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Building Automated Navigation System for River Nile in Egypt Using Remote Sensing and GIS Techniques

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Abstract In recent years the Government of Egypt initiated the efforts towards developing a navigation system in River Nile in Egypt. These efforts will increase the revenue from tourism; reduce the cost of shipping and the load on transportation network and overcome tourism ships which stuck near Luxor and Aswan city that happed every year during the peak of the tourism season between November-February due to decrease in water level that can affect 300 tourism boats with a capacity for accommodating over 60,000 tourists per week. Developing River Nile navigation system depends on the availability of updated data and information for River Nile depths all over the year in order to identify the best route that can be used for ships. River Nile water level always changes that effect changing of River Nile depths. This point is critical and has entertained thinking about using remote sensing technology that can derive bathymetric data from high-resolution multispectral satellite imagery. In this paper, Stumpf algorithm for estimating shallow water depth from multispectral data is applied in our study area near Esna district. This methodology is based on linear logarithm ratio model between image bands; the retrieved bathymetry is compared with echo sounder data. The validation results show that the applied method has acceptable performance, and the Root Mean Square Error (RMSEr) is 0.79 m. Then the second part in this paper building an automated navigation system for River Nile fleet in Egypt using Linear Reference and Dynamic Segmentation techniques based on the above retrieved bathymetry data and the other available collected data from different resources. The developed application is integration between Geomatics Engineering and Software Engineering on how maps, data, functions and information were used in a useful way using programming language to allow operation of all inertial navigation.

Keywords Bathymetric Mapping, Multispectral Remote Sensing, Linear Logarithm Ratio Model, Linear Reference System, Dynamic Segmentation and Automated Navigation System

1. Introduction

The Rive Nile has been recognized as a navigable channel throughout the history of Egypt. It extends for about 950 km from Aswan High Dam to Cairo, divided into two branches, Rosetta and Damietta branch, each branch is about 200 km in length and finally reaches the Mediterranean Sea [22], as shown in Figure (1).

The total drop in bed level from Aswan to the Mediterranean is about 80 m over 1100 km length. Therefore, the River Nile has a gentle slope, a low energy with a controlled discharge and water level, [3], as shown in Figure (2).

The increase in the River Nile fleet does not match the existing facilities on the River Nile. Change in the level of the River Nile bed and continues change of the water levels; along the River Nile from Old Aswan Dam to Delta Barrages are the significance problems that face the navigation in the River Nile. Most boats start to face problems when the discharge is less than 100 million m^3/day. Boats which have draft higher than 1.5 m find serious difficulties and when cruising as the flow discharge reaches 65 million m^3/day. Unfortunately, the peak season for hotel boats and tourism is during the period November-February [23]. This period matches the low discharge period, the issue, which is considered a real threat to the tourism industry. Besides; there are other problems such as: boat navigators are not well trained and rely on their basic experience about the River Nile path. The modern navigation channel does not exist by any standards the absence of the suitable navigational aids and landmarks, [22, 24]. In recent years the Government of Egypt initiated the efforts towards developing the River Nile navigation. These efforts will increase the revenue from tourism, and reduce the cost of shipping. The River Nile navigation has great importance because it will reduce the

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load on road transportation system with the drastically increased of population way of cargo transportation and tourism goods need to be transported inside Egypt. Reduce the ever increasing overcrowding on Egyptian motorways. Decrease in the air pollution and overall transport cost. Increasing the investment creation of job opportunities financed by new businesses based on rural cities [26].

Figure 1. The River Nile in Egypt [25]

