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Vertical Movement of North Egypt Based on Precise Point Positioning

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ملخص البحث

الهبوط هو ظاهرة طبيعية خطرة تؤثر على العديد من المناطق الحضرية فى كل مكان فى العالم خاصة المناطق الساحلية و دلتا الأنهار مثل دلتا النيل. لحساب الهبوط الذى يحدث فى الدلتا تم تحليل بيانات الشبكه المكونة من ثمانى محطات موزعة فى شمال مصر باستخدام واحد من البرامج العلمية Bernese. تم أستخدام اسلوب الرصد بمستقبل وحيد PPP لرصد التحركات الأرضية فى الإتجاه الرأسي فى الفترة من 2013 الى منتصف 2015. معدل الإزاحة الرأسية لنقاط الشبكة يتراوح بين + 3 الى - 10 مم/سنة مقديدا الى (ITRF 08). من المرجح ان هذا الهبوط نتيجة للإنضغاط الطبيعى الذى يحدث للتربة الرسوبية المكونة لطبقات الدلتا نتيجة التغير الموسمى لمنسوب المياه الجوفية.

Abstract

Land subsidence could be a natural hazard affects many massive urban areas everywhere in the world, significantly in coastal and rivers' delta regions like Nile Delta. Subsidence of Nile Delta was calculated using GNSS data from eight stations distributed in the north of Egypt using Bernese GNSS software. Precise Point Positioning (PPP) technique was used for data processing to monitor the vertical movement in the period from 2013 to mid of 2015 in 13 campaign style. The vertical movement was found to be ranged from +3 mm/year up to -10 mm/year down constrained to ITRF 2008. The measured subsidence is expected to happen due to the natural consolidation of sedimentary soil in the Nile Delta region caused by seasonal variation of ground water level.

Key words: Nile Delta – Subsidence – Bernese software

Introduction

PPP has received increased attention in the past several years within the GNSS community due to its great operational flexibility and accuracy promise. The major advantages of PPP lie in two aspects: system simplicity at the user's end and global consistency in terms of positioning accuracy. PPP has many different geodetic uses, especially in crustal movement (Zumberge *et al.*, 1997). Crustal movement is the movement of the earth's crust due to different load on the crust consisting of two major movement such as horizontal movement and vertical movement. Crustal movement are very important tool to understand of the earth's geodynamics. Land subsidence the downward movement of earth crust relative to specific surface like ellipsoid, geoid and mean sea level. Land subsidence caused by natural such as tectonic activities or natural consolidation of sedimentary soil or landslide and human activities such as underground mining of natural gas or underground water and consolidation due to large building loads. Many studies have been done to monitor land subsidence by many techniques like Precise Levelling, Global Navigation Satellite System (GNSS), Synthetic Aperture Radar Interferometry (InSAR). (Marín-Lechado *et al.*, 2010; Steigenberger *et al.*, 2012;

Moreau and Dauteuil, 2013). GNSS may be the optimum and most accurate geodetic technique in measuring subsidence. GNSS data can be collected in the form of campaign style or Continuous Operating Reference Stations (CORS) or campaign and one or more CORS in the study area. Analyzing GNSS observation for crustal movement performed using scientific software e.g. Bernese, GAMIT/GLOBK and GISPY/OSAIS with the main processing strategy relative positioning and Precise Point Positioning (PPP) (Ohzono *et al.*, 2006; Baldi *et al.*, 2009; Cenni *et al.*, 2013; Goudarzi, Cocard and Santerre, 2016).

