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Case Study

The Role of Spatial Geodetic Data Infrastructures (GDI): A Case Study in the Nile Delta, Egypt

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Abstract

Engineering activities and development plans rely chiefly on the availability of precise spatial data, which in turn depends on the accessibility of an accurate Geodetic Data Infrastructure (GDI) as reference frames for all geospatial measurements. A GDI is considered a key component in the undergoing National Spatial Data Infrastructure (NSDI) for Egypt. The current study proposes a structure of a GDI in Egypt that has multi-discipline utilizations and aims to develop an integrated database combining several types of geodetic datasets within a Geographic Information Systems (GIS) environment. The study develops such a GDI for the Nile delta region, as a case study, containing the available heterogeneous geodetic datasets. The problems and advantages of such a GDI are thoroughly investigated herein. Accordingly, some recommendations are presented, too, for constructing an integrated GDI over a national scale in Egypt.

Keywords: GDI, NSDI, GIS, Geodetic data, Nile Delta.

Introduction

In the last few decades, it has been a matter of reality that geospatial data play a critical role in the economic growth and sustainable development of countries. A Spatial Data Infrastructure (SDI) could be defined as a collection of geospatial data/metadata, technologies, standards, human resources, and policies that aims to acquire, process, and manage in an efficient manner. Spatial data includes, but not limited to, geodetic, topographic and cadastral information along with aerial photos, satellite imageries, and statistics. SDI has been proposed, in the nineties, as a tool for facilitating spatial data sharing among different users on a national, regional, or international basis[1]. A National SDI (NSDI) could be defined as technologies, policies, criteria, standards and technicians used to promote multiple-sources geospatial data sharing among local governments, the private sector, non-profit organizations, and academic units of a country[2]. Accordingly, SDI in general and NSDI in particular, composed of five factors[3]: organizations, human resources, information, access network, and financial resources. The implementation of SDI has numerous merits for decision-makers and development planners. For example, SDI provides unique datasets originating from multi-users that could be applied for multi-usages. Also, it creates unified policies for spatial data sharing and data access. It defines specific technical rules to be performed to check data quality and to integrate different data sources with different accuracies. In addition, SDI establishes institutional arrangements and user/provider relationships. Economically speaking, SDI reduces the costs and time of data collection in a region[4]. NSDI has been developed in several countries in the last few years, such as Pakistan[5], Tanzania[6], Europe[7], and Finland[8]. The development of an NSDI for Egypt has been investigated since two decades ago. For example, Hussein[9] has proposed a prototype SDI depending on the spatial and non-spatial data acquired by the Egyptian Survey Authority (ESA) and recommended that all other governmental and private organizations should cooperate in sharing their data/metadata in that unique national SDI. Ali[10] has designed the spatial database model of an SDI system on a multi-governorates basis in south Egypt. Since 2014, the Ministry of Planning has initiated a national project for building an NSDI in Egypt based on the cooperation of ministries, authorities, and academic units[11]. That NSDI depends upon conducting recent aerial photography of entire Egypt with a suitable spatial resolution permits the required accuracy of establishing a Geographic Information Systems (GIS) and a digital base map of a scale 1: 2,500. At the core of a NSDI, the geodetic datasets play a critical role in unifying multiple data sources, coordinate systems, and geodetic datums.

In addition, a Geodetic Data Infrastructure (GDI) produces several outputs essential for geodetic and environmental activities. Previous studies have highlighted the significance of constructing a GIS-based database comprising several types of geodetic data over a country[12]. This paper proposes the development of a GDI system within the undergoing ESDI project. The Nile delta region has been utilized as a case study where all available geodetic datasets have been collected, stored, and analyzed in terms of adequacy, spatial distribution, accuracy, and need for updating.