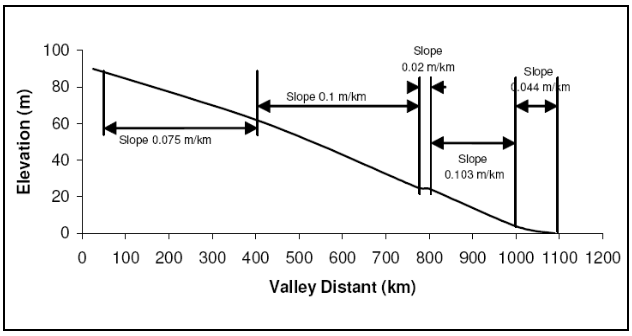


Figure 2. The River Nile Elevations in Egypt

Remote sensing technology is able to penetrate water column and identify shallow water objects [10]. Remote observations provide relatively low-cost information on shallow water bathymetry, compared to other known bathymetry retrieval techniques, such as Lidar scanning, multibeam systems and singlebeam echo sounder [6]. These methods provide high resolution and accurate data, but surveying in those cases is usually expensive and time consuming [7, 12]. The use of remote sensing imageries in shallow water habitat and bathymetric mapping was initiated by using medium and high resolution satellite images [21]. Sutanto [20] stated that multispectral sensor, can penetrate up to 20 meter below the sea surface in a clear water condition. Madden [15] used band ratio method of several Worldview-2 imageries bands and found that bands combination was the best to enhance shallow water bathymetric information. Alsubaie [8] who performed bathymetric mapping research in San Francisco Bay also agreed that band ratio gave a proper result. Guntur [10] argued that higher water turbidity results in less electromagnetic spectrum penetration through water column. In recent years many experiments aiming to estimate bathymetry in optically shallow waters with the use of remote optical observation. [4, 5] Basically, the most popular fundamental models of determining the bathymetry from optical imagery are defined, namely: the empirical optical band ratio transform algorithm proposed by Stumpf [19] using bottom albedo-independent bathymetry algorithm. Calibration of relative water depths resulted by this algorithm was done by using a set of ground truth points and another analytical approach proposed by Lyzenga [13, 14] and Philpot [18]. GeoEye satellite image used here to examine bottom albedo-independent bathymetry algorithm band ratio for providing shallow water bathymetric information. RMSEr calculated with respect to echo sounder traditional data. Then, building an automated navigation system for River Nile fleet in Egypt using Linear Reference and Dynamic Segmentation techniques based on the above retrieved bathymetry data and other collected data achieved. This developed system is available for MS WINDOWS and allows the user an easy operation of all inertial navigation. The developed application supports the system configuration and provides data visualization in real-time. It includes a powerful wizard to guide the operator step by step. This navigation system will help the fleet's navigators to navigate safely by getting all available surveying data like locations along River Nile (start and end coordinates points) or by real time pick up location, directions along River Nile with tracking the trip, route with suitable water discharge, water depths, River Nile width, nearest ports, barrages, dams, allowable speed and carry.

2. Available Data Used

2.1. Available Traditional Data from Echo Sounder

Traditional depths were measured by echo sounders with singlebeam and GPS receivers were applied in the area of Esna Bridge. It was essential to carry out fieldwork, using the most modern and accurate equipment in order to obtain useful information about the water depths and river bottom type. The fieldwork was under taken at (22-6-2009) with the acquisition of the GeoEye satellite imagery date. The reason for conducting this survey at the same time as image acquisition was to obtain more accuracy in the study methodology. A differential GPS positioning system was used for this work was an accuracy of ±20cm, to obtain accurate horizontal coordinates. [1, 2]

2.2. Available Satellite Image Data

GeoEye satellite image with 1.65 m spatial resolution over chosen study area, collected in 2009-07-10 08:40 GMT by spacing imaging's GeoEye-1 satellite. This image has been obtained and rectified. GeoEye-1, launched in September 2008, is an imaging satellite of DigitalGlobe. The spacecraft is in a sun-synchronous orbit with an operating altitude of 681km.GeoEye-1 collects images at 0.41m panchromatic and 1.65m 4-bands multi-spectral data. The sensor is optimized for large projects, as it can collect over 350,000 square kilometers of VHR satellite imagery every day. GeoEye-1 can revisit any point on Earth once every three days, or even sooner depending on latitude and elevation angle. [1, 2]

Table 1. GeoEye-1 Spatial and Spectral Resolutions

Band	Spectral range (*u*m)	Color range	Resolution (m)
1	0.45 – 0.51	Blue	1.65
2	0.52 – 0.60	Green	1.65
3	0.63 – 0.63	Red	1.65
4	0.76 – 0.90	Near-IR	1.65
pan	0.45 – 0.80	Panchromatic	1

2.3. Available Vector Data

2.3.1. NRI Data

The collected data form Nile Research Institute (NRI) of the Ministry of Water Resources and Irrigation for River Nile Basin, these data are 1:2,000,000 vector data for Egypt administration boundary and sample data in scattered areas as an example for attributes data like River Nile depths which are sections in excel sheets using singlebeam acoustic depth sounding from 2003 to 2009 in Nasser Lake and around this area also general information about River Nile width, nearest ports, barrages, dams, allowable speed carry, as shown in Figure (3).

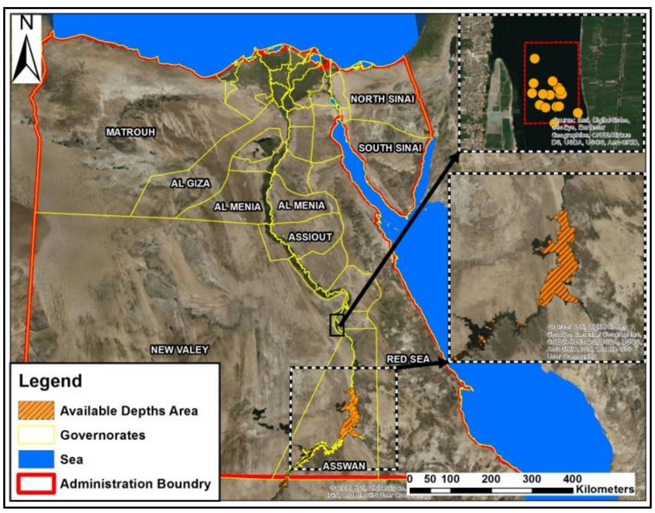


Figure 3. Egypt Administration Boundary and Available Data

2.3.2. Basemap for the River Nile in Egypt

Basemap produced from the author in a previous paper, titled Developing Updated Basemap for River Nile in Egypt Using Free Sources Satellite Images, Omayma Obada [16], this basemap created using on screen digitizing in registered free sources satellite images to digitize main streams and sub-streams within the River Nile catchment area.