The Nile delta area possess a complex geological and hydrological structures so that land subsidence and land uplift are existed interchangeably on the spatial coverage of the area. (Fugate, 2014) has reported vertical ground motions ranging from uplift of approximately 7.5 mm/year to subsidence of almost 8.5 mm/year over the northern region of the Nile Delta in the period 1993- 2000. Within the central Delta area, vertical land movements of ± 5 mm/year have been reported for the period 1993-2000 (e.g. (Aly, 2006)). (Aly *et al.*, 2012) reported that, the rate of subsidence in Mansoura city and Greater Mahala about are –9 and –5 mm year^{-1}, respectively. Additionally, the vertical movements in the Greater Cairo metropolitan area were estimated in the range from -7 mm/year to +3.8 mm/year in the period 2003-2009 (Poscolieri *et al.*, 2011). Furthermore (Mohamed *et al.*, 2015) the vertical land movements at these six locations range from +4.9 to -6.5 mm/year, while the horizontal ground movements vary from 4.2 to 6.6 mm/year in the north-east direction in the period 2012-2015. Similar situations of integrated complex land subsidence/uplift have been reported in other geographic locations (e.g. (Sneed *et al.*, 2001)).

Data Availability

The utilized dataset compresses GNSS raw data of the 8 stations belong to Egyptian Permanent GPS Network (EPGN) shown in Fig. 1 and Table , which were established and administrated by the National Research Institute of Astronomy and Geophysics (NRIAG) for measuring crustal movements and ALEX station in Alexandria organized by a French institute called Centre d'Études Alexandrines (CEALX). Due to the importance of the monument type and its quality, which affects directly the stability of these stations, the majority of EPGN stations were installed on concrete pillars; but in a few cases, some stations were installed on a roof of building such as the case in Helwan (PHLW), Alexandria (ALEX), and Mansoura (MNSR) for safety considerations (Saleh and Becker, 2013). The Selected stations are Alexandria (ALEX), Al Arish (ARSH), Borg Al Arab (BORG), Mansoura (MNSR), Matrouh (MTRH), Port Said (SAID) and Saloum (SLUM). Therefore, thirteen campaigns have been selected for each station in the period from January 2013 to June 2015, where each campaign contains a 3 to 5 day which contains 24 hour continuous GNSS dataset in the RINEX (Receiver INdependent EXchange) format, ALEX station data can be downloaded from the official website for this station www.station-gps.cea.com.eg.

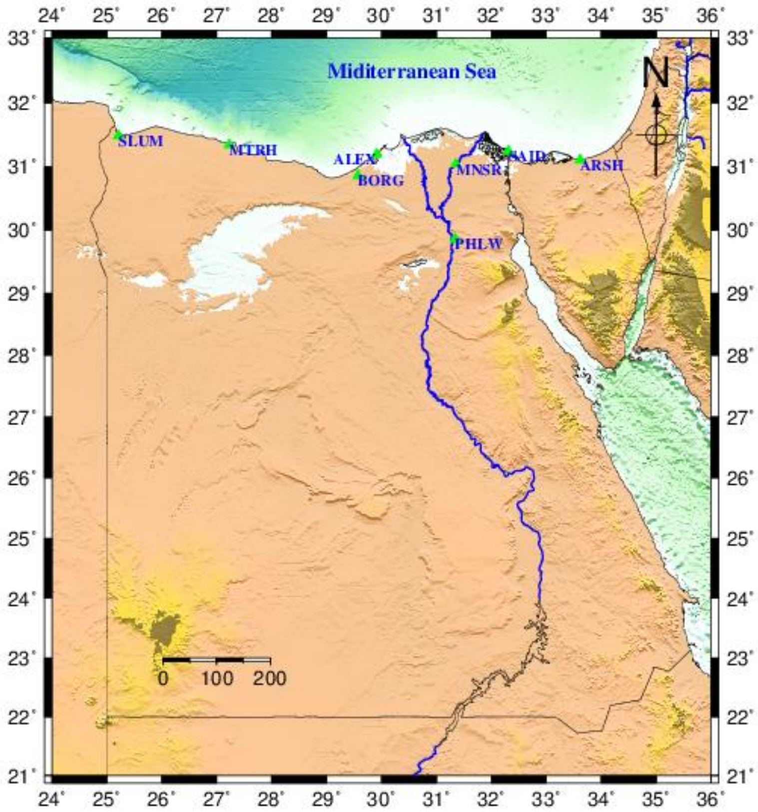

Fig. 1 Selected EPGN Stations in North Egypt

Data Processing

To check the validity of utilizing PPP in crustal deformation computation, PPP technique was applied in this research. The basic idea behind PPP is the estimation of precise satellites orbits and satellite clock errors based on observations from a high quality global fiducial network, and then the utilization of such information to solve the station parameters of any site world-wide. The PPP position determination is based on the processing of the following ionosphere-free combination of the un-differenced code and phase observations (Hofmann-Wellenhof, Lichtenegger and Wasle, 2008). The given equations show that the unknown parameters to be estimated in PPP include position coordinates, phase ambiguity terms, receiver clock offset, and the tropospheric effect.