SDI and GDI

A GDI is a major component of an NSDI system. It describes the characteristics of the geodetic framework to which all other spatial datasets are linked together. GDI is represented the fundamental core of the entire SDI structure[13]. A national GDI provides the basic required reference information for spatial data infrastructure in a country[14]. In addition, geodetic datasets within an SDI could be utilized in analyzing geodetic variations over time and inspecting their utilization in natural hazards. For instance, keeping records of sea levels at tide gauges allowing the investigation of Sea Level Rise (SLR) and its hazardous impacts particularly on coastal regions. Similarly, the crustal deformations could be estimated from 4D observations at Global Navigation Satellite Systems (GNSS) stations. An updated national geoid model, also, could be periodically estimated as long as the required geodetic datasets are updated. Accordingly, the current study proposes a structure of a GDI in Egypt that has multi-disciplines usage. Such a structure (Figure-1) aims to develop an integrated database combining several types of geodetic datasets. Its basic structure contains spatial data/metadata where the spatial data include both raster and vector formats. For each layer of geodetic data, basic metadata is mandatory. Such elements describe the geodetic characteristics of the datasets including source, date of measurements, accuracy, spatial coverage, and geodetic datums[15]. Vector datasets include, but are not limited to, Bench Marks (BM) of known orthometric heights, GNSS stations that could be divided into 3D and 4D data, gravity data (absolute and relative), and Tide Gauge (TG) records. On the other hand, raster datasets comprise the Digital Elevation Model (DEM), map of gravity anomalies, geoid maps, crustal deformation maps, and other relevant geodetic data. The proposed GDI will be based on the World Geodetic System 1984 (WGS84) ellipsoid and the Modified Transverse Mercator (MTM) map projection. It is known that the undergoing NSDI project is already utilized those criteria rather than the traditional Helmert 1906 and the Egyptian Transverse Mercator (ETM) datum and projection.

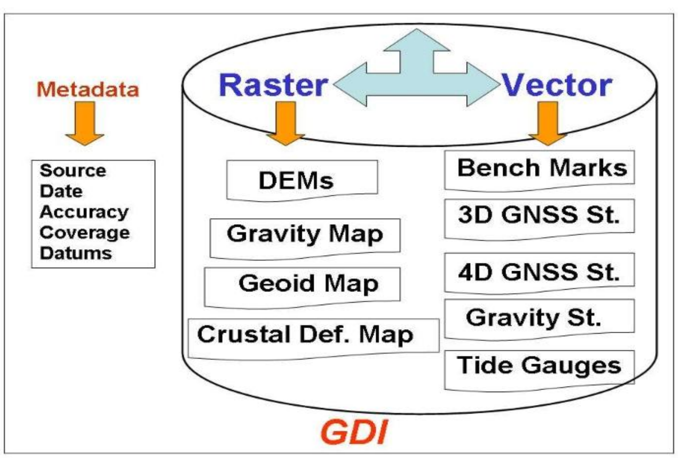

Figure-1: Proposed GDI Structure.

The study area: The study area, in the current research, covers the Nile delta region and its surrounding in northern Egypt (Figure-2). It lies between longitudes 29.7°E and 32.4°E and latitudes 29.9°N and 31.6°N. The Nile delta is considered one of the most densely populated regions worldwide, and also one of the low-lying deltas subject to the impacts of SRL phenomena. Since it contains almost half of the Egyptian population, several development activities and, hence, geodetic datasets are available within that region. The main concern, from a data perspective, is that several governmental authorities have acquired geodetic datasets that need to be collected, inspected, and combined in a unique GDI.

