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Assessment of Salt-Water Wedge in the Artesian Egyptian Nile Delta Aquifer Lands Using Remote Sensing and Geophysical Techniques

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Abstract

Since the past century, a decline in climate changes rate has been observed, especially along the coastal plains. These changes led to a rise insea water whichremarkably affectedthe coastal zone. The increase of sea water is causing an increment in the water-logged and salt-affected areas. On the other hand, these water-logged and salt-affected areas affected crop productivity and sustainable development acrossthe coastal zones. In this paper, a cost-effective approach will be deployed to monitor the water-logged areas and give recommendations to overcomethis problem. This approach will depend on the joint usage of Remote Sensing data to monitor the surface waterlogged areas together with the geo-electrical techniques results to detect the subsurface salt-affected zones. This precise determination for these areas can help to give recommendations to face this problem. This approach can be applied to all coastal zones around the Arabic countries that are facing the effects of the climate change problem. The results indicated that groundwater quality in this region could be severely impacted by the effects of sea level rise combined with changes in the Nile flow, leading to increased groundwater salinity.

Keywords: Climate change, geophysics, remote sensing,GIS, water logging.

Introduction

This study focuses on the salt-water wedge in the Egyptian Nile Delta aquifer, where most of the water used in agriculture comes from the Nile River. The Nile Delta occupies an area of about 22,000 km2; it represents two-thirds of Egypt's agriculture and represents the most fertile areas in Egypt. It also discusses the indicators of climate change and sea level rise in Egypt. Egypt, as one of the African countries, is particularly vulnerable to this due to climate change and high water usage. The study of coastal systems (Northwestern parts of Nile Delta) is due to it represents the most vulnerable systems to climate change. The dynamic coastal systems often show complex non-linear morphological responses to changes. The expected climate changes are due to some environmental parameters includingstorms, sea waves, sea level, temperature, CO2 concentration, water run-off, and water logging salt-affected soils. Those climate changes could affect the coastal systems either directly or indirectly (through the influences of its effects on both external marine and terrestrial systems). Recently, water logging as one of the most significant climate change indicators was studied by techniques that gave only information about its surface distribution (like remote sensing), but in this proposal, other techniques – like geophysics and GIS - were used to have a comprehensive figure. The use of remote sensing and geophysical techniques such as geo-electrical surveys are used to evaluate the vulnerability of the Nile Delta coast to the impacts of sea-level rise and water-logging. According to the Integrated Coastal Zone Management of the European Commission, coastal areas are considered of huge environmental, economic, social, and cultural relevance. So, implementation of the suitable monitoring and protection actions is very important for the preservation process and also, to assure the future use of this resource. For more than a century, the phenomenon has been investigated worldwide (**Werner and Gallagher, 2006**). Sea water intrusion is affected by natural and anthropogenic processes. Among all current global, environmental and social changes, climate change, is predicted by different global climate models (**IPCC, 2008**), and will have severe future effects, specially in the delta areas. There is a wide range of effects such as: sea level rise, rainfall patterns, floods and droughts frequencies, salinization, and settlement of land. These featuresmay have a significant impact on the natural resources, in particular, water resources either surface or groundwater. This is in particular a problem for the Mediterranean coastal region, and also for north western Nile Delta Coast in Egypt, that natural and socio-economic resources of existing high value and are developed fastly. In Egypt, fringes of Nile Delta covers an area of 22000 km2 (**EGSA, 1997**), whichis occupied by the most populated governorates in Egypt. Also, 60% of Egypt's population lives in the Nile Delta region (**Sherif, 2001**). Due to the soil properties (**Stanley and Warne, 1993; Dawoud, 2004**) and the existing irrigation system, agricultural activities are predominant in this area (approximately 63% of the total agricultural area). A productive aquifer is bounded by an upper semi permeable layer and alower impermeable rock layer. Aquifers are recharged by excessive irrigation in filtration and very limited rainfall that passes through the upper clay layers. The Nile Delta Aquifer is ahuge leaky aquifer between Cairo and the Mediterranean Sea. Coastal erosion in the Nile Delta region is affected not only by man-made coastal protection structures, but also by natural phenomena such as wave-driven coastal currents and sediment transport (**Sherif, 2001**). This region is one of the world's most affected deltas by sea level rise (SLR). Potential impacts of SLRs include increased threats to water security, degradation of groundwater quality, and negative impacts on agriculture and water use. On the other hand, climate change is a major crisis caused by rising average global temperatures. Human activity is believed to be the main cause of global warming (**El Banna and Frihy, 2009**). Coastal erosion in the Nile Delta region is affected not only by man-made coastal protection structures, but also by natural phenomena such as wave-driven coastal currents and sediment transport (**Sherif, 2001**). This region is one of the world's most affected deltas by sea level rise (SLR). Potential impacts of SLRs include increased threats to water security, degradation of groundwater quality, and negative impacts on agriculture and water use. On the other hand, climate change is a major crisis caused by rising average global temperatures. Human activity is believed to be the main cause of global warming (**El Banna and Frihy, 2009**). The Nile Delta has attracted the attention of numerous water scientists, who have studied it from various angles and have concentrated on either surface water or groundwater. Aquifers are characterised, categorised, and examined using a variety of instruments. According to the majority of studies, climate change is a serious problem that needs to be addressed immediately (**Sherif, 2001; Hereher, 2010; 2011**). The region's groundwater quality may be negatively influenced by the effects of sea level rise and changes in the Nile flow, which could result in higher groundwater salinity (**Dawoud, 2004**). This article deals with identification of the intruded salt-water wedge in the artesian Egyptian Nile Delta aquifer. The case is unique because most of this aquifer is invaded by salt water, and the major portion of its annual ground-water recharge is derived from the direct seepage from the Nile River and the huge net of irrigation canals serving about 3 million acres (11,561 km2) of fertile land, as well as the infiltration of excess irrigation water. The use of remote sensing data has been reported widely for monitoring water-logging patterns. After studying various case studies, it could be concluded that image processing techniques through extremely useful, should essentially be used in conjunction with field data like geophysical data. The geophysical data include geo-electrical surveys that have a great potentiality in imaging and detecting subsurface characteristics such as water table and the different types of ground aquifers as well as the hydrostatic levels for these aquifers will be used to monitor the subsurface water conditions. The saturated topsoil that is present in water-logged areas could detected through satellite image processing, but in other cases that have unsaturated topsoil could be classified as a not logged area while it suffered from water logging problem but not expressed at the surface as saturated topsoil. This second type of unsaturated topsoil needs detailed field studies such as the geophysical surveys and field observations in parallel with satellite image processing and GIS techniques. As results indicate, there are a number of achievements could obtained by using remote sensing techniques in adentifying the logged areas, it compatible with high precentages with those results obtained from geo-electrical studies for those areas. The overall aim of this research work was to find the degree of success of remote sensing as a new tool of monitoring waterlogging.