$$\Phi = \rho + (\delta t_r - \delta t_k)c + \lambda \mathrm{N} + \delta_{trop} + \delta_{tide} + \delta_{rel} + \varepsilon_{pc} \quad \textbf{(1)}$$

$$R = \rho + (\delta t_r - \delta t_k)c + \delta_{trop} + \delta_{tide} + \delta_{rel} + \varepsilon_{cc} \quad \textbf{(2)}$$

Where:

$$N = f_1 N_1 + f_2 N_2 \quad \textbf{(3)}$$

$$\lambda = \frac{c}{f_1^2 + f_2^2} \quad \textbf{(4)}$$

R	is the pseudorange
ρ	is the geometric range
c	is the speed of light
f_1 & f_2	are the GPS L1 and L2 frequencies
N_1 & N_2	are the phase ambiguity terms on L1 and L2 frequencies
Φ	is the carrier phase
λ	is the wavelength of the combination
δt_r & δt_k	are the clock errors of the receiver and satellite respectively
δ_{trop} & δ_{tide} & δ_{rel}	Are the tropospheric, tidal, and relativistic effect respectively
ε_{cc} & ε_{pc}	denote the residuals after the combination of code and phase respectively

All the GNSS observations were processed in the methods of PPP with the automatic processing engine (BPE) of the BERNESE GNSS software (BSW) version 5.2 (Rolf Dach, Simon Lutz, Peter Walser, 2015). An overview of the GPS data processing strategy in this study is summarized in

Table **1**.

Table 1 Data Processing Strategy

Parameters	Description
Software	BSW V5.2
Data Processing Methods	Precise Point Positioning
Observation Data	L1, L2 CODE and Phase
Satellite Ephemeris	Precise Ephemeris
Ambiguity Resolution	Quasi Ionosphere Free
Tropospheric Correction	Dry and Wet GMF Model
Earth Gravity Potential	JGM3
Antenna Model	Absolute Model

Precise satellite orbits and clock products with the centimeter-level accuracy needed for PPP are now widely available from a number of public organizations. One of these well-known organizations is the International GNSS Service (IGS). Precise satellite orbits, for both GPS and GLONASS satellites, have been obtained from IGS final orbit. Next, using PPP strategy, precise geodetic heights have been estimated for each station in each session in the International Terrestrial Reference Frame (ITRF08).

Analysis of Crustal Movement

We applied the processing one day, two days and three days of RINEX file to get the least RMS of the position as shown in Fig. 2. The selected solution is the three days Rinex file as the RMS has no better changes. Normal Equation Solution, for sensing of crustal movement velocity, created after PPP processing was processed using

ADDNEQ2 module in the method of Free Network Solution for the entire study period to get the final solution.