2.3.3. FAO Data

FAO (Food and Agriculture Organization) provides free data for rivers and water bodies around the world obtained from Hydro SHEDS (Hydrological Data and Maps Based on Shuttle Elevation Derivatives at Multiple Scales). It is a mapping product that provides hydrographic information for regional and global-scale applications in a consistent format. [27]. It offers a suite of geo-referenced data sets, including river networks, watershed boundaries, drainage directions, and flow accumulations. Hydro SHEDS is based on high-resolution elevation data obtained during a Space Shuttle flight for NASA's Shuttle Radar Topography Mission (SRTM). [28] SRTM elevation data were obtained by a specially modified radar system that flew on board the Space Shuttle Endeavor during an 11-day mission in February of 2000. SRTM Water Body Data files are a by-product of the data editing performed by NGA to produce the finished SRTM data. Ocean, lake and river shorelines were identified and delineated from the 1 arc-second data (pixel resolution 30m) and were saved as vectors in ESRI 3-D Shapefile format. [29] Streams Names, Paths, Directions, main and sub catchment area and Dams information were extracted from FAO data to complete River Nile Basin Geodatabase, as shown in Figure(4).

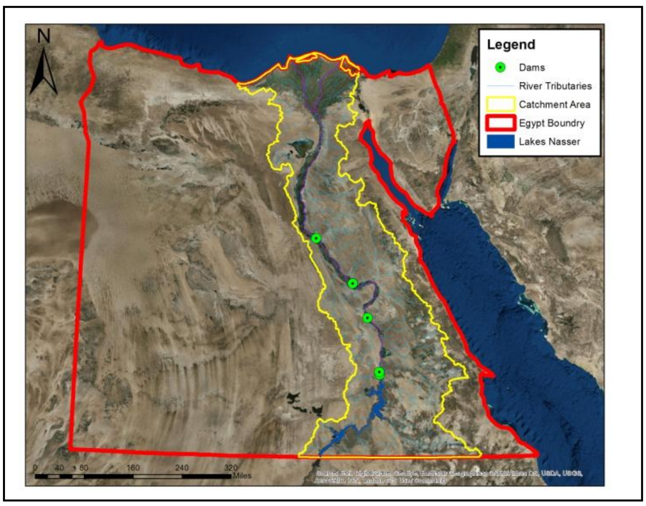


Figure 4. River Nile in Egypt FAO Data

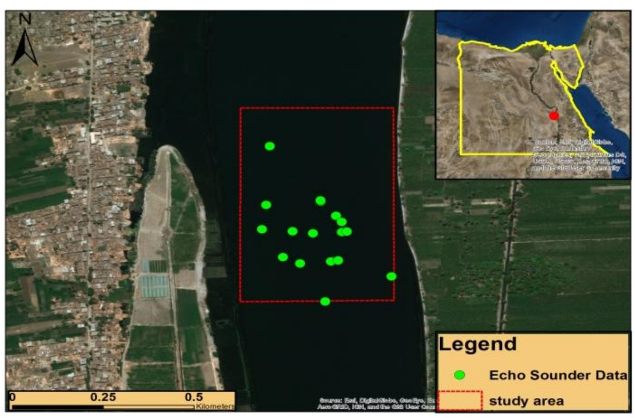


Figure 5. GeoEye-1 Satellite Imagery for Esna

3. Study Areas under Investigation

The first part, the bathymetric derivations from GeoEye-1 satellite imagery will be in Esna located on the west bank of the River Nile, 55 km south of Luxor, as shown in Figure (5).

The second part, developing an automated navigation system applied on all River Nile in Egypt.

4. Methodology

4.1. Bathymetric Derivations from GeoEye-1 Satellite Imagery

Several steps were involved in the preparation of the spectral and bathymetric data for water depth mapping. They included atmospheric correction, geometric correction, and the extraction of bathymetric values from the nautical chart and the corresponding pixel values from both images. [11] A detailed discussion is provided below.

