Alexandria University
Alexandria Research Centre for Adaptation to Climate Change
(ARCA)

Developing a Reliable Digital Elevation Model for Climate Change Applications

Case study: The Nile Delta, Egypt

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1. Introduction

The vulnerability of coastal areas to climate change associated risks, in particular, inundation by sea level rise (SLR) is usually determined by a number of factors including global or absolute sea level rise, relative sea level rise which is the sum of global sea level rise and vertical movement of land, land topography and its elevation. Accordingly, any vulnerability assessment should, on one hand, integrate all these factors and on the other hand, such an assessment should be based on accurate elevation information.

When assessing physical vulnerability to inundation by sea level rise, the sea level rise takes place gradually and ranges, according to different scenarios, from a few centimeters to one or two meters. This, in turn, necessitates the availability of an accurate elevation information reflecting subtle variations in land topography and elevation. Moreover, the reliability of assessment results is based generally on the accuracy of elevation information that is utilized in such an assessment. Therefore, before assessing the vulnerability to inundation by sea level rise, the employed elevation information and its source should be firstly examined to ensure that such information captures the land topography accurately and consequently, can provide more reliable results.

Traditionally, land elevation information is extracted through interpolating raster surface on the basis of elevation information of spot heights or contour lines depicted on topographic maps. The accuracy of the produced raster surfaces, in such a case, relies mainly on the interpolation method and the density of spot heights or contour lines assuming accurate topographic maps. In addition to such traditional source of elevation information, remote sensing techniques provide satellite imagery-based Digital Elevation Models (DEMs) such as ASTER and SRTM (Bhakar et al., 2010).

Such satellite imagery-based DEMs are characterized by low absolute vertical accuracy ranging from 16 to < 5 meter (Zandbergen, 2008; Valeriano and Rossetti, 2012). In some applications such as the vulnerability to inundation by sea level rise where the risk ranges from 26 – 82 cm on average according to RCPs scenarios, using of such satellite imagery-based DEMs may be misleading.

The Nile Delta, which has high concentration of population, economic activities and infrastructure and services, is expected to be highly susceptible to climate change and associated sea level rise. Accordingly, the vulnerability of the Nile Delta to inundation by SLR was repeatedly assessed (Abdrabo and Hassaan, 2015, El Raey et al., 1999, El-Nahry and Doluschitz, 2009, El-Raey, 1997, El-Raey et al., 1999, El-Raey et al., 1995a, El-Raey et al., 1995b, Frihy, 2003, Hassaan, 2013, Hassaan and Abdrabo, 2013, Milliman et al., 1989). The previous research work estimated that considerable proportions of the Nile Delta are expected to be inundated by sea level changes.

It should be noted that the previous assessments utilized old source of elevation information and adopted outdated methodologies. For instance, mostly, assessments were based mainly on topographic maps of scale 1: 100,000 and 1: 50,000. This, in turn, entails the need for generating more accurate and reliable elevation information in the case of the Nile Delta. For this purpose, a systematic methodology should be developed to integrate various data sources, update elevation information and employ updated information elevation in generating accurate and reliable DEM.

2. Objective

The main objective of this report is to develop and apply a systematic approach to generate an accurate and reliable DEM for the Nile Delta. The suggested approach is discussed in details in the third section of this report, while, the fourth section is concerned with discussing the implementation of the suggested methodology and assessing the accuracy of the produced DEM.

3. Methodology

Creating an accurate DEM for the Nile Delta has a number of challenges including:

- The dynamic nature of the Nile Delta shoreline, which considerably affected the morphology of the Nile Delta coastal zone particularly the delta promontories.
- In response to the dynamic nature of the shoreline, a number of protective measures were undertaken to slow down shoreline retreat. These measures included constructing seawalls alongside the Nile delta in different locations during late 1980s and early 1990s. Such seawalls have a relatively high elevation, thus they changed notably the morphology of the shoreline in different parts of the Nile delta. However, due to their local situation and limited extension, these man-made features are not shown on topographic maps; the traditional source of elevation information.
- Outdated and generalized elevation information of the Nile Delta. Traditionally, elevation information is extracted from topographic maps of scale 1: 50,000 or scale 1: 100,000, which were produced during late 1980s and early 1990s. The relatively small scale of such old maps obscures subtle elevation information, which may exist at local level.

To produce an accurate and reliable Dem for the Nile Delta, there was a need to address these challenges. For this purpose, a methodology of three steps was developed. The suggested methodology consists of three main subsequent steps: data preparation, data manipulation and data interpolation (Figure 1). The following sub-sections will discuss each of these three steps in detail.