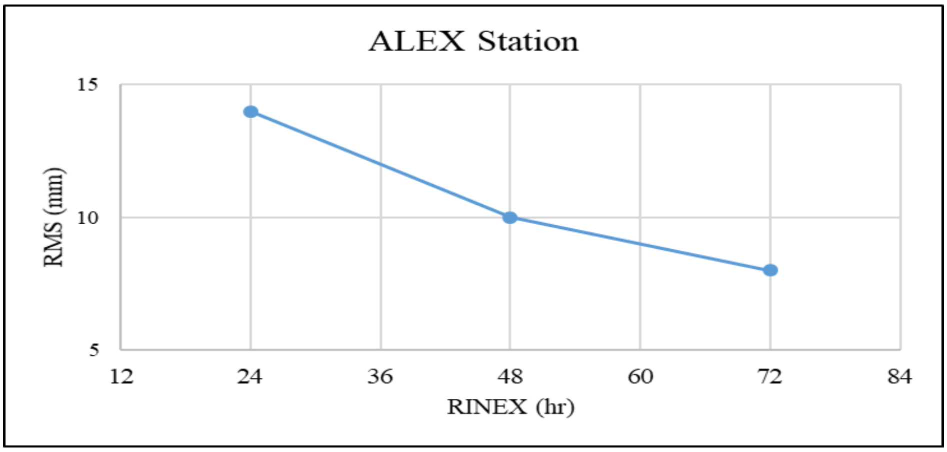

Fig. 2 RMS of processing days for ALEX station

Lastly, comparing station's heights enables the determination of vertical movement rate between two successive sessions at each station. The rates of vertical land movements have been estimated through linear regression (e.g. linear velocity and intercept). The value of correlation coefficient (R), which constitutes a statistical measure about the amount of variations in the original data that the regression formula could explain. The higher the value of that coefficient, the more precise the regression equation developed. Fig. 3 (a: f) shows the liner trend and the correlation coefficient range (0.35 – 0.85) of eight EPGN stations. The small value of correlation coefficient due to that the ellipsoidal height component has the most value of error which making the final position of each session has a great different from the next one. The final coordinate for each station summarized in Table 2.