The study area

The primary study region is Egypt's Nile Delta, which is degrading and posing health risks to the public as a result of industrialization, population expansion, and economic development. The area is susceptible to the effects of climate change, including rising sea levels, less precipitation, and problems with water security.

The Nile Delta's upper northwest region (30°0´E, 30° 45´E and 31°0´N, 31°30´E) is the study site. The research region is significant because, at 1,360 people per km2, it is among the world's most densely populated agricultural areas. Although making up only 2% of Egypt's total territory, it is home to 41% of the country's population and over 63% of its agricultural land. Figure 1 shows an illustrative location map of the study area.

Materials And Methods

The image processing analysis was performed in the Remote Sensing and GIS. Laboratory, Department of Natural Resources Survey, Environmental Studies & Research Institute, Sadat City University- using ERDAS IMAGINE (Version 9.2) software from ERDAS Inc.,. Vector data from maps were digitized; GIS analysis and processing were performed with both ARC-INFO and ARC-VIEW software from Environmental Systems Research Institute (ESRI Inc.).

The main materials used

(1) Maps, encoded by digitizing it, then editing it to restore any digitizing errors
(2) Satellite images from LANDSAT ETM images acquired in 2020.

In addition to all collected Geo-electric results data from other Authors (to be used in verification with satellite remote sensing image processing results).

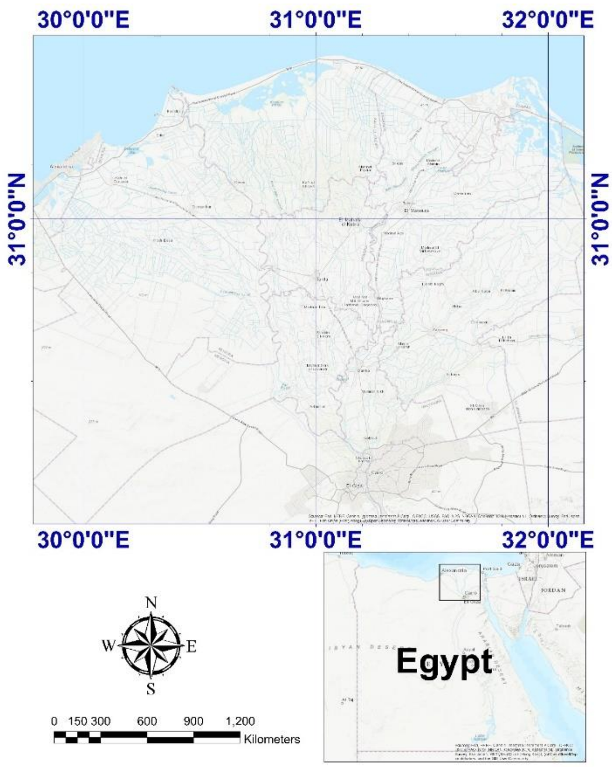

Fig. 1. Map of the study area.