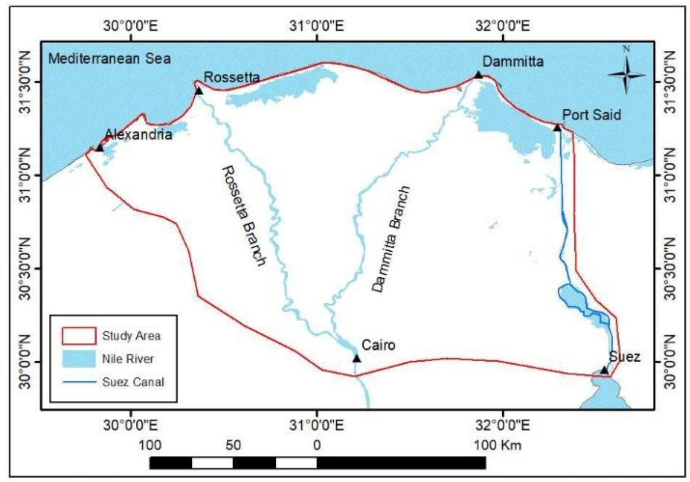

Figure-2: The Study Area.

The topography of the study area (Figure-3) is relatively flat where the heights above Mean Sea Level (MSL) decrease as going north. Al-Karagy and Dawod[16] have investigated the accuracy of several Global Digital Elevation Models (GDEMs) and found that the AEC2 DEM is the optimum one based to represent the Egyptian topography. From this model, it has been found that MSL-based heights of the study area range from -59 m to 872 m with an average of 35 m.

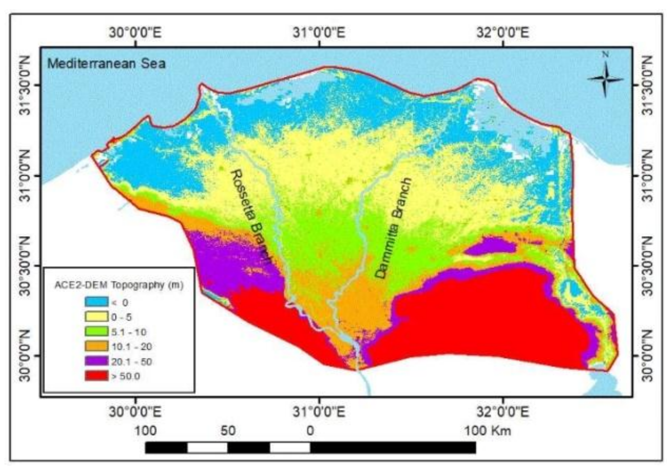

Figure-3: Topography of the Study Area.

Available Datasets

Regarding the available 3D and 4D GNSS stations within the study area, it has been found that there exist 3 stations belong to the High Accuracy Reference Network (HARN) established by the Egyptian Survey Authority (ESA) in 1995. Out of the 112 National Agricultural Cadastral Network (NACN) established by ESA, there exist 27 GNSS stations within the study area. Both HARN and NACN networks can be considered as 3D GNSS networks in Egypt. Both networks have been tied to the International Terrestrial Reference Farm (ITRF) of 1994 epoch 1996. On the other hand, ESA has established, in 2010, a Continuously Operation Reference Station (CORS) network as a 4D geodetic reference frame in Egypt. This network has been tied to ITRF of 2008 epoch 2011. Within the study area, it has been found that 23 CORS stations exist. Figure-4 depicts the distribution of GNSS stations in the study area. It is a matter of fact that such first-order geodetic stations are quite significant in executing surveying and mapping projects. Thus, GNSS stations present a major component in the GDI in Egypt.

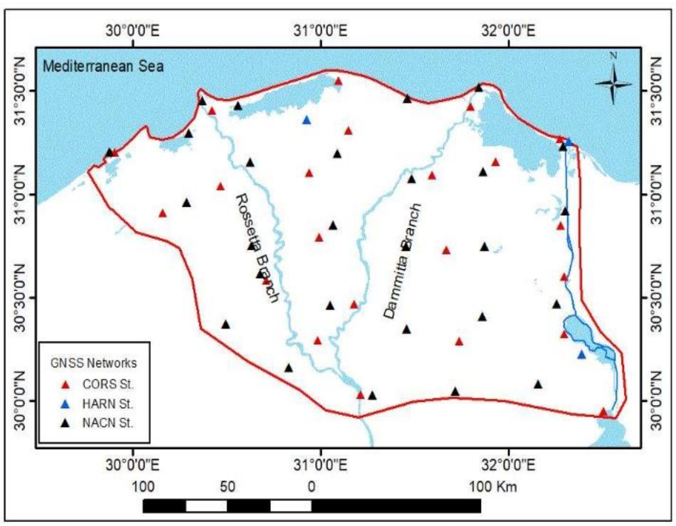

Figure-4: GNSS Networks at the Study Area.

