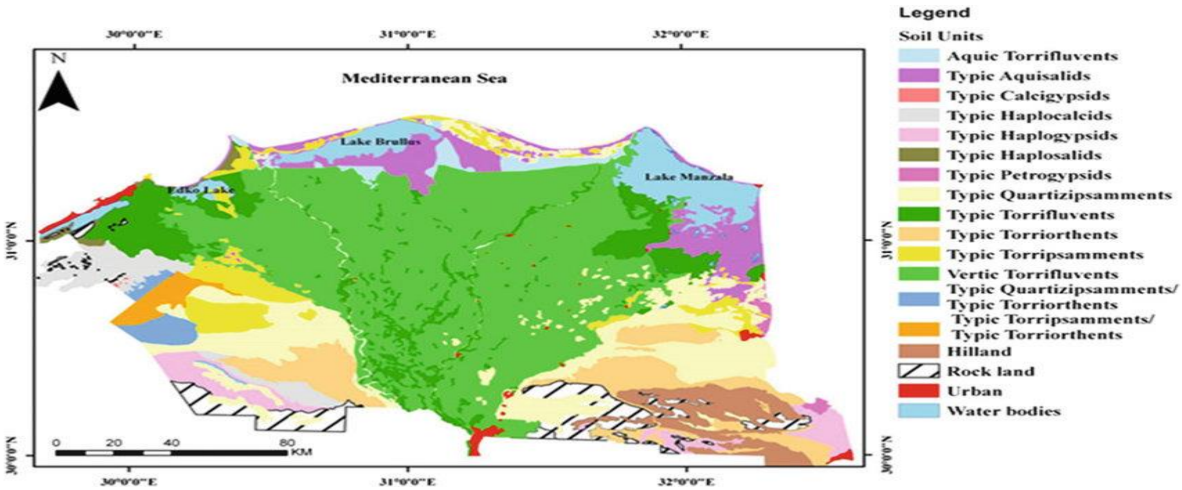


Figure (2)
Soil map of the Nile Delta region, Egypt

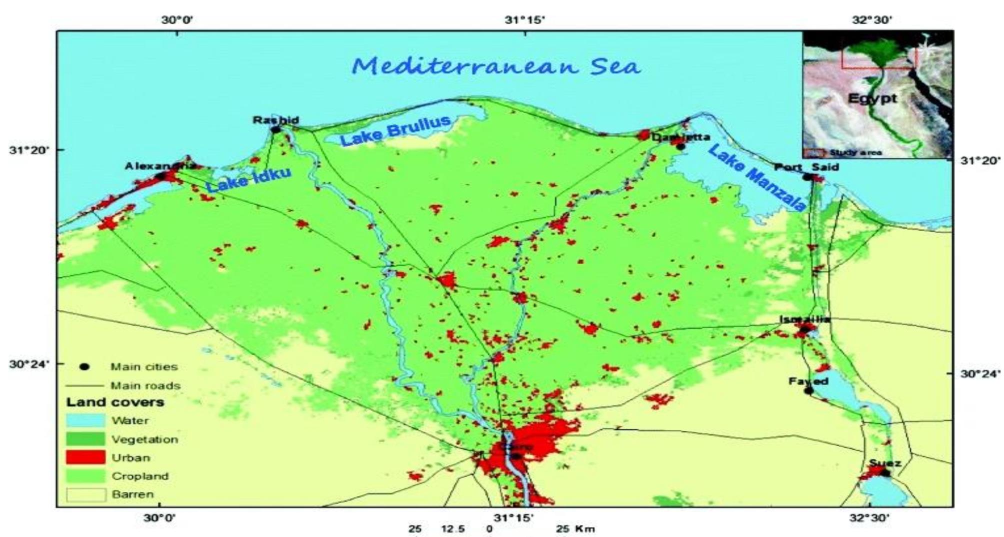


Figure (3)
Location map and land cover types from MODIS data of Nile Delta, Egypt

- Overlay and analyze these datasets to identify areas currently suitable for specific crops.

3.4 Climate Change Scenarios:

Obtain or develop climate change scenarios for the Nile Delta, considering factors like temperature increases, precipitation changes, and sea-level rise.

According to:

IPCC Reports: The Intergovernmental Panel on Climate Change (IPCC) provides the most comprehensive assessment of climate change projections globally. Their Sixth Assessment Report offers valuable insights. (https://www.ipcc.ch/)

Regional Climate Change Models (RCMs): Search for RCMs focused on the Eastern Mediterranean and North Africa region. These models offer higher resolution data compared to global models.

National Climate Change Reports: The Egyptian government or relevant agencies might have published reports with specific projections for the Nile Delta.

The Nile Delta faces significant threats from climate change, with potential impacts on water resources, agriculture, and coastal communities. Here's a summary of projected changes based on existing climate change scenarios:

3.4.1 Temperature Increase:

The scenario for temperature increase in the Nile Delta paints a concerning picture, with projections indicating a significant rise in average annual temperatures over the coming decades.

- Current Climate:
  - The Nile Delta experiences a hot desert climate with average annual temperatures ranging from 20°C to 24°C (68°F to 75°F) [17]
- Projected Increase:
- Climate change scenarios warn of a substantial increase in average annual temperatures. The Intergovernmental Panel on Climate Change (IPCC) reports suggest potential increases of [18]:
  - ❖ 2-4°C by mid-century (2050) compared to a baseline period (usually 1986-2005). 4-6°C by the end of the century (2100).
- Potential Impacts:
- Rising temperatures translate into a cascade of negative consequences, including:

- More Frequent and Intense Heat waves: These pose health risks, especially for vulnerable populations like children and the elderly [19].
- Increased Evaporation Rates: This leads to higher water demands for agriculture and other uses, straining already limited resources [20].
- Changes in Crop Yields: Food security for the region's population is at risk due to potential declines in agricultural productivity [21].
- Stressed Water Resources: Higher temperatures lead to faster depletion of rivers, lakes, and groundwater.
- Loss of Biodiversity: Natural ecosystems adapted to the current climate could face disruptions and potential extinction events [22].

The scenario for temperature increase in the Nile Delta is a cause for concern. Proactive adaptation strategies, including improved water management practices and investments in drought-resistant crops, are crucial to ensure the long-term sustainability of the region.