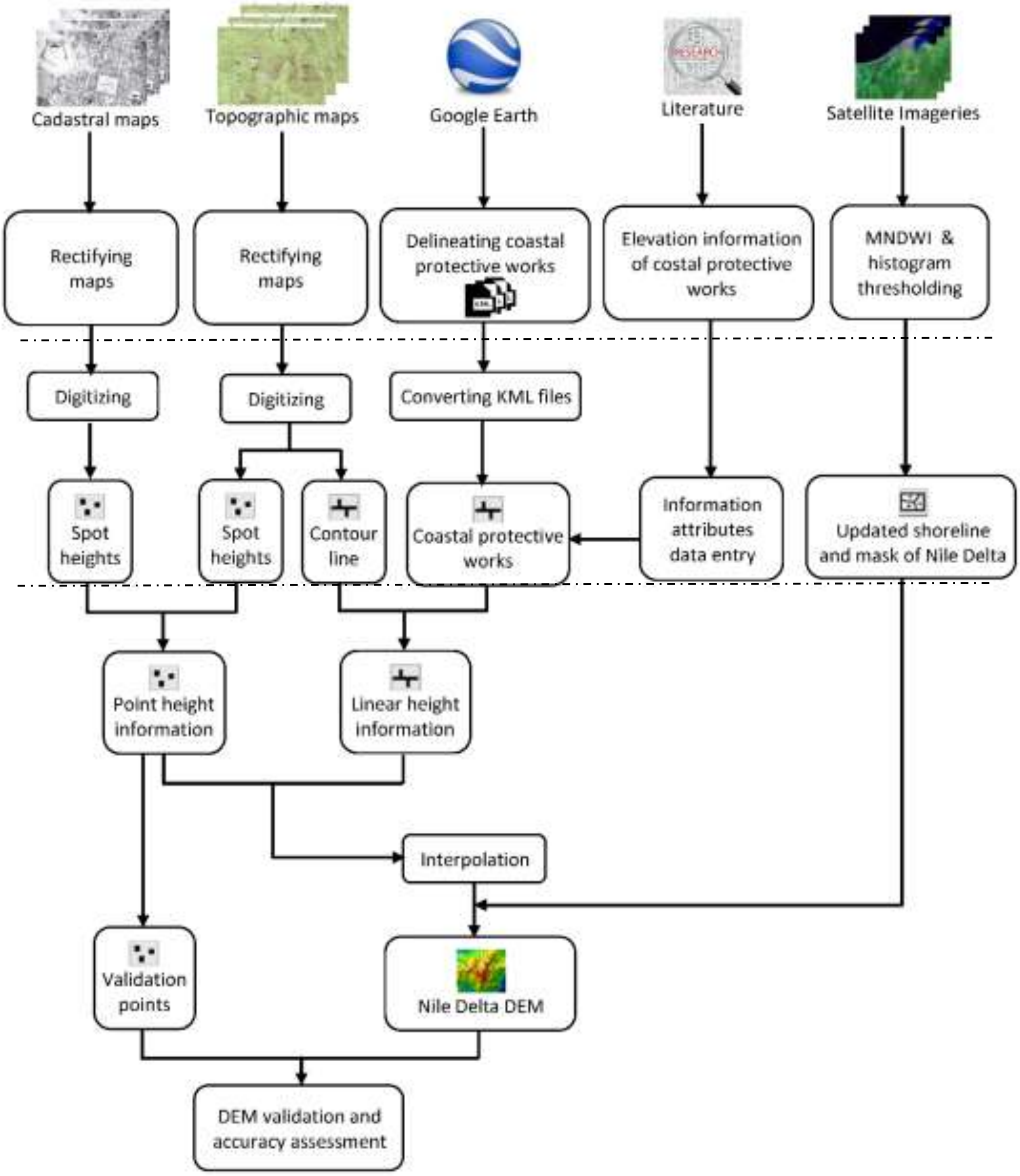


Figure 1: Scheme/ workflow (of the Methodology) for generating a reliable DEM for the Nile Delta showing five data sources used to extract point and linear height information followed by interpolation and validation

4. Implementation of the developed methodology

4.1. Data preparation

This step included developing a list of potential different sources of elevation information and integrating elevation information from these sources. For this purpose, the following data sources were utilized (Table 1).