Fig. 3 Linear Trends of Vertical Movements

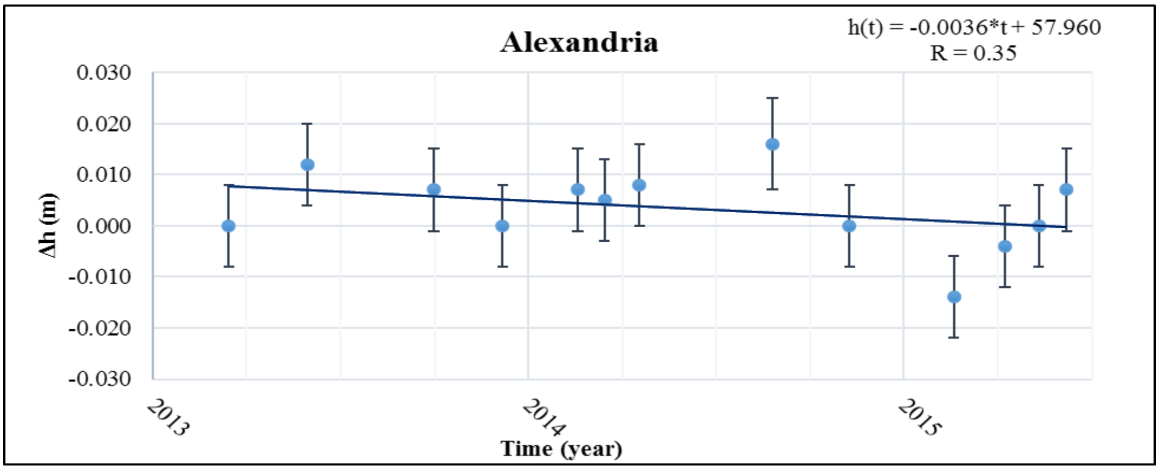

Fig. (3 – a) Linear Trends of Vertical Movements at ALEX station

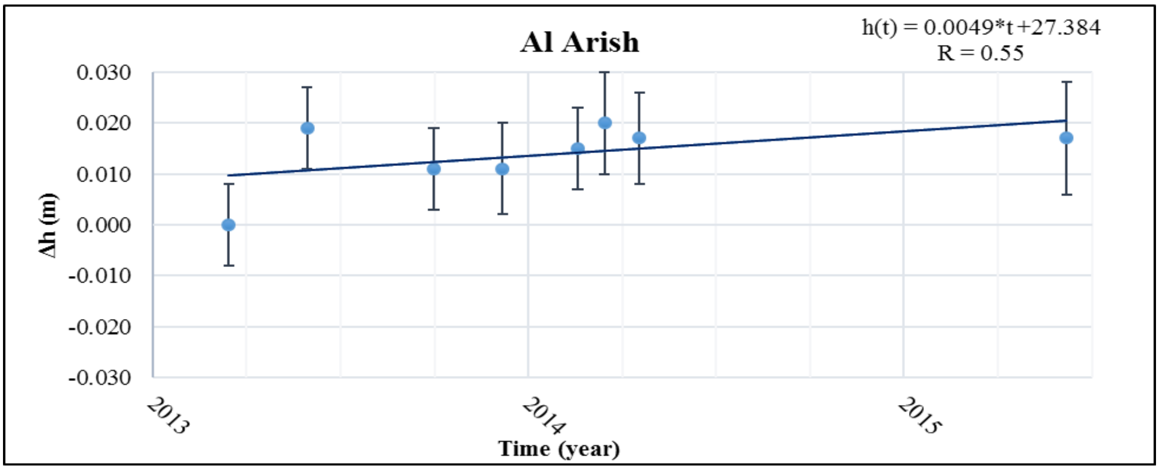

Fig. (3 – b) Linear Trends of Vertical Movements at ARSH station

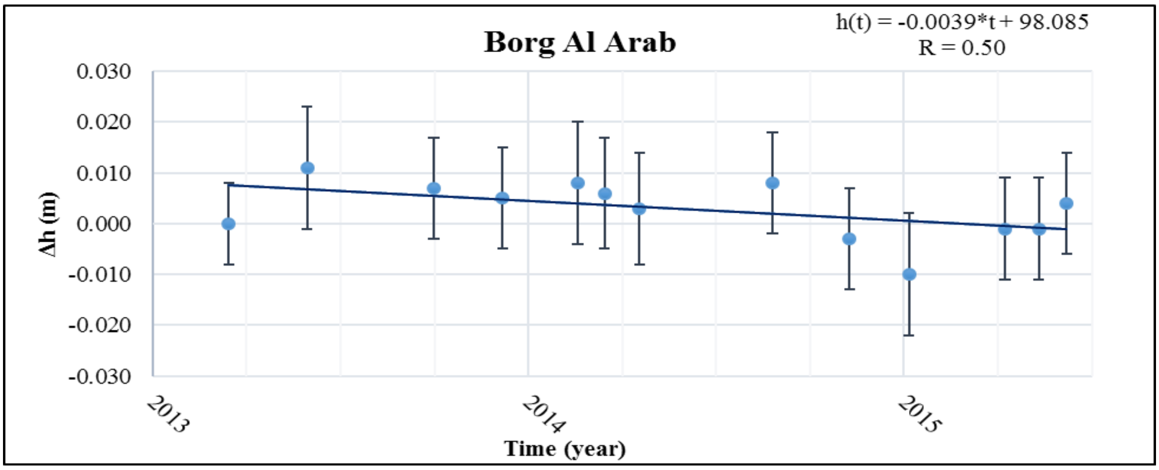

Fig. (3 – c) Linear Trends of Vertical Movements at BORG station