3.4.2 Precipitation Changes:

- Projections for precipitation changes are more uncertain than temperature increases.
- Some models suggest a slight decrease in average annual rainfall, while others indicate potential shifts in precipitation patterns with drier summers and wetted winters.
- Increased frequency and intensity of extreme precipitation events like storms and floods are also expected.

3.4.3 Sea-Level Rise:

- Global sea level rise projections suggest an increase of 0.3-0.8 meters by 2050 and 0.6-1.0 meters by 2100 relative to the present day.
- However, local factors like land subsidence in the Nile Delta could exacerbate sea-level rise, leading to even higher water levels.

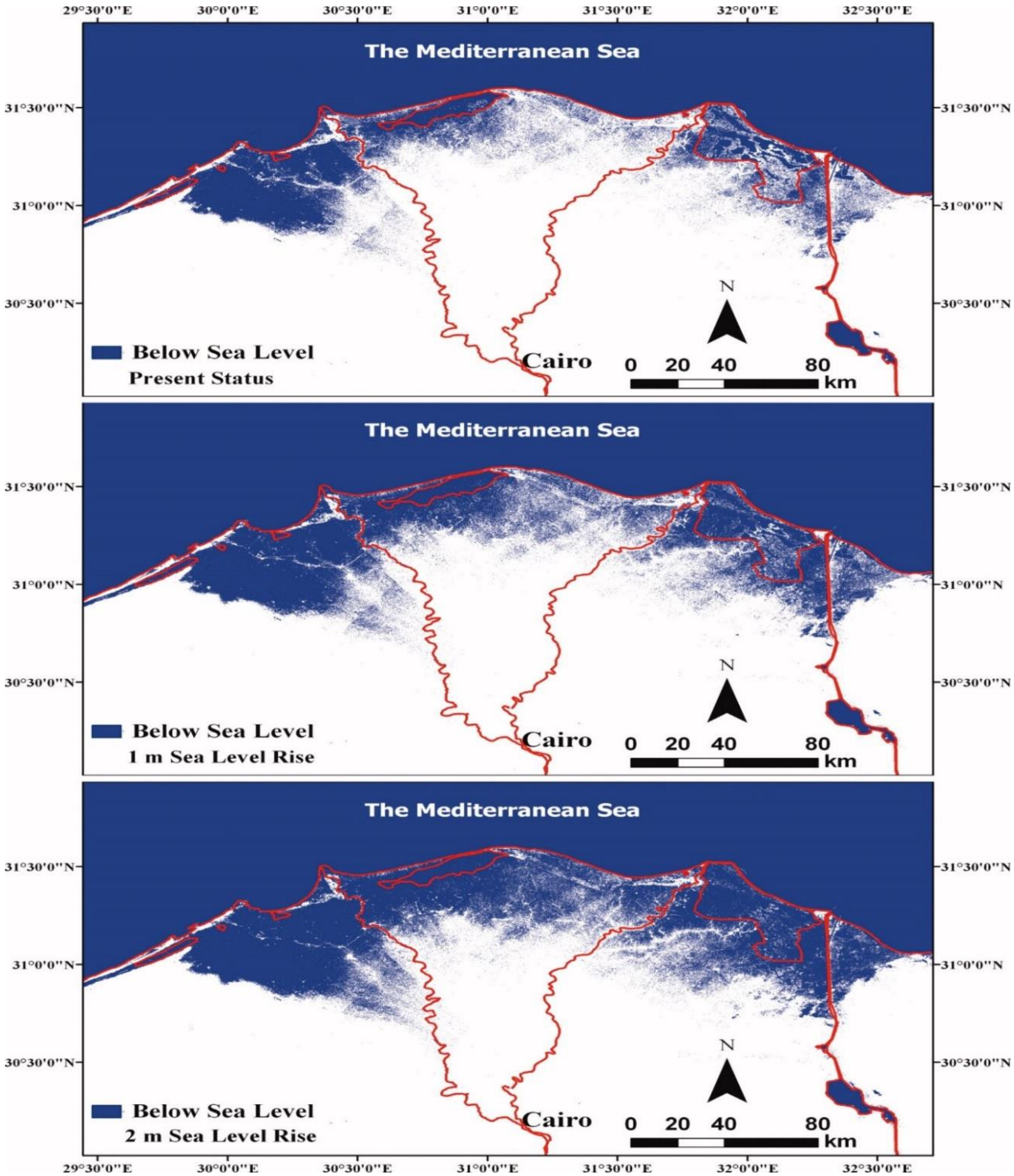


Figure (4)

DEM classification for: Nile Delta today (top), 1 m sea level rise (middle) and 2 m sea level rise (bottom). Blue refers to areas to be flooded by the sea. Available in colour online.

3.5 Modeling and Impact Assessment:

- **Salinity Intrusion Modeling:** Utilize GIS and hydrological modeling tools to assess potential impacts of sea-level rise on coastal agricultural land and freshwater resources.
  Salinity intrusion poses a significant threat to the Nile Delta's freshwater resources. GIS and remote sensing data offer valuable tools for developing and improving salinity intrusion models in this region.
  Here's a breakdown of the factors, criteria, and considerations involved:

Factors Influencing Salinity Intrusion:

- **Hydrogeological Factors:**

- **Hydraulic Conductivity:** The ease with which water can flow through the aquifer. Higher conductivity allows faster saltwater intrusion [23].
- **Porosity:** The amount of space within the aquifer that can store water. Lower porosity limits freshwater storage, making the aquifer more vulnerable to saltwater intrusion [23].
- **Aquifer Thickness:** A thicker aquifer provides a larger buffer against saltwater intrusion [24].

- **Hydrological Factors:**

  - Sea Level Rise: Rising sea levels exert a greater pressure on freshwater aquifers, pushing saltwater inland [25].
  - Groundwater Pumping: Excessive groundwater extraction lowers the water table, creating a pressure gradient that draws saltwater towards the pumping wells [26].
  - Land Cover and Use.

By incorporating these factors, criteria, and considerations, GIS and remote sensing data can significantly enhance salinity intrusion modeling in the Nile Delta. This approach offers valuable insights for informed water resource management strategies to combat salinization and ensure the sustainability of this critical freshwater resource.