First, for the study area, the spatial data used is the LANDSAT satellite images, the sensor has a spatial resolution of 30 m for the six reflective bands (after exclusion the thermal band 60 m), and includes a panchromatic (pan) band with a 15 m resolution, spheroid International, and

Datum European 1950.with a 15-meters grid. (After mergingthe images together). A first order polynomial transformation is found to be the best model that gives the minimum RMSE.

Image classification groups pixels into classes based on their spectral attributes and assigns them to information classes. There are two types of classification: Unsupervised, using no prior knowledge, and supervised, using analyst-provided training data. According to many publications (give examples of these references), the best way to get perfect image classification results, is to use the "Hybrid" classification technique. That technique refere to unsupervised followed by supervised classification.

Image classification

Both unsupervised classification and supervised classification were applied. Processing of the study area achieved using LANDSAT7-ETM+ dated 2020. A false and color composite was produced by combination 432-RGB. The thermal band in Landsat was excluded in order to have high accurate classification.

After processing, clustering technique (unsupervised classification) 255 classes were correlated on the basis of their spectral signature, similar classes were combined to produce land cover file.Then, 28 ground control points (GCP) were collected during afield survey and using stratified random distribution algorithm, in two separate groups (each of them represented by 28 points). By the mean of both GCP's and signatures obtained from unsupervised classification, the scene was supervised classified using Maximum Likelihood Classifier (MLC) algorithm.

CORINE classification scheme was used to nominate all classes obtained. CORINE standard classification scheme that established by the European Commission was used. This classification scheme aimed at gathering information relating to the environment on certain priority topics for the European Union (land cover, coastal erosion, biotopes, etc.) (**Centre for Ecology and Hydrology, 2002**).

Results and Discussion

Classification of the study area achieved using LANDSAT7-ETM+ dated 2020. A false and color composite was produced by combination 432-RGB, Fig. 2. After processing clustering technique (unsupervised classification) 255 classes were correlated on the basis of their spectral signature. Similar classes were combined. Then, with the field survey data the scene was classified by supervised classification technique (Maximum Likelihood Classifier MLC algorithm). Only 7 themes or classes were found separableas depicted in Fig. 3), Those 7 classes are:

1.Deep water (open sea); 2. Shallow water (include the coastal water);
3.Vegetation (type 1); 4.Vegetation (type 2);
5.Bare soil; 6. Soil (type 2) 7. Urban

As the main goal of this study is to identify the specific areas with high water content (qualitatively not quantitatevely) the detailes of classification process (like GCP, training areas, confusion matrix, … etc.) were ommited to meet the paper goals and its qualitative approach.

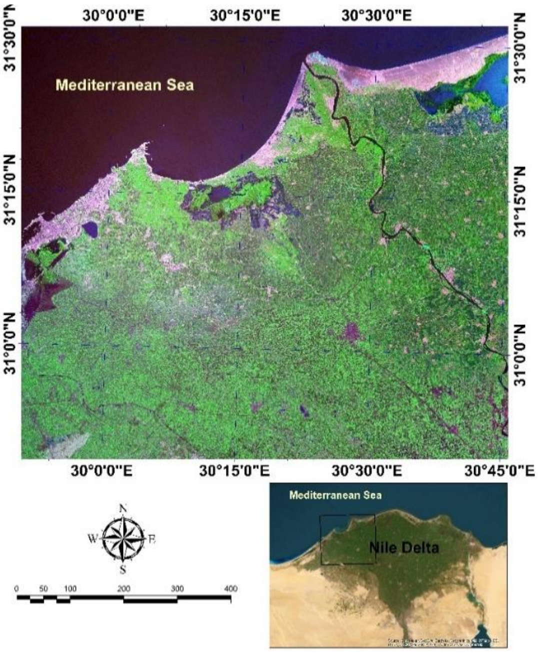

Fig. 2. False Color Satellite Image of the Study Area.