4.1.1. Atmospheric Correction

The atmospheric correction is based on the algorithm developed by Gordon [9] and by Stumpf [19] and Pennock [17] for several remote sensors, including Coastal Zone Color Scanner, Advanced Very High Resolution Radiometer, and Landsat Thematic Mapper. In this model, the reflectance of water, Rw, of a particular spectral band is defined as:

$$R_w = \frac{\pi L_w(\lambda)}{E_d(\lambda)}$$

Where (L_W) the water-leaving radiance, (E_d) the down-welling irradiance entering the water, (Λ) The wavelength of the spectral band, (R_w) found by correcting the total reflectance (R_t) for the aerosol and surface reflectance, as estimated by the near-IR band, and for the Rayleigh reflectance (R_r). This can be expressed as:

$$R_w = R_T(\lambda_i) - Y(\lambda_{IR}) - R_r(\lambda_i)$$

Where (i) denote visible bands, (IR) near-infrared band, (Y) the constant to correct for spectral variation and depends on aerosol type. In this study, the correction presumes a maritime atmosphere with a spectral variation similar to that of the water surface specular reflectance. This assumption is reasonable for GeoEye-1 data with no cloud cover. Water vapours with large diameters might require a separate aerosol correction.

4.1.2. Geometric Correction

Image was geometry rectified and transformed to the Universal Transverse Mercator projection (UTM) with the WGS-84 datum.

4.1.3. Water Depth Extraction Model

Water absorptivity varies spectrally from band to band. As the depth increases, the reflected irradiance decreases faster in the high absorptivity spectral band (e.g. green band) than in the low absorptivity band (e.g. blue band). Based on that, Stumpf et al. (2003) developed a reflectance ratio model as follows.

$$Z = m_1 \frac{\ln\left(nR_w(\lambda_i)\right)}{\ln\left(nR_w(\lambda_j)\right)} - m_0$$

Table 2. Observed Echo Sounder and Image Estimated Depths

point	Easting (m)	Northing (m)	Observed Echo sounder Depth	Image Estimated Depth
1	455328.9	2802782	9.27	9.18
2	455197.4	2802796	6.07	7.14
3	455343.5	2802930	9.05	9.18
4	455160.9	2803158	6.03	6.75
5	455357.7	2802878	9.02	9.1
6	455360.3	2802878	9.02	8.61
7	455373	2802879	9.02	8.27
8	455358.8	2802911	9.08	8.36
9	455166	2803151	7.32	7.64
10	455150.9	2802966	7.28	7.27
11	455301.1	2802977	10.12	9.1
12	455495.7	2802733	7.35	7.92
13	455349	2802785	8.32	8.69
14	455244.2	2802775	7.93	8.27
15	455139.4	2802887	6.34	7.64
16	455223.3	2802880	7.71	8.53
17	455279.2	2802873	6.83	8.36
18	455300.1	2802981	9.91	8.53

Where: R_w (λ_i) and Rw (λ_j) the atmospherically corrected pixel value for bands i and j, (m_1) a tunable constant to scale the ratio to depth and (n) a fixed constant mainly for ensuring a positive value after the log transform and a linear response between the ratio and the depth and (m_0) an offset value when Z = 0. In the ratio model, only two parameters (i.e. m_0 and m_1) need to be estimated. Procedurally, we first corrected the tidal effect on the remotely sensed data to the bathymetric datum, then computed for blue and green bands the averages of the pixel values of along the 0m and 5m bathymetric lines using Relative Water Depth tool enabled in ENVI, which were input into the model to estimate equation coefficient m1 and constant m0. These parameters were further fine-tuned for producing better matches between the model output (Z) and the sampled in-situ data until the Root Mean Squared Error (RMSEr) of the model was managed down to an acceptable level, as shown in the Table (2).

From the previous calculation and using observed echo sounder data to validated image estimated depths to ground truth depths, the differences between the observed depth and the estimated depth ranges from 0.01m to 1.53 m with RMSEr of 0.79 m. the below figure shows how log ratio method using ground control points fit with image estimated depths value by linear method.

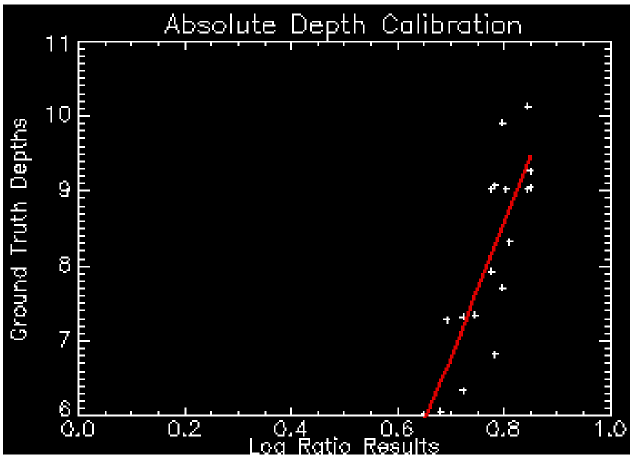


Figure 6. Imagery Absolute Depth Calibration Using Linear Method

The below figure shows the Esna Study area with depths classifications which varies from 6m to 10.5 m.