Table 1: Different data sources of elevation information

Source	Data to be captured
Topographic map scale 1: 50,000	Delineating spot heights
	Delineating contour line
Cadastral map scale 1:500	Delineating spot heights
Google Earth	Delineating recent coastal protection engineering works
Literature	Acquiring attribute data on coastal protection work
Satellite imageries	Updating shoreline

4.1.1 Topographic maps of scale 1:50,000

These topographic maps were produced by the Egyptian General Survey Authority (EGSA) in early 1990s with technical assistance from Geonex Corporation as part of a project with the United States Agency for International Development (USAID project number 0132-263). These maps depict elevation information in the form of contour lines with 1-meter interval and spot heights. The area of the coastal governorate of the Nile Delta was covered by 50 topographic maps scale 1:50,000 (Figure 2).

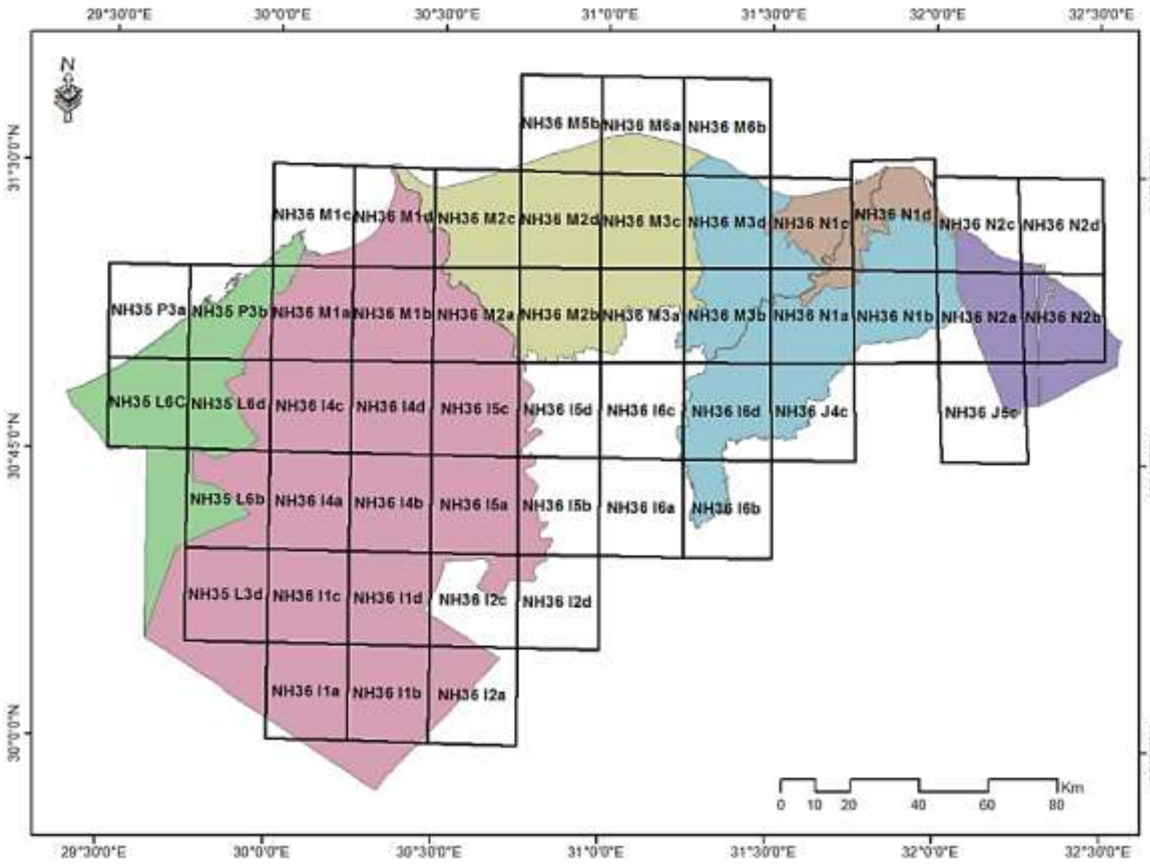


Figure 2: Index of EGSA Topographic maps of the Nile Delta coastal governorates

4.1.2 Cadastral maps scale 1:5000

Cadastral maps reveal valuable elevation information in the form of spot heights and contour line. Yet, these type of large scale and detailed maps were produced only for the built-up area of urban centers and the peripheral areas and urban-rural margins were not delineated in the cadastral maps. Collected from various data sources, 32 cadastral maps of scale 1:5000 for Alexandria city were acquired, which were produced by EGSA in the late 1970s.