- **Flood Risk Assessment:** Develop flood inundation models using GIS and historical flood data to identify areas at risk from future floods, considering potential changes in precipitation patterns. Here's a breakdown of the factors, criteria, and considerations involved [27], [28]:

- **Historical Flood Data:**
    - ❖ Collect data on past flood events, including flood extent maps, water level records from gauging stations, and satellite imagery of inundation areas.
    - ❖ Ensure data accuracy and consistency for reliable model development..
- **Digital Elevation Model (DEM):**
    - ❖ Obtain a high-resolution DEM that accurately represents the topography of the Nile Delta.
    - ❖ Consider using LiDAR (Light Detection and Ranging) data for detailed elevation information, especially in critical areas.
- **Land Cover and Use Data:**
    - ❖ Collect data on land cover types (e.g., urban areas, agricultural land, wetlands) within the Nile Delta.
    - ❖ This data influences water flow patterns during flood events.
- **River Network Data:**
    - ❖ Include data on the Nile River and its tributaries, including channel geometry, flow rates, and historical discharge records.
- **Hydraulic Modeling:**
    - ❖ Employ hydraulic modeling tools within GIS to simulate the movement of floodwater across the landscape based on topography, river discharge, and land cover characteristics.
    - ❖ Common software includes HEC-RAS (Hydrologic Engineering Center – River Analysis System) or FLO-2D.
- **Flood Inundation Mapping:**
    - ❖ Utilize GIS to generate flood inundation maps that depict the areas likely to be flooded under different flood scenarios (e.g., 10-year flood, 100-year flood).
- **Calibration and Validation:**
    - ❖ Calibrate the model using historical flood data to ensure its accuracy in predicting inundation extents.
    - ❖ Validate the model with independent flood data sets to assess its reliability.

- **Sea Level Rise:**

    - ❖ Consider incorporating potential sea-level rise projections into the model to understand how it might affect future flood inundation patterns.

- **Climate Change:**

    - ❖ Factor in potential changes in precipitation patterns due to climate change to assess how they might influence flood frequency and intensity.

- **Infrastructure Data:**

    - ❖ Include data on critical infrastructure like dams, levees, and bridges to evaluate their potential impact on floodwater flow and identify vulnerable areas.
    - ❖ By considering these factors and employing appropriate techniques, GIS and historical flood data can be powerful tools for developing flood inundation models in the Nile Delta, Egypt. These models can contribute significantly to flood risk reduction and ensure the safety and well-being of communities in this flood-prone region.

4 Study Area

The study area covers most of the Nile delta region north of Egypt from Alexandria at the west (29.6°E) to Port Said at the east (32.3°E) and from the northern Mediterranean coasts at the north (31.6°N) to Cairo at the south (30.0°N), as shown in (Figure 7). It is bounded by the two branches of the Nile river “Damietta and Rosetta”, and extending from both sides to cover coastal areas, with an overall area of approximately 23,235 km2. The length of the study area is approximately 180 km from north to south, and it covers about 300 km of coastline at the Mediterranean Sea (17.75% of the Egyptian Mediterranean coast). The shoreline is occupied by three major coastal lakes “Lake Burullus, Lake Idku, and Lake Mariut”. The Suez Canal runs to the east of the Delta, entering the coastal Lake Manzala in the northeast of the Delta. The topography of the region smoothly slopes northwards towards the Mediterranean coast, where the difference in elevation between its southern peak, at Cairo, and northern coastal fringes is approximately 18 meter (Embabi 2000)0

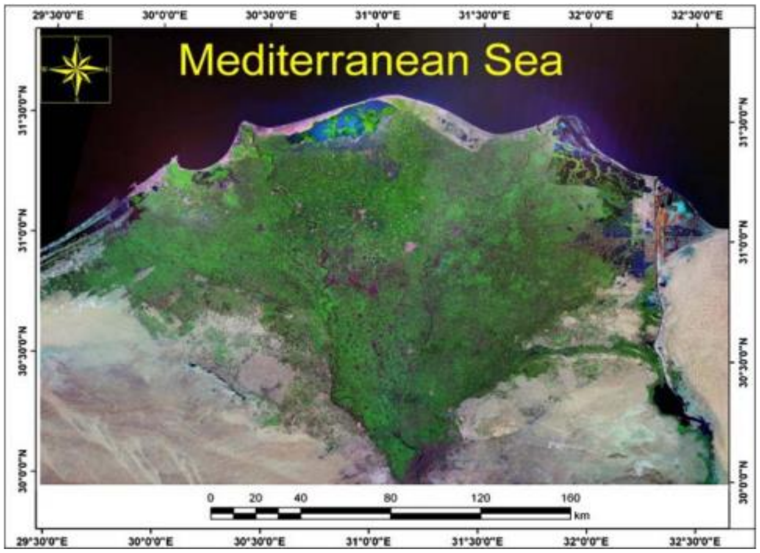


Figure (5)

Location of the investigated area

5 Methodology:

Vulnerability is a complex concept influenced by various factors, including exposure to hazards, sensitivity, and adaptive capacity. To identify areas more vulnerable than others, we need to develop scenarios that combine different climate change impacts and assess their effects on different sectors. Modeling is developed by considering the following procedure with the aid of the RS and GIS techniques (see Fig. 8). A conceptual flowchart diagram of formation and analyzing the proposed model is depicted in Fig 8.

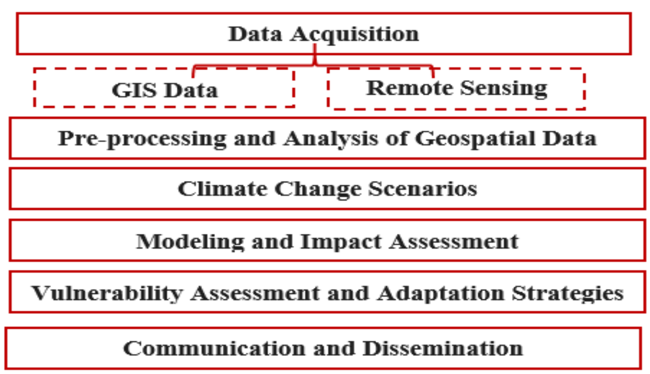


Figure (6)

flow chart of Formation and Analyzing the Proposed Model

The Nile Delta is a vital agricultural region for Egypt, facing significant climate change threats. Effective agricultural extension services are crucial to support farmers in adapting to these challenges. Here's how GIS and Remote Sensing (RS) can be integrated into agricultural extension for climate change adaptation in the Nile Delta:

5.1 Vulnerability Assessment and Adaptation Strategies:

- Integrate the results from various models and spatial analyses to generate a comprehensive vulnerability assessment of the Nile Delta's agricultural sector to climate change.
- Identify areas with high vulnerability to specific climate change impacts (e.g., drought, salinity, floods).
- Develop and evaluate potential adaptation strategies using GIS to address identified vulnerabilities, such as:
    - Promoting drought-resistant and salt-tolerant crop varieties.
    - Implementing water conservation techniques (e.g., drip irrigation).
    - Improving drainage systems to manage potential increases in salinity.
    - Developing flood protection measures (e.g., levees) in high-risk areas.
    - Identifying alternative land uses for areas becoming unsuitable for traditional agriculture.

5.1.1 Vulnerability Assessment Framework:

To assess vulnerability quantitatively, used a composite index approach, combined multiple indicators. Some potential indicators include as shown in figure 9:

- **Exposure indicators:** Identify areas likely to experience the specific climate change impac(Sea level rise, temperature increase, precipitation change, storm frequency and intensity**).**
- **Sensitivity indicators**: Population density, agricultural productivity, water availability, infrastructure quality, ecosystem health.
- **Adaptive capacity indicators:** GDP per capita, education level, access to healthcare, governance effectiveness, early warning systems.

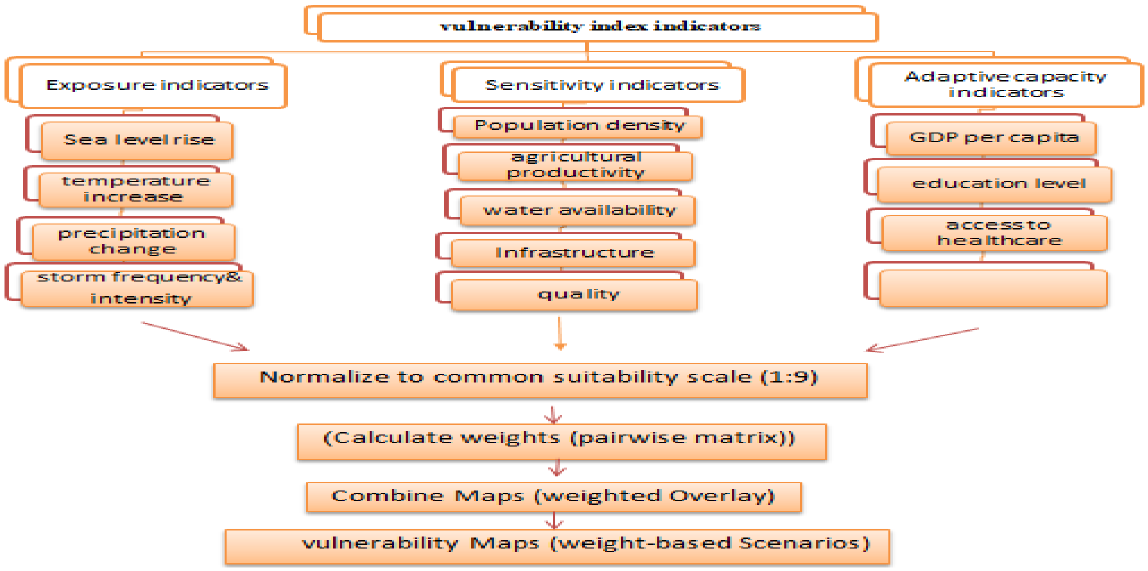


Figure (7)

A conceptual model for the suitable weighted map

Benefits of Vulnerability Assessment:

- **Targeted Adaptation Strategies:** Identify areas requiring priority interventions for adaptation measures such as improved water management practices, drought-resistant crops, and flood protection infrastructure.
- **Resource Allocation:** Guide resource allocation for climate change adaptation efforts towards the most vulnerable regions and communities.
- **Enhanced Resilience:** Promote long-term resilience of the Nile Delta by proactively addressing climate change vulnerabilities.

5.1.2 Areas Potentially Vulnerable to Specific Impacts:

- **Drought:** Areas with low average rainfall, limited water storage capacity (sandy soils), and high dependence on rain-fed agriculture are more vulnerable to drought. The southern fringes of the Delta might be more susceptible.
- **Salinity Intrusion:** Low-lying coastal areas, regions with intensive groundwater pumping, and areas with high aquifer permeability are more vulnerable to saltwater intrusion. The northern Nile Delta is particularly at risk.
- **Flooding:** Low-lying areas near river channels, floodplains, and areas with inadequate drainage infrastructure are more vulnerable to flooding. The northern part of the Delta and areas around major distributaries are potentially susceptible.

5.1.3 vulnerability index:

A. Assign weights to each indicator based on its importance.

The relative importance of an evaluation criterion over other criteria determined by assigning a weight value to each criteria factor. There are a lot of methods for weighting criteria [29]. This research will include just the weighting methods using by integration of GIS/MCDA. The weighting methods can be categorized into two main classes: global and local methods. Firstly, the global methods such as: pairwise comparison, rating, ranking and entropy approaches. The homogeneity assumption of the preferences is the base for these global weighting methods. Consequently, they define a single weight value to each criterion. GIS/MCDA applications mainly depend on one of these global techniques: pairwise comparison, rating or ranking [30] as shows in table (4) AHP weighting for Vulnerability indecatiors.