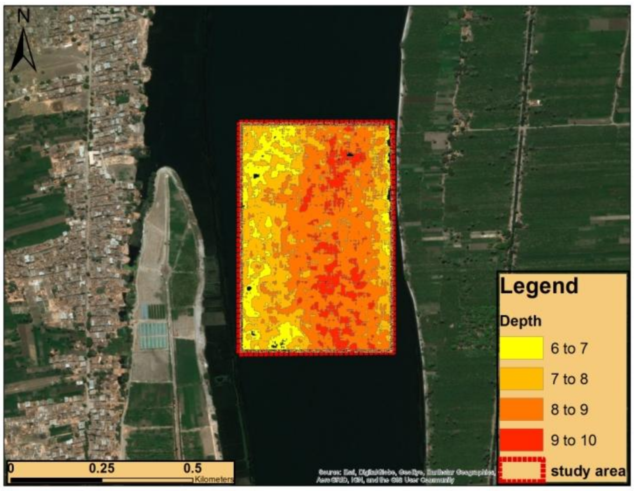


Figure 7. Esna Study Area with Estimated Depths

4.2. Developing an Automated Navigation System for River Nile in Egypt

The work flow for different phases to build an automated navigation system for River Nile in Egypt is illustrated here, as shown in Figure (8).

4.2.1. Converting Data Phase

Converting data or standardizing data phase is the process by which data collected from different sources in various formats (KMZ, DWG, Shapefile, text...) is transformed to a common format (Geodatabase). [30]. Geodatabase have a comprehensive information model for representing and managing geographic information. This model is implemented as a series of tables holding feature classes, raster datasets, and attributes. In addition, advanced GIS data objects add GIS rules for managing spatial integrity and tools for working with numerous spatial relationships of the core features, raster and attributes. It supports storing information about collected data as metadata. [31]

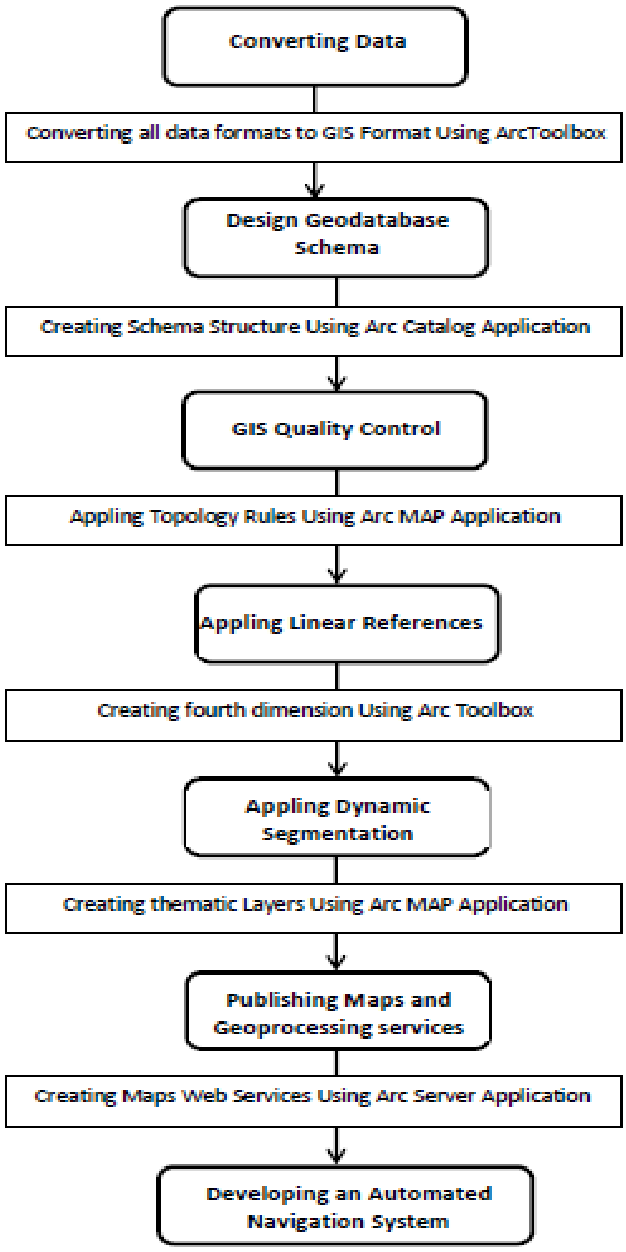


Figure 8. Workflow Phases

4.2.2. Design Geodatabase Schema Phase

Design Geodatabase schema phase involves organizing geographic information into a series of data themes layers that can be integrated using geographic location. Geodatabase design begins by identifying the data themes to be used, then specifying the contents and representations of each thematic layer, as shown in Figure (9) [32]. Geographic features are represented for each theme as points, lines, polygons, or raster along with their tabular attributes and data are organized into datasets, as feature classes, attributes, raster datasets, and additional spatial and database elements will be needed for integrity rules, for implementing rich GIS behaviour as topologies, networks, and finally defining spatial and attribute relationships between datasets.