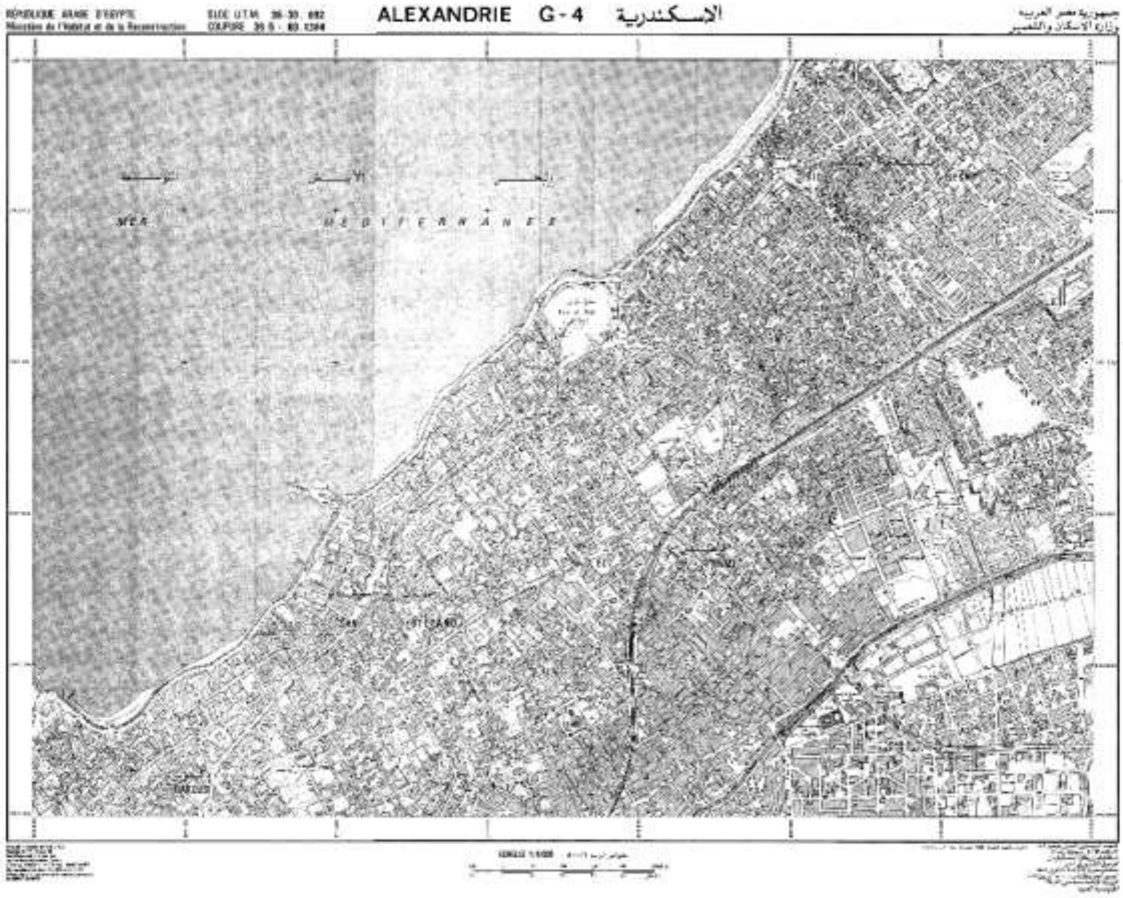
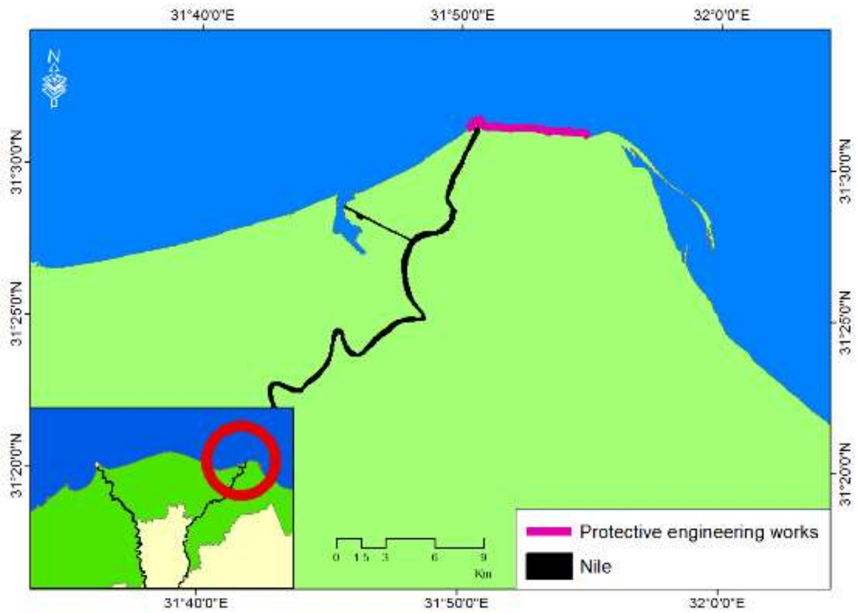