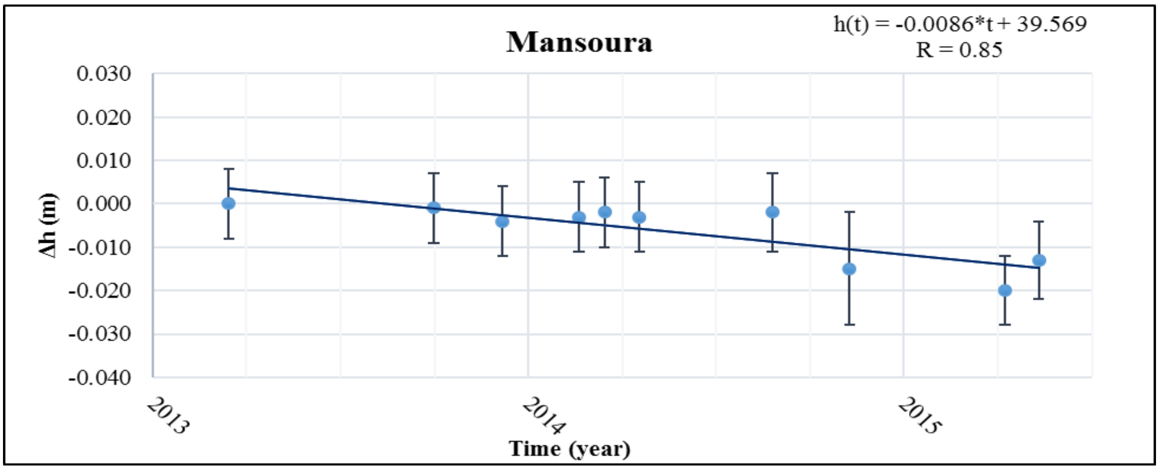

Fig. (3 – d) Linear Trends of Vertical Movements at MNSR station

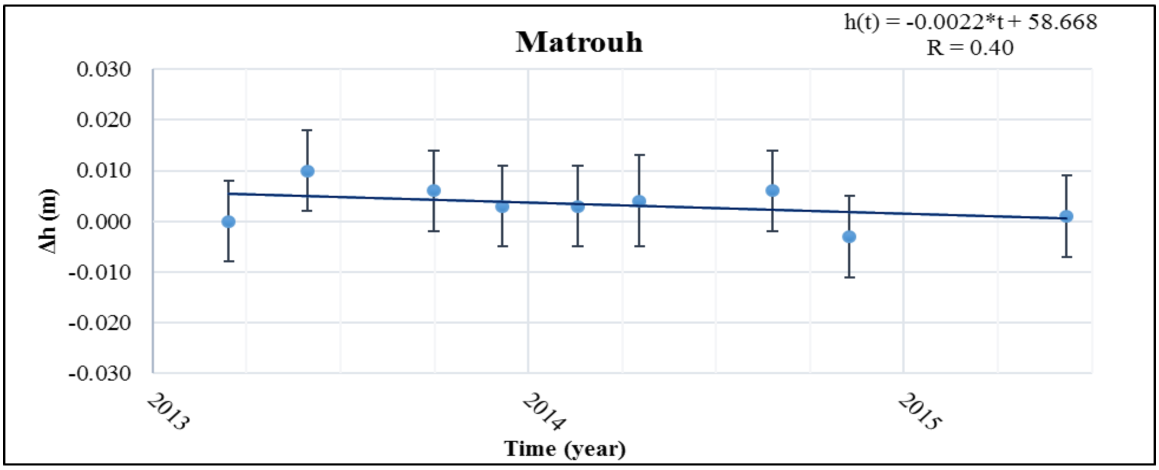

Fig. (3 – e) Linear Trends of Vertical Movements at MTRH station

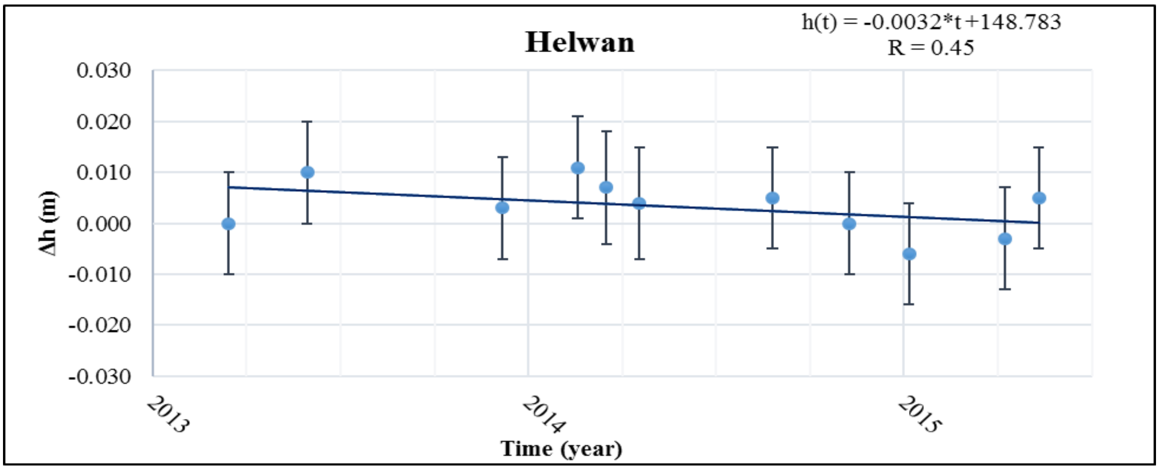

Fig. (3 – f) Linear Trends of Vertical Movements at PHLW station