Table (4)
AHP weighting for indacators

AHP weighting for Exposure indicators					
Attribute	Sea level rise	temperature increase	precipitation change	storm frequency	intensity
Sea level rise	1	9/7	9/5	9/4	9/3
temperature increase	7/9	1	7/5	7/4	7/3
precipitation change	5/9	5/7	1	5/4	5/3
storm frequency	4/9	4/7	4/5	1	4/3
intensity	3/9	3/7	3/5	3/4	1
AHP weighting for Sensitivity indicators					
Attribute	Population density	agricultural productivity	water availability	infrastructure	quality
Population density	1	9/7	9/5	9/4	9/3
agricultural productivity	7/9	1	7/5	7/4	7/3
water availability	5/9	5/7	1	5/4	5/3
infrastructure	4/9	4/7	4/5	1	4/3
quality	3/9	3/7	3/5	3/4	1
AHP weighting for Adaptive capacity indicators					
Attribute	GDP per capita,	education level	access to healthcare		
GDP per capita,	**1**	**9/7**	**9/5**		
education level	**7/9**	**1**	**7/5**		
access to healthcare	**5/9**	**5/7**	**1**		

B. Normalize the data for each indicator to a common scale (e.g., 0-1).

Criteria attributes have different measuring scales. In order to perform analysis, standardization has to be performed through transformation of attributes into a common suitability. For each factor, the attributes were rated in reference to a common scale. Thus for each sub routine, the criteria attributes were transformed from the original values to a common suitability scale ranging from (1) to (9). Higher index values indicate higher vulnerability. As shows in table (5)

Table (5)

Normalized pairwise AHP comparison matrix and relative weights for Exposure indicators

Attribute	Sea level rise	temperature increase	precipitation change	storm frequency	intensity	**Row Sum**	**Weight**
Sea level rise	5	45/7	9	45/4	15	46.68	0.32
temperature increase	45/7	5	7	35/4	35/3	38.85	0.27
precipitation change	25/9	25/7	5	25/4	25/3	25.93	0.18
storm frequency	20/9	20/7	4	5	20/3	20.75	0.14
intensity	15/9	15/7	3	15/4	5	13.56	0.09
						145.77	**1**

C. Calculate a composite index for each region by summing the weighted indicator values.

Then, the simple additive weight method, known as the Weighted Linear Combination (WLC), was used to combine the criteria [31]. This process is often used in vulnerability studies where several factors affect the suitability of a site (Esri, 1996). The GIS overlay process can be used to combine the factors in the form of a WLC process to yield to the weighted maps corresponding to the three visions as schematically presented in the flow charts shown in figure 9.

5.1.4 Communication and Dissemination:

Generate maps, graphs, and other visualizations using GIS to effectively communicate the spatial patterns of climate change impacts and potential adaptation strategies.

Disseminate findings to stakeholders involved in the Nile Delta's agriculture sector, such as farmers, policymakers, and extension service.

6 Results and discussion

The spatial modeling approach, using remote sensing and GIS data, effectively assessed sectorial climate challenges in the Nile Delta region of Egypt. The key findings include:

Increased vulnerability to sea level rise: Low-lying coastal areas are highly susceptible to inundation, particularly in the northern delta. Digital elevation models (DEMs) derived from remote sensing data, combined with sea level rise projections, enabled the identification of specific vulnerable zones.

Agricultural land loss: Climate change impacts, such as saltwater intrusion and soil salinization, are projected to reduce arable land in the delta. Spatial analysis of soil properties, water quality, and land use/land cover (LULC) change, using remote sensing and GIS, highlighted areas at risk of agricultural decline.

Water scarcity: Changes in precipitation patterns and increased evapotranspiration due to rising temperatures are expected to exacerbate water scarcity in the delta. Spatial modeling of water resources, incorporating climate projections and hydrological data, revealed areas facing significant water deficits.

Urban heat island effect: Rapid urbanization and land use changes contribute to the urban heat island effect, particularly in densely populated cities like Alexandria. Analysis of land surface temperature (LST) derived from thermal remote sensing data, in conjunction with urban morphology data, quantified the spatial extent and intensity of this phenomenon.

7 Discussion

The study demonstrated the value of integrating remote sensing and GIS techniques for assessing climate change impacts and vulnerabilities in the Nile Delta. The spatial modeling approach provided detailed insights into the geographical distribution of climate challenges across various sectors, including:

Agriculture: The study underscored the need for adaptation strategies to protect agricultural productivity, such as developing salt-tolerant crops, improving irrigation efficiency, and implementing coastal protection measures.

Water resources: The findings highlighted the importance of integrated water management strategies to address water scarcity, including water conservation, rainwater harvesting, and non-conventional water resources.

Urban planning: The study emphasized the need for climate-sensitive urban planning to mitigate the urban heat island effect, such as promoting green infrastructure, improving building energy efficiency, and optimizing urban ventilation.

The spatial modeling framework developed in this study can be further enhanced by incorporating socio-economic data and local knowledge to assess the vulnerability of communities and inform targeted adaptation interventions. The use of high-resolution remote sensing data and advanced modeling techniques can also improve the accuracy and reliability of the assessments.

Overall, this study provided valuable information for decision-making and policy formulation to address climate change challenges and promote sustainable development in the Nile Delta region.

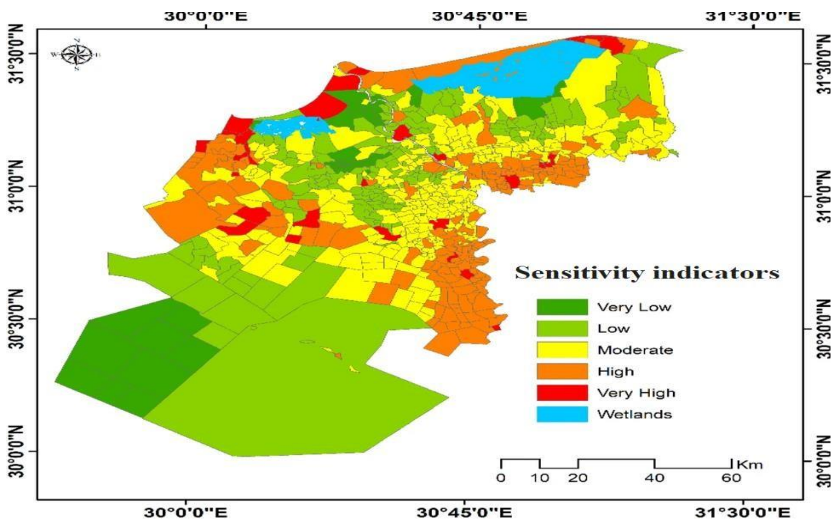
Climate change poses a significant threat to the Nile Delta, Egypt, with various impacts like drought, salinity intrusion, and flooding. Here's how to identify areas with high vulnerability to these specific climate change impact.

many alternatives with varying priorities should be investigated in order to gain wider overview of the output results. These alternatives along with its corresponding weights are basically defined by experts and stakeholders. In this context, three different study cases regarding weighting are considered as listed in Table 6, along with the corresponding output results regarding the vulunrability site in each case. Those final vulunrability maps of the three study cases are easily obtained by using weight sum tool in the ArcGIS software.