Figure 3: Example of a Cadastral map of scale 1:5000 for Alexandria

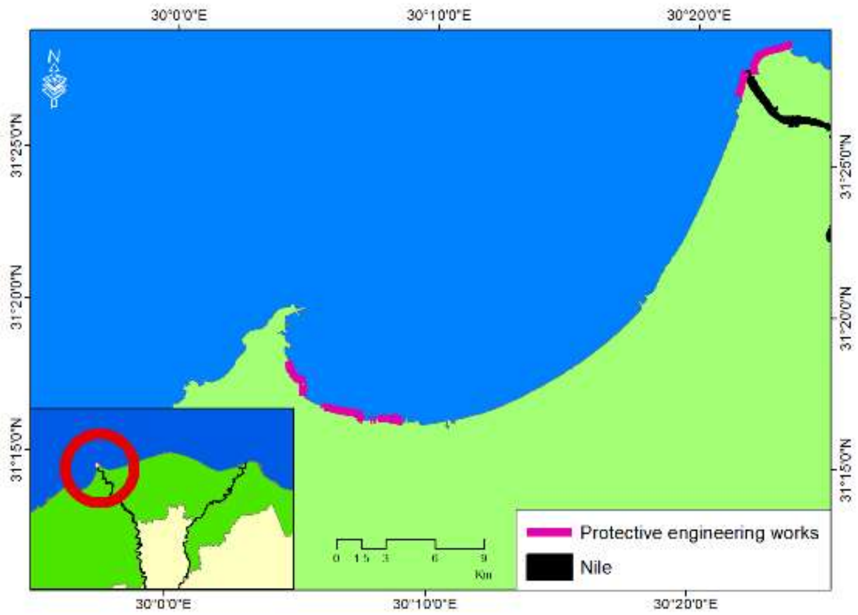
4.1.3 Google Earth

As the available cadastral and topographic maps were dated to the late 1970s and 1990s, respectively, these maps didn't reflect a number of man-made structures, which erected more recently and have changed the morphology and topography of the shoreline despite their limited extension. For example, as a remedial action to deal with retreating shoreline accelerated during 1970s and 1980s, a number of protective measures were undertaken. Such engineering protective works were not depicted in neither cadastral nor topographic maps due to their limited extension and being recently established.

Many of these local man-made features were delineated through Google Earth and a number of KML files representing the location and extension of each of these features were created (Figure 4).



(a) Damietta promontory



(b) Rosetta promontory and Abu Qir Bey

Figure 4: Protective engineering works along the coast of the Nile Delta as obtained from Google Earth

4.1.4 Literature

To collect data on the attributes of the protective engineering works, in particular elevation information, various literatures were reviewed. Table (2) summarizes the attributes of main protective engineering works alongside the coastline of the Nile Delta extracted from literature. Generally, the height of the protective engineering works ranges between 2 and 6.75 meter above mean sea level. This means that they have significant impact on the topography and morphology of the coast line alongside the Nile Delta. Accordingly, integrating their heights in generating DEM for the coastal zone of the Nile delta is necessary for ensuring accuracy of such a DEM.

Table 2: Attributes of main protective engineering works established alongside the Nile Delta coastline

<table>
<tr><th colspan="2">Construction</th><th>Type</th><th>Built Date</th><th>Reinforce Date(s)</th><th>Height (m)</th><th>Reference</th></tr>
<tr><td rowspan="2">Damietta Seawall</td><td>East seawall</td><td rowspan="2">Dolos seawalls</td><td rowspan="2">-</td><td rowspan="2">-</td><td>6.75</td><td rowspan="2">(Frihy, 2003)</td></tr>
<tr><td>West seawall</td><td>6.75</td></tr>
<tr><td rowspan="2">Rosetta Seawall</td><td>East seawall</td><td>Dolos</td><td>1989-1991</td><td rowspan="2">-</td><td>6.75</td><td>(Frihy, 2003)</td></tr>
<tr><td>West seawall</td><td>Groins</td><td>1989-1990</td><td>6.75</td><td>(Ismail et al., 2012)</td></tr>
<tr><td colspan="2" rowspan="4">Muhammed Ali Seawall</td><td rowspan="4">Groins</td><td>1780</td><td>1980</td><td>2.5</td><td>(Frihy, 2003)</td></tr>
<tr><td rowspan="3">1830</td><td>1920-1930</td><td rowspan="3">2 – 3</td><td rowspan="3">(Ismail et al., 2012)</td></tr>
<tr><td>1981</td></tr>
<tr><td>2011</td></tr>
<tr><td colspan="2">Alexandria, Eastern Harbor</td><td>Seawall</td><td>-</td><td>-</td><td>2.5 – 4.5</td><td>Personal contacts with Coastal Protection Authority</td></tr>
</table>