Another constituent of a GDI is the GNSS/Levelling stations where both WGS84-based ellipsoidal and MSL-based orthometric heights are known at each point. From such points, a geometric geoid could be developed which is vital in the utilization of GNSS applications. Heterogeneous datasets from several organizations have been compiled into a unique dataset as a part of the proposed GDI. It has been found that 332 GNSS/ Levelling stations exist within the study area as depicted in Figure-5.

A geoid map plays a chief role in surveying and mapping activities in Egypt. It facilitates the conversion of GNSS heights to MSL levels needed for civil engineering projects. Geoid modelling has been a traditional task for the geodetic community in Egypt in the last few decades. The first pioneer Egyptian geoid model has been developed by Alnaggar[17]. The most recent geoid for Egypt has been performed by Al-Karargy and Dawod[16]. From that model, it has been found the geoidal heights or geoidal undulations over the study area vary between 13.99 m and 17.78 m with a mean of 15.39 m (Figure-6).

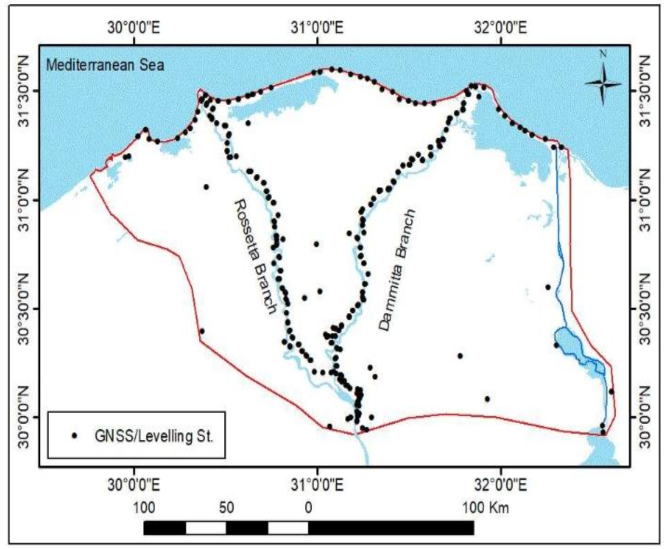

Figure-5: Available GNSS/Levelling Points.

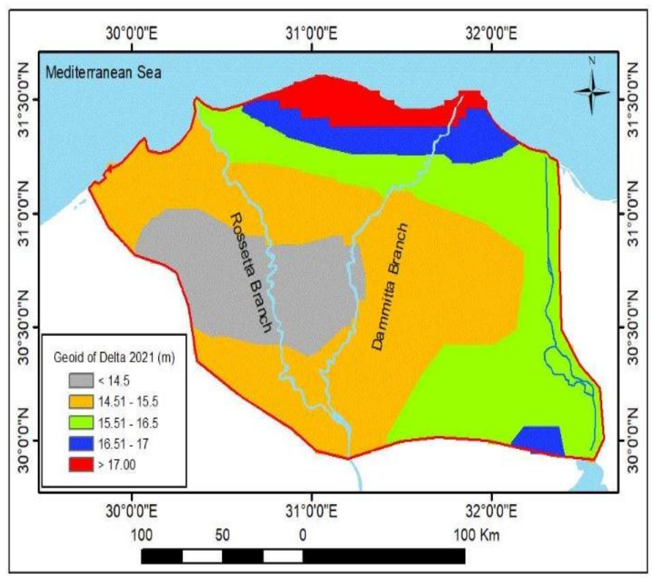

Figure-6: Geoid 2021 of the Study Area.