Table (6)
Assigned weights for multiple study cases

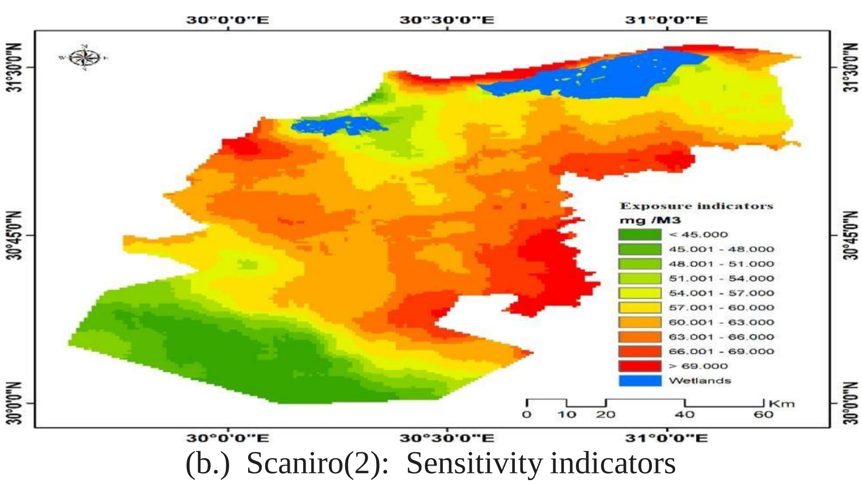
Study Case	**Alternative Vision**		
	Exposure indicators	Sensitivity indicators	Adaptive capacity indicators
Scaniro(1)	0.50	0.33	0.17
Scaniro(2)	0.33	0.50	0.17
Scaniro(3)	0.33	0.17	0.50

To have meaningful and concise judgments on the output results, the obtained vulnerabikity site in each study case should be investigated and evaluated based on the previously-mentioned criteria and its standardized suitability, Nevertheless such lands have to be modeled in the multi criteria evaluation as constraints and masked out. Results of running the weighted linear combination WLC revealed interesting results for each study case. As such aggregation results in continuous suitability images, such images were reclassified into nine suitability classes for each one. Changing the set of weights for the themes changed the trade-off between them. Reducing the weight for a specific theme means prioritizing another one. All final output study cases are illustrated in figure 8 .



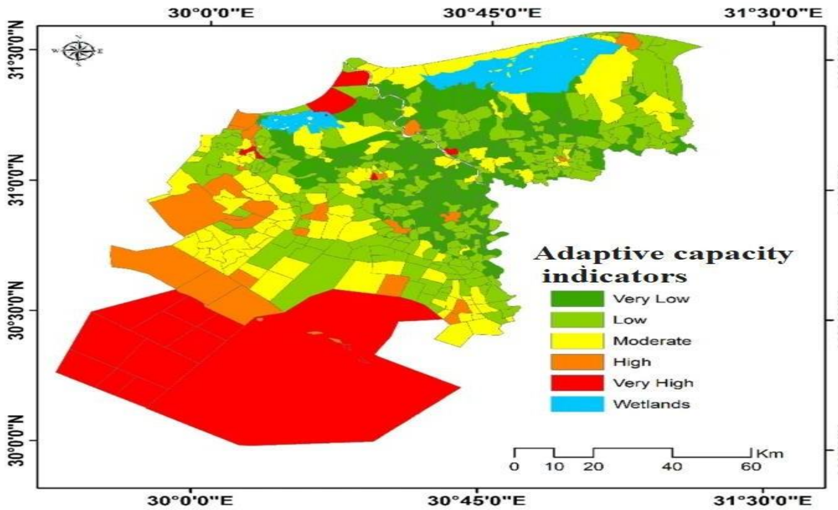
(a.) Scaniro(1): Exposure indicators

Figure (8)



(b.) Scaniro(2): Sensitivity indicators

Figure (9)



c.(Scaniro (3): Adaptive capacity indicators

Figure (10)

vulnerability index indicators maps

These results reveal some important findings that can be summarized as:

In scaniro (1): Exposure indicators:

Northern Coast: Areas around Alexandria, Rosetta, and Port Said are at high risk of sea-level rise, coastal erosion, and saltwater intrusion.

Eastern Delta: The Gamasa Ras El Bar area is particularly vulnerable to sea-level rise, inundation, and groundwater salinization.

The western and central parts of the Delta are particularly vulnerable to these risks.

Large cities within the Delta, such as Cairo and Alexandria, are at risk from heatwaves, flooding, and air pollution exacerbated by climate change.

In scaniro (2): Sensitivity indicators:

areas in the northern Delta, particularly around Lake Borollos, as highly sensitive due to soil salinity and waterlogging.

In scaniro (3): Adaptive capacity indicators:

Rural areas: Lower levels of education, income, and access to technology can limit adaptive capacity. Areas with a strong reliance on agriculture are particularly vulnerable to climate change impacts.

Urban slums: Lack of access to basic services, poor housing conditions, and limited livelihood opportunities hinder adaptive capacity.

Remote areas: Areas with poor infrastructure and limited access to government services have lower adaptive capacity.

Additional Considerations:

- **Sea Level Rise:** Rising sea levels will exacerbate coastal inundation and increase vulnerability to flooding and salinity intrusion.
- **Climate Change Projections:** Utilize data on projected changes in precipitation patterns, temperature, and sea level rise to assess future vulnerability scenarios.

By employing a vulnerability assessment framework and utilizing various data sources and techniques, it's possible to identify areas with high vulnerability to specific climate change impacts in the Nile Delta. This knowledge allows for targeted adaptation strategies, resource allocation, and ultimately, increased resilience of the region in the face of a changing climate.