4.1.5 Satellite images

It was noted that, the shoreline of the Nile delta has been changing dramatically due to coastal hydrodynamics. Accordingly, there was a need for updating shoreline delineated from the topographic maps, which were updated as previously denoted. To update the shoreline of the Nile Delta, three Landsat imageries were utilized (Table 3).

Table 3: Satellite imageries

Type	Path	Row	Acquisition date
Landsat 7	176	38	11/11/2000
Landsat 8	177	38	07/11/2013
Landsat 8	177	38	23/11/2016

4.2. Data manipulation

This involved all processes related to data extraction from different data sources and integrating different forms of elevation information into one geo database for the Nile delta.

4.2.1 Maps rectification

Firstly, all topographic maps were rectified to GCS_WGS_1984 coordinate system. This is followed by digitizing contour lines and spot heights on these maps. Similarly, the cadastral maps were rectified to UTM WGS84.

4.2.2 Maps digitizing

This step involves creating point and line feature classes and digitizing elevation information of clearly identifiable reference points (spot heights) and contour lines from the rectified maps. The total number of spot heights from cadastral maps and topographic maps was 49971 points of which 60 points were selected for accuracy assessment purpose, and the remaining 49911 were employed in interpolating DEM for the Nile Delta. Furthermore, 2399 contour lines were digitized from topographic maps in addition to 39 linear elements representing various engineering protection works alongside the coastline of the Nile Delta. This brings the total number of linear features with elevation information (contour lines and engineering protection works) to 2438. The attributes of both linear and point features will be employed in interpolating DEM for the Nile Delta.

4.2.3 Converting KML files into feature class

All KML files delineated through Google Earth representing coastal engineering protective works alongside the coastline of the Nile Delta were converted and integrated into one line feature class and their elevation attribute was updated.

4.2.4 Image analysis

Satellite imageries were interpreted to extract updated shoreline of the Nile Delta through a combination of Modified Normalized Difference Water Index (MNDWI) and histogram thresholding techniques.

MNDWI was used generally to derive water surfaces from Landsat images according to the following equation:

$$MNDWI = \frac{GREEN - MIR}{GREEN + MIR}$$

MNDWI is based on the fact that water surfaces have high reflectance in green wavelengths compared to Mid Infrared wavelengths (MIR) (Figure 5). Therefore, the resulted value of MNDWI is expected to be positive for water surfaces and negative for other land covers than water (Xu, 2007). MNDWI is a better discriminator of water bodies compared to the more famous Normalized Difference Water Index (NDWI) as it better separates the water from the built-up areas. Thereafter, histogram thresholding technique can be applied to separate water bodies from other land covers and shoreline is consequently delineated.

As a result, a new updated shoreline of the Nile Delta was delineated and utilized in creating a polygon feature class representing the mask of the Nile Delta territory.