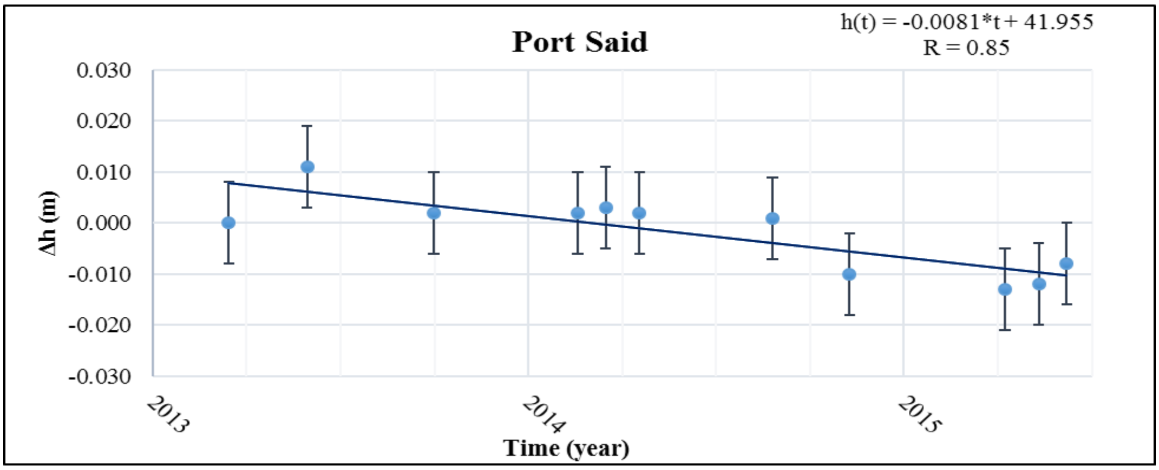

Fig. (3 – g) Linear Trends of Vertical Movements at SAID station

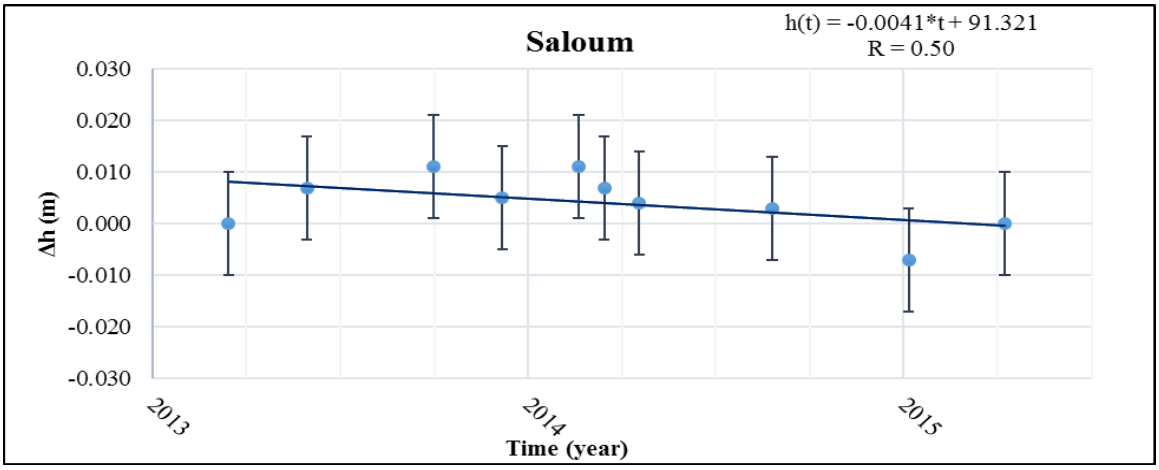

Fig. (3 – h) Linear Trends of Vertical Movements at SLUM station

Table 2: Selected EPGN station velocities including the annual horizontal velocity of the tectonic plate, estimated from this study in ITRF08, using PPP.