8 Conclusion:

This study effectively demonstrates the power of integrating remote sensing and GIS for assessing sectorial climate change challenges in the Nile Delta, Egypt. Spatial modeling revealed critical vulnerabilities across key sectors: increased risk of inundation due to sea level rise in coastal areas, potential loss of agricultural land due to saltwater intrusion and salinization, exacerbation of water scarcity due to changing precipitation patterns and increased evapotranspiration, and the intensification of the urban heat island effect in densely populated cities. These findings underscore the urgent need for targeted adaptation strategies, including developing salt-tolerant crops, improving water management practices, and implementing climate-sensitive urban planning. The developed spatial modeling framework provides valuable information for decision-making and policy formulation aimed at promoting sustainable development and mitigating the adverse impacts of climate change in this vulnerable region. Further enhancements, such as incorporating socio-economic data, local knowledge, and high-resolution remote sensing data, will further refine the accuracy and utility of these assessments.

Addressing the Vulnerability Mapping and Weighting:

The additional information about using weighted overlays and different weighting scenarios significantly strengthens the study. By considering multiple alternatives with varying priorities assigned by experts and stakeholders, the research acknowledges the inherent uncertainties and diverse perspectives in vulnerability assessments. Using the weighted sum tool in ArcGIS to generate vulnerability maps for each scenario allows for a comparative analysis, providing a more robust and nuanced understanding of spatial vulnerability. This approach allows decision-makers to:

- **Explore different prioritization schemes:** By comparing vulnerability maps generated with different weights, stakeholders can understand how varying priorities (e.g., prioritizing agricultural land over urban areas, or vice versa) influence the spatial distribution of vulnerability.
- **Identify areas of consistent high vulnerability:** Areas that consistently appear as highly vulnerable across all weighting scenarios are of particular concern and should be prioritized for immediate intervention.
- **Consider trade-offs and uncertainties:** The multi-scenario approach highlights the trade-offs associated with different adaptation strategies and helps to manage uncertainties inherent in climate change projections and impact assessments.

In summary, the inclusion of the weighted overlay analysis significantly enhances the study's practical value by providing a more comprehensive and flexible framework for assessing and addressing climate change vulnerability in the Nile Delta. It allows for a more informed and participatory approach to adaptation planning.

Executive Summary

The Nile Delta, a vital region for Egypt, faces significant climate challenges including rising temperatures, altered precipitation patterns, and sea-level rise. This necessitates robust assessments to understand the sectoral vulnerabilities and inform adaptation strategies.

Spatial modeling, leveraging remote sensing (RS) and geographic information systems (GIS), offers a powerful solution.

- ❖ This approach can map vulnerabilities and predict impacts across critical sectors like agriculture, water resources, and coastal zones.

- ❖ Existing national policies on climate change adaptation and water management can be strengthened by integrating spatial modeling outputs.

Moving forward, several key areas require focus:

- Enhanced data access and sharing of high-resolution geospatial data is essential.
- Capacity building initiatives should equip professionals with expertise in spatial modeling, RS, and GIS.
- Developing sector-specific models tailored to agriculture, water management, and coastal protection is crucial.
- Scenario-based assessments can evaluate potential impacts under various climate change projections.
- Creating vulnerability maps will pinpoint areas most susceptible to specific climate threats.
- Integrating social and economic data with spatial models provides a holistic understanding of the social and economic consequences of climate change.

Climate change poses significant challenges for the Nile Delta, and spatial modeling using remote sensing (RS) and geographic information systems (GIS) is a crucial tool for assessing sectoral impacts and developing adaptation strategies. Here's an overview of relevant policies and future studies:

Current Policies:

- **National Adaptation Plans (NAPs):** Egypt has developed NAPs outlining adaptation strategies for various sectors, including agriculture, water resources, and coastal zones. These plans can potentially incorporate spatial modeling outputs to inform specific actions in the Nile Delta.
- **National Strategy for Climate Change (NSCC):** The Egyptian government has established an NSCC to address climate change across various sectors. Spatial modeling can support the implementation of this strategy in the Nile Delta by providing data-driven insights.
- **National Water Resources Management Plan:** Egypt has a national water plan focusing on water security. Spatial modeling can help assess future water availability under climate change scenarios in the Nile Delta, informing water management strategies.

9 Recommendation policies:

- **Improved Data Acquisition and Sharing:**
  - Policies promoting open access to high-resolution geospatial data (satellite imagery, LiDAR data) are crucial.
  - Collaboration between government agencies, research institutions, and private companies can facilitate data sharing and analysis.
- **Capacity Building and Training:**
  - Investing in training programs that equip professionals with skills in spatial modeling, RS, and GIS is essential.
  - Educational programs at universities and research institutions can focus on climate change and geospatial technologies.
- **Developing Sector-Specific Models:**
  - Refining spatial models tailored to specific sectors like agriculture, water resources management, and coastal zone protection.
  - Integrating these models with existing sectoral planning frameworks to improve decision-making.
- **Scenario-Based Assessments:**
  - Utilizing spatial models to assess potential impacts of climate change under different emission scenarios (e.g., low, medium, high)
  - This can inform policymakers on the range of challenges and guide adaptation strategies accordingly.
- **Vulnerability Mapping:**
  - Creating detailed vulnerability maps for the Nile Delta, identifying areas most susceptible to specific climate change impacts (e.g., drought, floods, sea-level rise).
  - These maps can be used for targeted adaptation interventions and resource allocation.

- **Integration with Social and Economic Data:**
  - ❖ Combining spatial modeling outputs with socioeconomic data (e.g., population density, infrastructure) to understand the social and economic consequences of climate change impacts.
  - ❖ This holistic approach informs policies that address both environmental and societal challenges.

10 Future studies

- Develop a spatial model to assess the impact of rising temperatures on agricultural suitability in the Nile Delta.
- Use remote sensing to monitor land cover changes and desertification risks in the Delta.
- Create a flood inundation model for the Nile Delta to predict potential impacts of increased precipitation events.
- Develop a coastal vulnerability model to assess the risks of sea-level rise and saltwater intrusion on coastal communities.
- Assessing agricultural suitability in a warming climate.
- Monitoring land cover changes and desertification risks.
- Predicting flood inundation zones under extreme precipitation events.
- Evaluating coastal vulnerability to rising sea levels and saltwater intrusion.

By implementing these recommendations, spatial modeling can serve as a cornerstone for building resilience in the Nile Delta. It will enable a comprehensive understanding of climate change impacts, facilitate the development of targeted adaptation strategies, and ultimately contribute to a more sustainable future for the region.