Gravity data is another main geodetic data to be incorporated in the proposed GDI in Egypt. The recent gravity network in Egypt has been established by SRI in 1997, called the Egyptian National Gravity Standardization Networks 1997 or simply ENGSN-97[18]. It consists of 5 absolute gravity stations and 145 relative gravity stations. Within the study area, it has been found that 28 ENGSN-97 points exist. Additionally, it has been realized that the gravity field in this region range from 979,267.5 mGal to 979,504.8 mGal with an average of 979,369.4 mGal (Figure-7).

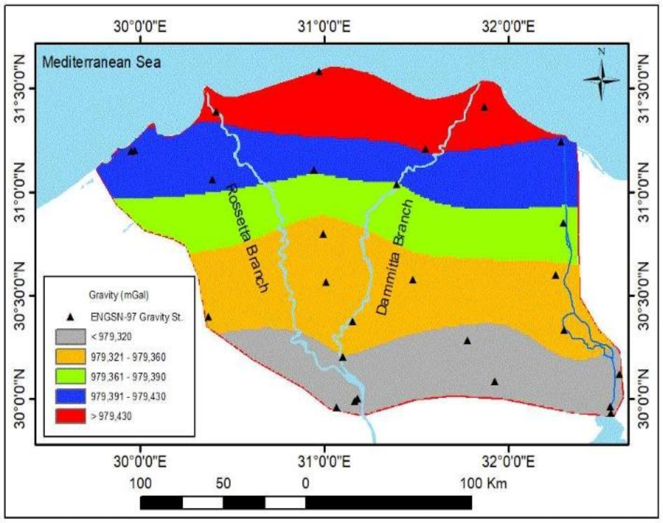

Figure-7: Gravity Variations at the Study Area.

Bench Marks (BM) with known MSL heights constitute an important component in the proposed GDI and all civil engineering activities in Egypt. In the last few years, SRI has established a unique BM network particularly for water resources management projects. Figure-8 presents the distribution of the collected 593 BM stations within the study area. Such network consists of 247 BM along the Nile river, 231 BM on main drains, 58 BM over the coastlines, and 57 BM along main irrigation canals.

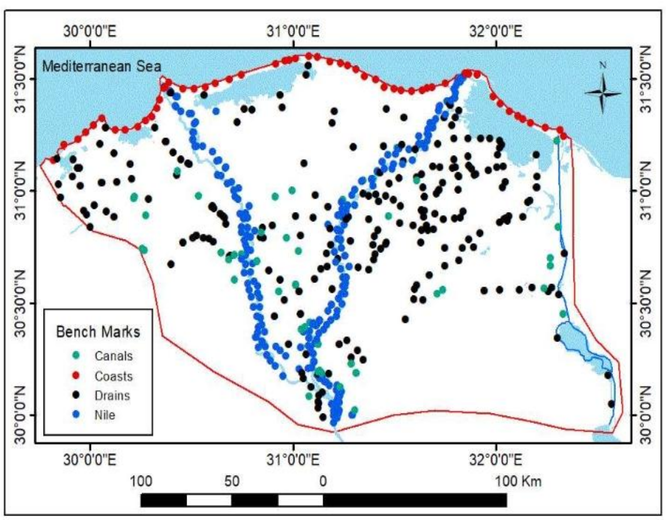

Figure-8: Bench Marks at the Study Area.

Tide Gauges (TG) are the geodetic stations where sea levels are continuously observed. Such geodetic stations are extremely noteworthy in monitoring Sea Level Rise (SRL) and studying its risks, particularly over coastal regions. Within the study area, five TG stations exist (Figure-9). Two of them, namely Alexandria and Port Said, belong to SRI while the other three belong to the Costal Research Institute of the National Water Research Center (NWRC).