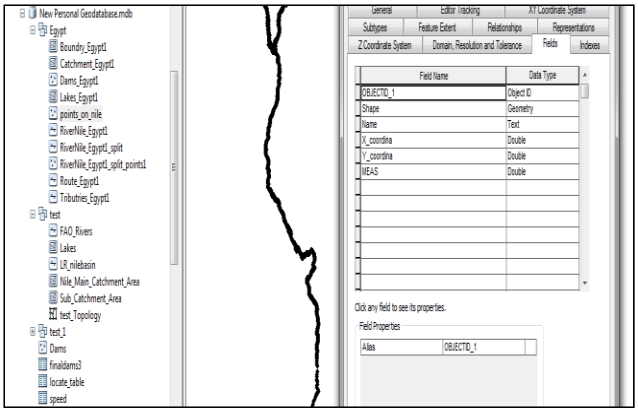


Figure 9. Geodatabase for River Nile in Egypt after Converting Data and Designing scheme

4.2.3. GIS Quality Control Phase

Data Quality Control phase (DQC) is the process of controlling the usage of data with known quality measurement, this process based on Automated and Manual procedures. These procedures depend on spatial relationship matrix called Topology. Topology is Logical spatial relationships between features in the same layer or in different layers. Topology rules can be applied depending on the spatial relationships defined in designed geodatabase schema, most topology violations have fixes that used to correct errors. The topology errors handled using ArcMAP application using Fix Topology Tools; the used topology rules in this phase are defined and determined, as shown in the Figure (10).

After handling the different errors then the Geodatabase for River Nile in Egypt ready for applying the following: Linear Referencing, Dynamic Segmentation, River Navigation and Routing techniques. [33].

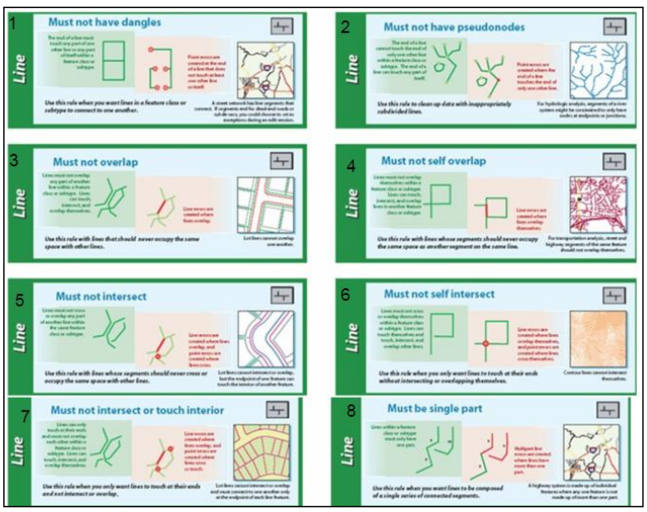
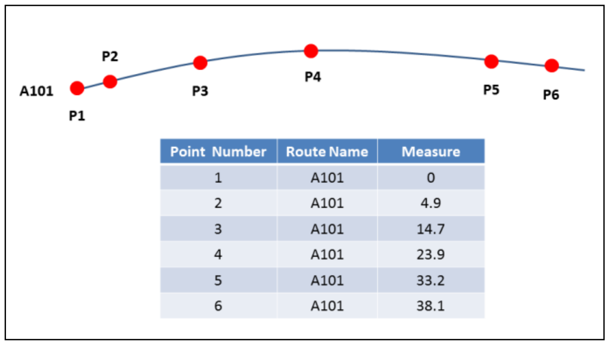


Figure 10. Topology rules used in Quality Control Phase

4.2.4. Appling Linear Reference Phase

Linear Referencing is the method of storing geographic locations by using relative positions along a measured linear feature, as shown in Figure (11). [34]



Point Number	Route Name	Measure
1	A101	0
2	A101	4.9
3	A101	14.7
4	A101	23.9
5	A101	33.2
6	A101	38.1

Figure 11. Linear Reference Concept Overview

Distance measurements are used to address location along River Nile. Linear Referencing is called River Addressing, it allows objects such as field monitoring stations, which collect information about water quality analysis, toxic release inventories, drinking water supplies, structure, and pump station to be located along a river or stream system. The measurement scheme used in River Addressing and Navigation system allows the measurement of flow distance between any two points on a flow path. These systems simplify the recording of data by using a relative position along an already existing linear feature. That is, location is given in terms of a known linear feature and a position, or measure along it. From GIS Quality Control phases, Data prepared for applying linear reference and by using Create Route tool from Linear referencing tool set in ArcToolbox application used to apply Linear Referencing along on all River Nile in Egypt, as shown in Figure (12).