References

- "https://www.delta.com/us/en/delta-vacations/africa-and-middle-east-vacations/cairo-vacation-packages," [Online].
- "https://www.ipcc.ch/," [Online].
- "https://www.fao.org/climate-change/en," [Online].
- "https://nilebasin.org/goals/climate-change-adaptation," [Online].
- "https://www.worldwatercouncil.org/en," [Online].
- "https://link.springer.com/book/10.1007/978-3-319-56124-0," [Online].
- "https://link.springer.com/book/10.1007/978-3-319-56124-0," [Online].
- "https://www.ramsar.org/," [Online].
- The Intergovernmental Panel on Climate Change (IPCC), "Climate Change 2021 The Physical Science Basis," Intergovernmental Panel on Climate Change. , Switzerland, 2021.
- Mahmoud M. El Banna, "Erosion and accretion rates and their associated sediment characters along Ras El Bar coast, northeast Nile Delta, Egypt," *Environ Geol,* p. 41–49, 2007.
- Akram El-Ganzori, Mohamed Ezzat Elshamy, Mohamed Hassan, TOWARDS A CLIMATE CHANGE ADAPTATION STRATEGY FOR THE WATER SECTOR IN EGYPT, UNESCO Cairo Office, 2012.
- Moustafa M Fouda, Mohamed Said Abdelwarith, Noha Samy, Heba Shrawy, "Report on the baseline situation for IMAP common indicator 15 “Location and extent of the habitats potentially impacted by hydrographic alterations”," Egypt, 2021.
- Mohamed E. Hereher, "Vulnerability of the Nile Delta to sea level rise: an assessment using remote sensing," *Geomatics, Natural Hazards and Risk,* vol. 1, no. 4, pp. 315-321 , 2010.
- A. H. El-Nahry, R. Doluschitz, "Climate change and its impacts on the coastal zone of the Nile Delta, Egypt," *Environ Earth Sci,* vol. 59, p. 1497–1506, 2010.
- Hemida, Aya A., Marwa Khalifa, Morad Abdelsalheen, and Samy Afifi, "A systematic review of coastal vulnerability assessment methods in the Egyptian context: the case study," *HBRC Journal,* vol. 19, no. 1, p. 161–181, 2023.

- Ibrahim A. Elshinnawy and Abdulrazak H. Almaliki, "Vulnerability Assessment for Sea Level Rise Impacts on Coastal Systems of Gamasa Ras El Bar Area, Nile Delta, Egypt," *Sustainability,* vol. 13, 2021.
- Maged M. A. Hussein and Ebtisam E. E. Mohamed, "Temperature Trend over Nile Delta, Egypt in 20th Century," *Advances in Research,* vol. 7, no. 2, pp. 1-14, 2016.
- IPCC Sixth Assessment, 2023.
- Khaldoon A. Mourad , Lina Nordin , Yvonne Andersson-Sköld , "Assessing flooding and possible adaptation measures using remote sensing data and hydrological modeling in Sweden," *Climate Risk Management,* vol. 38, 2022.
- Marco Neira , Kamil Erguler , Hesam Ahmady-Birgani , Nisreen DaifAllah AL-Hmoud , Robin Fears , Charalambos Gogos , Nina Hobbhahn , Maria Koliou , Leondios G. Kostrikis , Jos Lelieveld , Azeem Majeed , Shlomit Paz , Yinon Rudich, Amal Sa, "Climate change and human health in the Eastern Mediterranean and Middle East: Literature review, research priorities and policy suggestions," *Environmental Research,* vol. 216, 2023.
- Sandeep Kumar, Rajesh Kumar Jatav and Ranjeet Singh, "A REVIEW ON IMPACT OF CLIMATE CHANGE ON WATER RESOURCES IN A RIVER BASIN," *International Research Journal of Engineering & Applied Sciences, IRJEAS,* vol. 8, no. 3, 2020.
- Kassem, H.S.; Bello, A.R.S.; Alotaibi, B.M.; Aldosri, F.O.; Straquadine, G.S., "Climate Change Adaptation in the Delta Nile Region of Egypt: Implications for Agricultural Extension," *Sustainability ,* vol. 11, no. 3, 2019.
- Fares M. Howari, Mohsen M. Sherif, Vijay P. Singh and Mohamed S. Al Asam, "Application of GIS and Remote Sensing Techniques in Identification, Assessment and Development of Groundwater Resources," *Applied Geomatics,* 2007.
- Asaad M. Armanuos, Sobhy R. Emara, Ahmed Shalby, Mohamed I. Metwally, Am Pris John and Abdelazim Negm, "Groundwater in the Nile Delta Aquifer, Egypt: Assessment, Modelling and Management with Climate Change in the Core," in *Groundwater in Arid and Semi-Arid Areas*, 2023, p. 233–287.
- Hereher, M. E., "Coastal vulnerability assessment for Egypt's Mediterranean coast," *Geomatics, Natural Hazards and Risk,* vol. 6, no. 4, pp. 342-355, 2013.
- Ismail Abd-Elaty, Akbar A. Javadi and Hany Abd-Elhamid, "Management of saltwater intrusion in coastal aquifers using different wells systems: a case study of the Nile Delta aquifer in Egypt," *Hydrogeology Journal ,* vol. 29, p. 1767–1783, 2021.
- Kamal Srogy Darwish, "Geospatial Assessment and Mapping of Coastal Erosion Vulnerability Along the Nile Delta Coast: A Remote Sensing and GIS Approach," in *Hazard Modeling and Assessment of the Nile Delta Coast* , 2023, p. 181–218.

- Kamal Srogy Darwish, "Assessment of the Nile Delta’s Coastline Dynamics: A Remote Sensing and GIS-Based Computational Approach," in *Hazard Modeling and Assessment of the Nile Delta Coast*, 2023, p. 101–128.

- Hobbs, B.F, " A comparison of weighting methods in power plant siting," *Decision Sci.,* p. 725–737., 1980.

- Malczewski, J., "GIS-based multi criteria decision analysis: A survey of the literature," *International Journal of Geographical Information Science,* vol. 20, no. 7, p. 703– 726., 2006.

- "GIS-based multi criteria decision analysis: A survey of the literature," *International Journal of Geographical Information Science,* 2006.