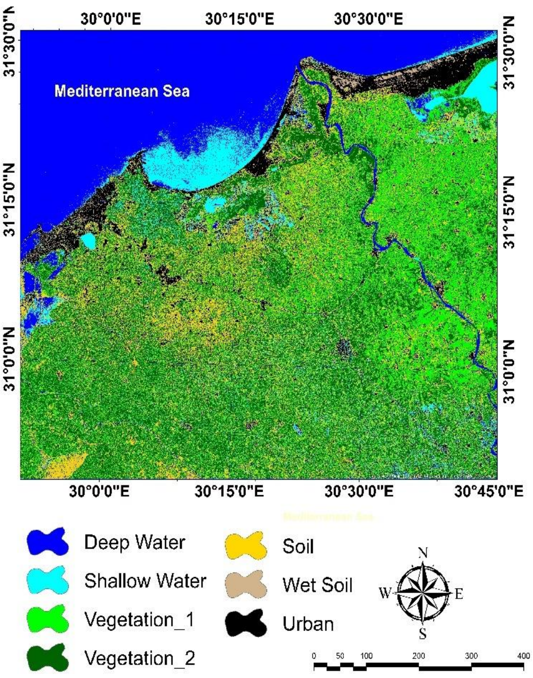

Fig. 3. Supervised Classification Image of the Study Area.

Classification Accuracy assessment

After finishing classification process and producing the supervised classification image, vector file represented the selected training areas, which created before - during the training stage of classification. Classification accuracy were 97.15%.

Identifying water-logged areas

As the main goal of the paper is to measure the potentialof remote sensing techniques in identifying the water-logged areas (like those areas affected by saltwater intrusion according to climate changes), this step is performed to obtain a separate GIS layer for this type (which named in supervised classification images as Soil type 2, as shown in Fig. 4). this class represents those areas affected by water and salts, and could be sabkha or water-logged areas.

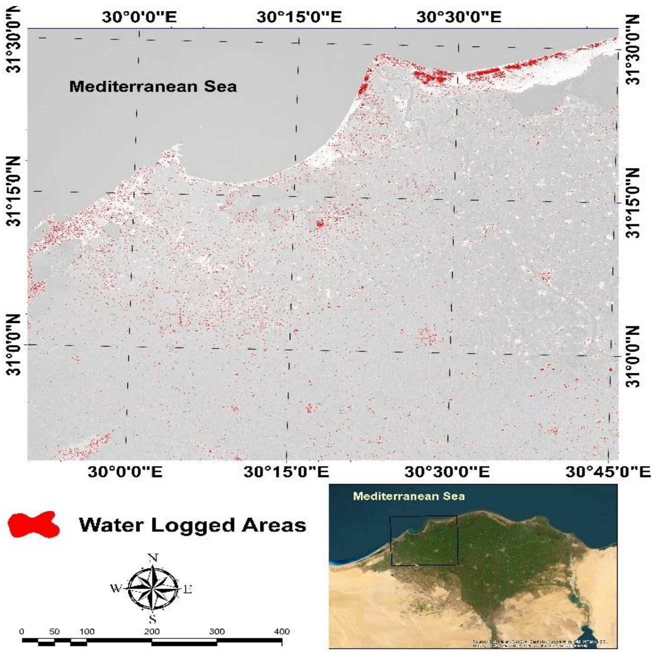

Fig. 4. Distribution of Water-Logged Areas in the Study Area.

Verification of Results

The next step after creating a layer of possible water-logged areas, is the verification of the geophysical data of the hot spots or areas. This step is to identify the actual type of each hot spot, to clarify if it belongs to the estimated class (water-logged area) or belongs to other class (ex. sabkha). It was noticed that controlling salinity and seawater intrusion still need to future strategies andtherefore it is essential for the adaptation and mitigation of salt water intrusion into the Nile Delta Aquifer. Still also need a number of methods to adopt for controlling seawater intrusion to protect groundwater reserves in the aquifer.

Conclusion and Future work

Research outcomes can beconsidered a powerful approach that wouldbe used to determine the water-logged and salt-affected areas whichare located around the coastal areas and can be affected by climate change. The matching of remote sensing and geophysical techniques together with the recent field data is considered to be a very robustaddition to improve results and get out precise outcomes that make this approach applicable to determine the water-logged areas distributed at the coastal areas which distributed over most the Egyptian coastal areas and other Arabian countries.

Of course, the continued record of high-quality satellite altimeter observations of the ocean, further improvement of the international ground reference framework, and maintenance and expansion of the associated geodetic network are top priorities. These improved observations could, for example, explain changes in the gravitational field associated with the evolution of mass distribution on Earth, or use observations of sea-level rise, ocean thermal expansion, and sea-level rise. should be combined with a more sophisticated analysis of Changes in the Earth's cryosphere in mixed solutions.

To address these challenges, irrigation strategies need to be changed in and a reduction in pollution sources is crucial. Egypt is particularly vulnerable to water stress because of its high water utilization rate, driven mostly by agriculture which contributes to the national GDP. Inefficient irrigation systems and unsustainable agricultural practices are causing problems such as high water losses and land productivity decline. Remote sensing and GIS techniques, along with field data, can be used to assess the vulnerability of the Nile Delta coast to sea level rise and monitor water-logging patterns.

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