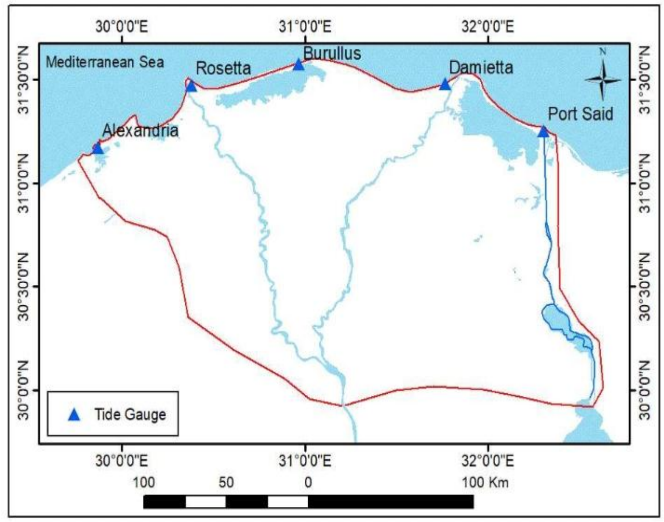

Figure-9: Tide Gauges at the Study Area.

Land subsidence is a natural phenomenon occurred mainly in low-land deltas worldwide. It is a hazardous phenomenon affecting huge infrastructures such as dams, reservoirs, and infrastructures. It should be frequently monitored by GNSS, levelling, or remote sensing satellite images. Mohamed et al.[19] have utilized seven GNSS CORS stations to estimate land subsidence over the Nile delta region in 2012-2015. Their results indicated that the land subsidence rate ranges from -4.8 mm/year to +6.5mm/year with an average of 1.41mm/year (Figure-10).

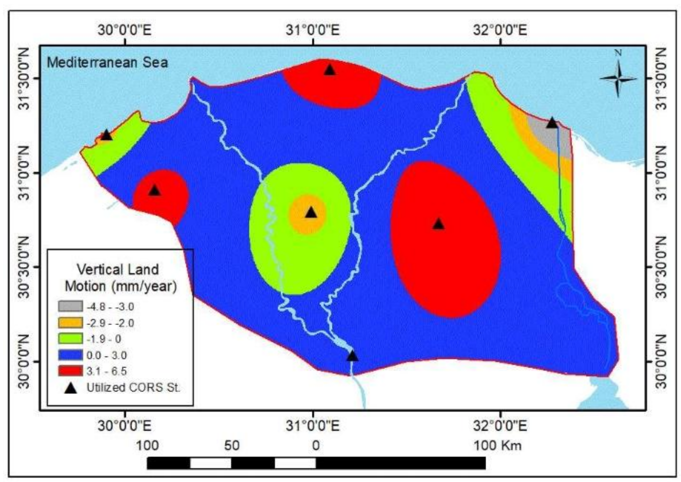

Figure-10: Land Subsidence at the Study Area.

Analysis and Discussion

Having the proposed GDI constructed with the SDI of Egypt, several benefits could be accomplished. Specialized SDI users could analyze the components of the GDI and utilize it in several applications. However, the GDI components should be updated regularly in terms of accuracy and spatial coverage. For instance, Figure-4 shows that the spatial distribution of GNSS networks over the study area is relatively homogeneous. But, both HARN and NACN GNSS networks have been established a few decades ago. Due to urban expansion, many of such stations have been damaged and, therefore, need to be re-constructed and re-observed. On the other hand, Figure-5 reveals that the spatial distribution of available GNSS/Levelling stations in the study area is not uniform. Such a fact jeopardizes the development of a national geoid model to be applied in GNSS-based surveying and civil engineering projects. More GNSS/Levelling stations are required to get ride of such a dilemma. A similar situation exists for the distribution of available gravity networks in Egypt as depicted in Figure-7. Although the number of available BM is relatively good, their distribution (Figure-8) lacks a uniform pattern. It is a matter of reality that all surveying and geomatics applications depend on the availability and accuracy of BM network. On another sense, specialized SDI users could investigate the GDI components (spatial and attribute datasets) to reveal significant pieces of information. The TG stations at both Alexandria and Port Said, owned and operated by SRI, have sea levels observed over a long period[20]. Having their annual averages as attribute data within the proposed GDI, relative Sea Level Rise (SRL) trends could be obtained (Figure-11). Adding the subsidence rate at each TG (Figure-10) to such relative SRL values, absolute SRL could be estimated. Such piece of information is extremely noteworthy in monitoring the impacts of climate changes on Egypt, particularly over the coasts of the Nile delta region.