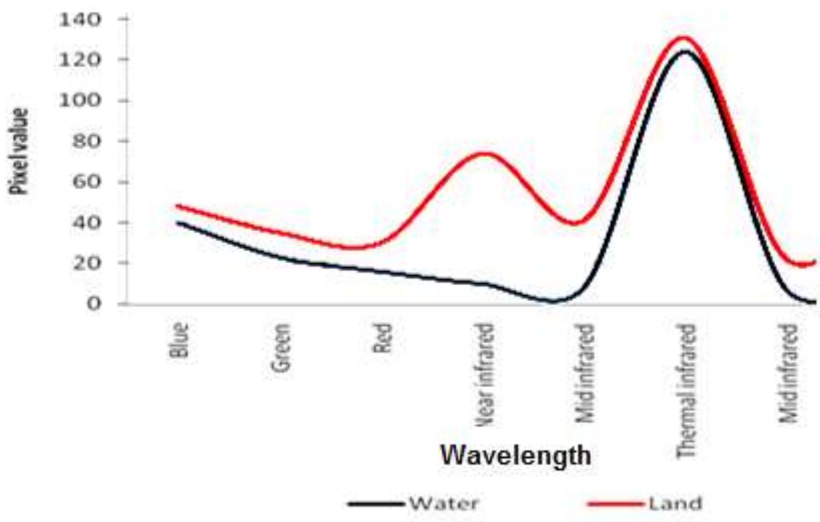


Figure 5: Varied spectral behavior of water and land surfaces

4.3 DEM production

4.3.1 Raster interpolation

The vector point and line feature classes representing spot heights and contour lines digitized from EGSA maps were used to produce DEM for the Nile Delta through interpolation. Simply, interpolation means estimating unknown values that fall between known values. Accordingly, a raster surface is produced representing the surface value in all parts of the considered area. Using spot heights and contour lines digitized, a DEM for the Nile Delta was produced (Figure 6) through interpolation (Topo to Raster Tools). Also, the polygon feature class of delta territory created in step (3.2.4) was employed to mask the interpolated DEM.

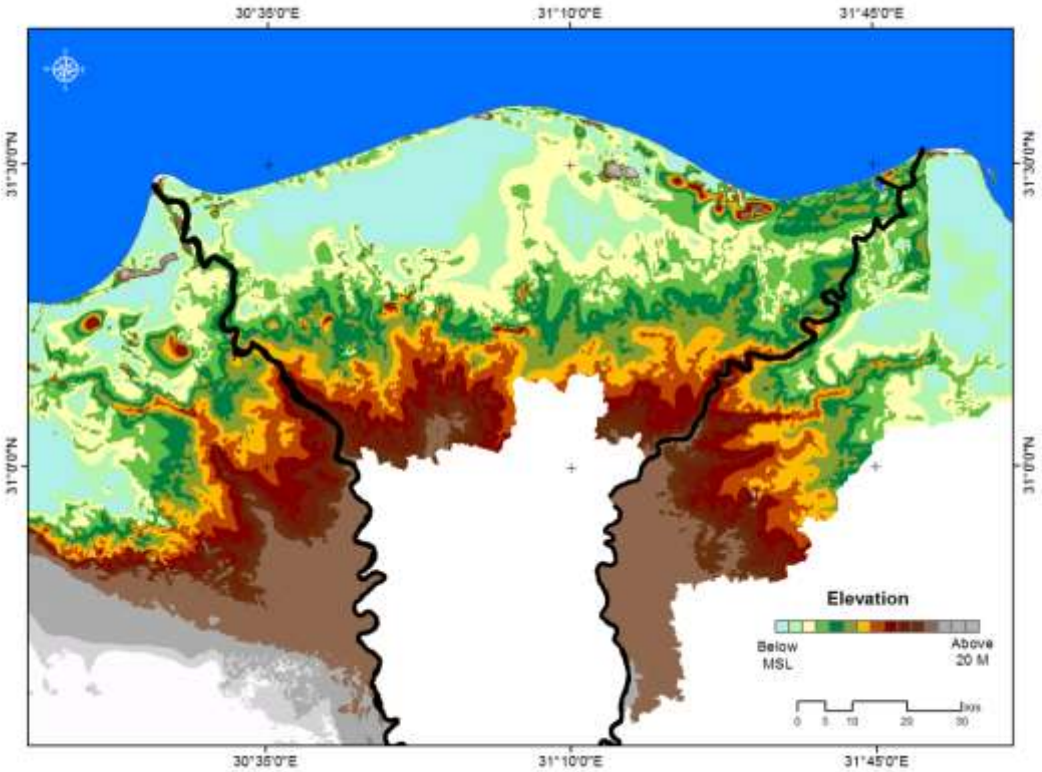


Figure 6: DEM for the Nile delta produced using the propose methodology

4.3.2 Accuracy assessment

To assess the accuracy of the produced DEMs, 60 points representing spot heights digitized from topographic maps of scale 1: 50,000 and cadastral maps of scale 1:5000 were selected randomly for this purpose.

Using these 60 points, the cell value of interpolated DEM at the locations of the reference point was extracted and the value was recorded at the attribute table of the reference points.

Firstly, the interpolated values of these points were compared to their reference values, in this respect the scatterplot of interpolated values versus reference values revealed high level of consistency (Figure 7).