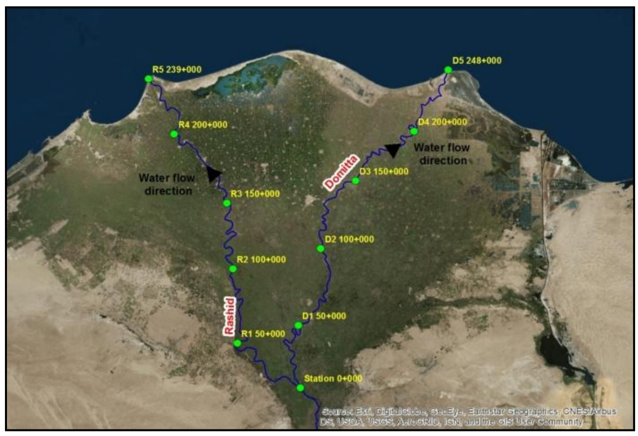


Figure 12. Appling Linear Reference over River Nile in Egypt

4.2.5. Appling Dynamic Segmentation Phase

Dynamic segmentation is the process of computing the map location (shape) of events stored in an event table and allows multiple sets of attributes to be associated with any portion of a linear feature, as shown in Figure (13). The result of this process is a dynamic feature class known as a route event source. A route event source can serve as the data source of a feature layer in ArcMap Application. A dynamic feature layer behaves like any other feature layer. It is possible to decide whether to display it, the scale at which it should be visible, what features or subset of features to display, how to draw the features, whether to store it as a layer file or export it, and so on. [25]

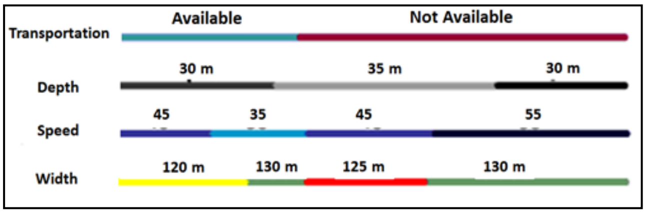


Figure 13. Applying Dynamic Segmentation with Different Thematic Layers

In this phase thematic collected data, (depth, width, water discharge, allowable speed, fishing, nearest ports, dams and barrages for River Nile in Egypt), converted to feature event by applying multi dynamic segmentation for each properties, as shown in Figure (14).

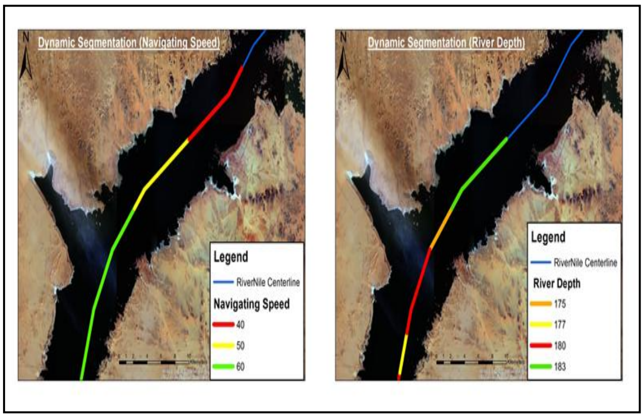


Figure 14. Dynamic Segmentation Permissible Speed and Variation in Depths in Nasser Lake

4.2.6. Publishing Maps and Geoprocessing Services Phase

ArcGIS Server is used by the software developer and Web developer to create Web, desktop, and mobile applications. ArcGIS Server is the core server geographic information system (GIS) software. It is used for creating and managing GIS Web services, applications and data. ArcGIS Server services supply mapping and GIS capabilities for Web and client applications. ArcGIS Server is available for the Microsoft Windows .NET Framework and the Java Platform. It support the different types of Web services as Feature (for Web editing), Geodata (for geodatabase replication), Geocode (for finding and displaying addresses/locations on a map), Geometry (for geometric calculations such as calculating areas and lengths), Geoprocessing (for scientific modeling and spatial data analysis), Globe (for 3D and globe rendering), Image (for serving raster data and providing control over imagery delivery, such as satellite imagery or ortho photos), Keyhole Markup Language (KML), Map (for cached and optimized map services), Mobile (for running services on field devices), Network Analyst (for routing, closest facility location, or service area analysis), Search (for enterprise search of GIS assets), Web Coverage Service (WCS), Web Feature Service (WFS) and Transactional Web Feature Service (WFS-T), and Web Map Service (WMS). [36]

All required data which prepared in the previous phases will be published using ArcGIS Server Application to be used by any client side platform in the developed web application “River Nile Navigation System”. Data was published as feature services and other geoprocessing tools were published as geoprocessing services and System Architecture, as shown in Figure (15).