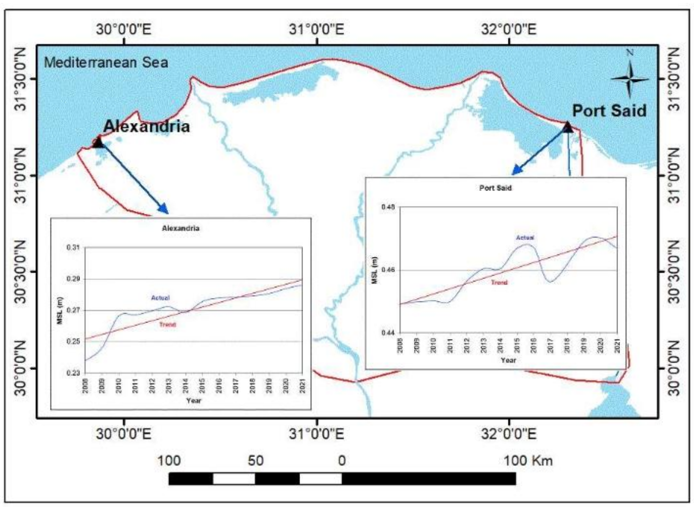

Figure-11: Mean Sea Level Trend at the Study Area.

Concerning the status and the key difficulties facing the development of a precise and comprehensive GDI in Egypt, several factors should be considered. First, the loss of many terrestrial geodetic control points due to urban expansion in the last few decades. Second, the accuracy variations of such geodetic networks since they have been observed over a long time using equipment and techniques vary significantly in precision. Third, there is a great demand to update national geodetic datums. For instance, the vertical datum of Egypt is the MSL of Alexandria in 1906. It is a matter of fact that such a datum need to be re-defined due to the SRL over the twentieth century[21]. Additionally, the GNSS-based horizontal geodetic datums vary between ITRF1994 for the HARN network and IREF2008 for the CORS network. Lastly, the need for honest cooperation between all governmental, civil, military, and private sectors to collect all available geodetic datasets to build an up-to-date precise GDI over a national scale.

Conclusion

GDI is considered a major constituent of a national SDI for a country. GDI offers optimal utilization of natural and human resources and facilitates efficient planning of development activities in Egypt. As a major component of the presently undergoing development of an NSDI in Egypt, an GDI is proposed in this research study. The available geodetic datasets, as far as the authors concern, have been collected in a GIS environment as a proposed GDI structure in the Nile delta region. Other components of such GDI could be suggested and incorporated too, such as aerial photographs, satellites imageries, topographic maps, and light detection and ranging (LIDAR) datasets. Furthermore, such a proposal should be enlarged to construct a GDI over a national scale in Egypt.

Based on the previous analysis and conclusions, some recommendations could be drawn. i. The collection of all available geodetic datasets in a unique GIS framework is urgently needed. ii. The update of both vertical and horizontal geodetic datums of Egypt should be carried out as soon as possible. iii. A national plan for densification of geodetic control networks, of all types, should be initiated and all governmental and private organizations should be participated in its activities to complete it in a short time. iv. Having developed a national updated GDI, it should be available and accessible to specialized governmental and academic users for analysis and utilization. v. A continuous update of a GDI is needed utilizing state-of-the-art technologies and equipment to accomplish, regularly, accurate definitions of geodetic data and datums in Egypt.

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