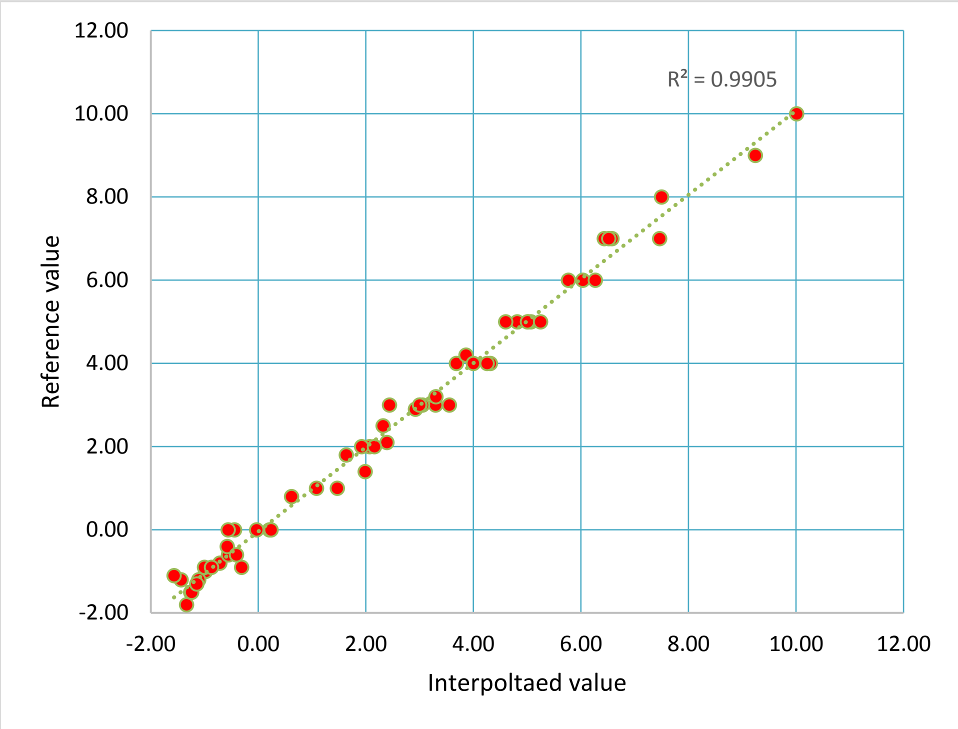


Figure 7: The scatterplot of interpolated values vs reference values showing a strong correlation

This was followed by calculating mean absolute error (MAE) between interpolated DEM and reference points which refers to how far the elevation information of the interpolated DEM deviates from the elevation information of reference points on average. Generally, MAE is estimated according to the following formula:

$$MAE = \frac{\sum_{i=1}^{n}(|\,Z_i\ - Z^r{}_i\,|)}{n}$$

Where:

MAE is the Mean Absolute Error

Z_i is elevation values extracted from produced DEM

$Z^r{}_i$ is elevation value of the corresponding reference point at place *i*.

n is number of points.

The accuracy assessment that involved comparing elevation information extracted form SRTM-based DEM and that of reference points revealed the estimated Mean

Absolute Error (MAE) was 24 CM. This means that the elevation information of SRTM-based DEM is on average within ±24 CM of the reference points, with minimum and maximum error was 0 and 59 Cm, respectively. Compared to the magnitude of expected sea level rise that range from 26 to 82 Cm under different RCPs scenarios up to 2100, such a relatively low error makes the produced DEM more sensitive different scenarios of risk (sea level rise) and thus indicates to its reliability in assessing vulnerability of inundation by sea level rise.

5. Final note

Creating DEM for the Nile Delta is one of the prerequisites for assessing the vulnerability to climate change impacts, in particular, inundation by sea level rise. Due to the crucial role of DEM and its importance, there is a need for producing reliable DEM reflecting subtle variations in the elevation of the Nile Delta. For this purpose, a systematic methodology for generating a reliable DEM for the Nile Delta was developed.

The developed methodology benefited from all elevation information extracted from available data sources including topographic maps with different scales. Yet, dramatic changes in the Nile Delta shoreline during the last four decades and undertaken measures to slow down shoreline retreatment, which entails building a number of protective measures, had significant impacts on the morphology of the Nile Delta coastline. This, in turn, made the elevation information of some parts of the Nile Delta coastline outdated and needed to be updated. For this purpose, ancillary data sources were employed including literatures, which have some detailed information on protective engineering works built mainly since early 1990s and their elevation information.

As a result of the developed and implemented methodology, a more reliable DEM for the Nile Delta was produced. This DEM will be employed in various research activities to be undertaken by ARCA, either solely by its core team or in collaboration with other researchers and/or research institutes interested in climate change work.

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