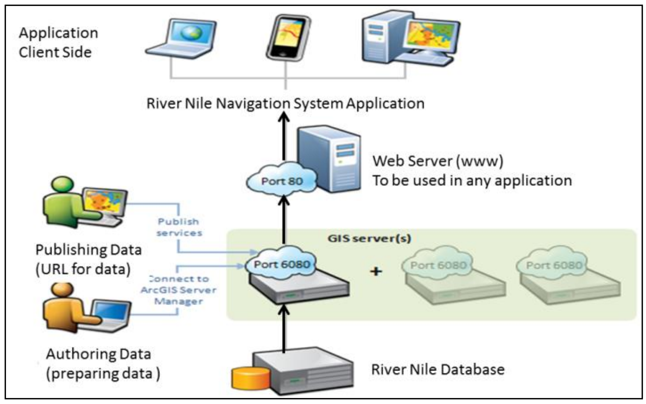


Figure 15. Web Application Architecture for Navigation System

4.2.7. Building Automated Navigation System for River Nile in Egypt Phase

A web application is an application that uses a website as the interface. Users can easily access the application from any computer connected to the Internet using a standard browser. Web application is accessible anytime, anywhere and via any client side platform with an Internet connection. The user interface of web applications is easier to customize and easy to use. This extends ability to receive and interact with data, maps and information in a way that suits them. Web application architecture makes it possible to rapidly integrate enterprise systems, improving work-flow and other business processes. By taking advantage of internet technologies you get a flexible and adaptable business model that can be changed according to shifting market demands. Web applications are typically deployed on dedicated servers, which are monitored and maintained by experienced server administrators. This is far more effective than monitoring hundreds or even thousands of client computers; this means that security is tighter. [37]

The most important phase in this study is building an automated navigation system for River Nile in Egypt, using Java script programming language, JavaScript is one of the three core technologies of World Wide Web content production. It is used to make webpages interactive and provide online programs, and all modern web browsers support. JavaScript supports many functional and programming styles. [38]

On this application integration between Geomatics Engineering with Software Engineering on how maps, data, tools, functions and information were used in an easy useful way using programming language to build up an automated navigation system web application, as shown in Figures (16).

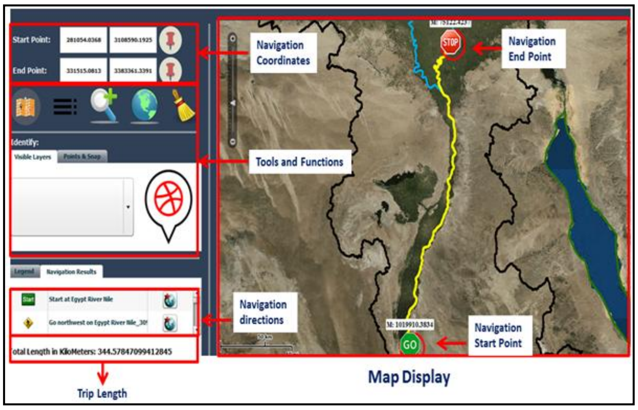


Figure 16. River Nile Navigation System Main Screen

The River Nile Navigation application has main screen which divided into two parts. The left part contains main tools and functions. The right part has map display. The main tools available in this application; a list for all data layers that user can choose which layer can be visible in map display, navigation tools (zoom in, zoom out, zoom to full extend), identify tool, clear any selection tool. This navigation system will help the fleet's navigators to navigate safely by getting all available surveying data like locations along River Nile (User can select or identify starting point from map display for his trip and then select destination point) or by real time pick up location, and the system can providing directions along River Nile and information about his trip as distance in KM with tracking the trip, centerline with suitable water discharge, water depth, River Nile width, nearest ports, barrages, dams, allowable speed, and allowable carry. This application can be integrated with Global Positioning System (GPS) to provide user location on the map display, and this system can be extended to be used as tracking system for all movements inside River Nile in Egypt.

5. Conclusions

It is necessary to use and update all the available data to develop a navigation system in River Nile in Egypt. Improvement of navigation in the River Nile will increase the cargo load shipped and increase tourism boats. Then, minimize or eliminating of the overcome tourism ships stuck near Luxor and Aswan city that happed every year during the peak of the tourism season. Monitoring River Nile depths, which derived from high-resolution multispectral satellite imagery as bathymetric data, and rebuild an updated route for tourism ships through the developed application is available application. The remote sensing approach demonstrated in this study was proven effective for River Nile water bathymetry mapping. This is especially true when the study area is inaccessible for field data collection. The GeoEye multi-spectral band satellite image used in this study are compatible in spectral resolution for bathymetry mapping. Although the resultant water depths had a good precision with RMSEr 0.79 compared to echo sounder data. This method can be used in cases that frequency bathymetric data needed as our case in River Nile in Egypt. The applied approach in Esna can be generalized in any part in the River Nile in Egypt to estimate water depths to be used in navigation. Linear Reference (One-Dimension system) applied for the first time in River Nile in Egypt. Using Linear Reference system to address River Nile in Egypt features done successively. Dynamic Segmentation gives ability to present more data and information in a simple and easy way along Nile River. The developed application proved the useful of integration between Geomatics Engineering with Software Engineering on how collected maps, data, functions and information were used in an easy useful way using programming language to build up an automated navigation web application system that allows easy operation of all inertial navigation.

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