4-ID character	Longitude (°)	Latitude (°)	Height (m)	Ve (mm/year)	Vn (mm/year)	Vu (mm/year)
ALEX	29.911	31.197	57.96	26.90	17.40	-3.60
ARSH	33.617	31.107	27.377	22.40	19.50	4.90
BORG	29.573	30.863	98.083	21.30	18.70	-3.90
MNSR	31.352	31.041	39.565	23.30	18.90	-8.60
MTRH	27.23	31.345	58.666	21.20	17.10	-2.20
PHLW	31.343	29.862	148.781	21.50	21.10	-1.20
SAID	32.314	31.246	41.952	21.00	18.90	-8.10
SLUM	25.212	31.491	91.318	21.30	18.40	-4.10

Results and Discussions

The linear trend of the ellipsoidal height for the eight EPGN stations show that the north part of Egypt has surfed form subsidence. As it is depicted in Fig. 3, the vertical movement during the period from 2013 to the middle of 2015 shows that all stations have subsidence rat expect ARSH has uplift about 4.0 mm/ year as it is in the Sinai sub-plate. The SAID and MNSR station have great value of subsidence about 8.5 mm per year downward, the other stations shows subsidence rate about 4.0 mm/year downward as shown in Fig. 4. According to (Altamimi, Collilieux and Métivier, 2011) as shown in Fig. 5 the African plate suffer from a subsidence rate in its North direction and uplift form Northeast direction which adequate with our result .Furthermore, a spatial model of vertical movements in the north Egypt area has been developed using the Krigging statistical method within the surfer software (Golden Software, 2014). In the northern Nile Delta as shown in Fig. 6, it has been assumed that the areas underlain by the highest sediment thickness are currently subsiding the fastest and would be impacted most severely by projected sea-level rises.

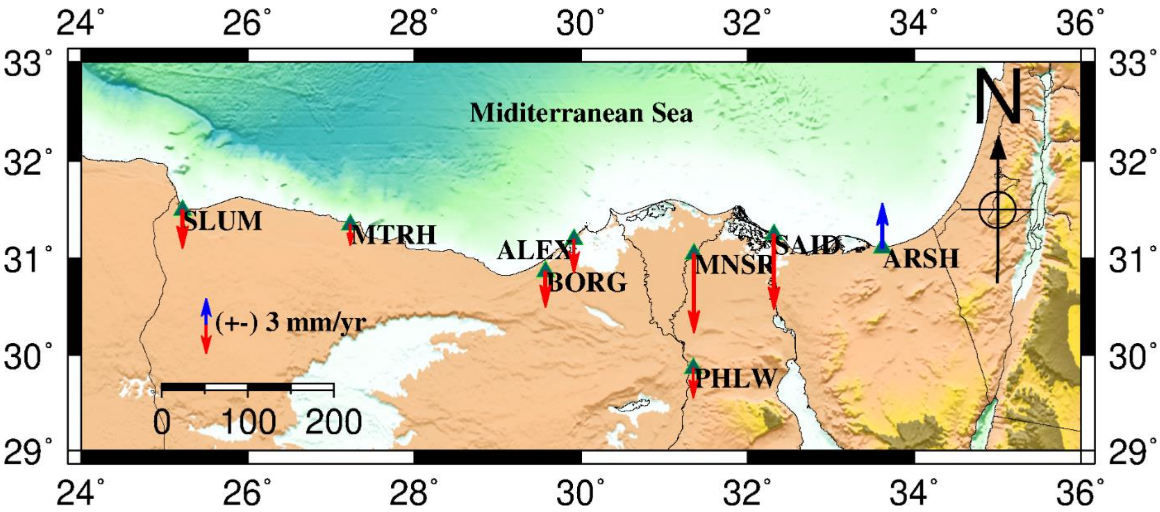

Fig. 4 The vertical movement of north Egypt network

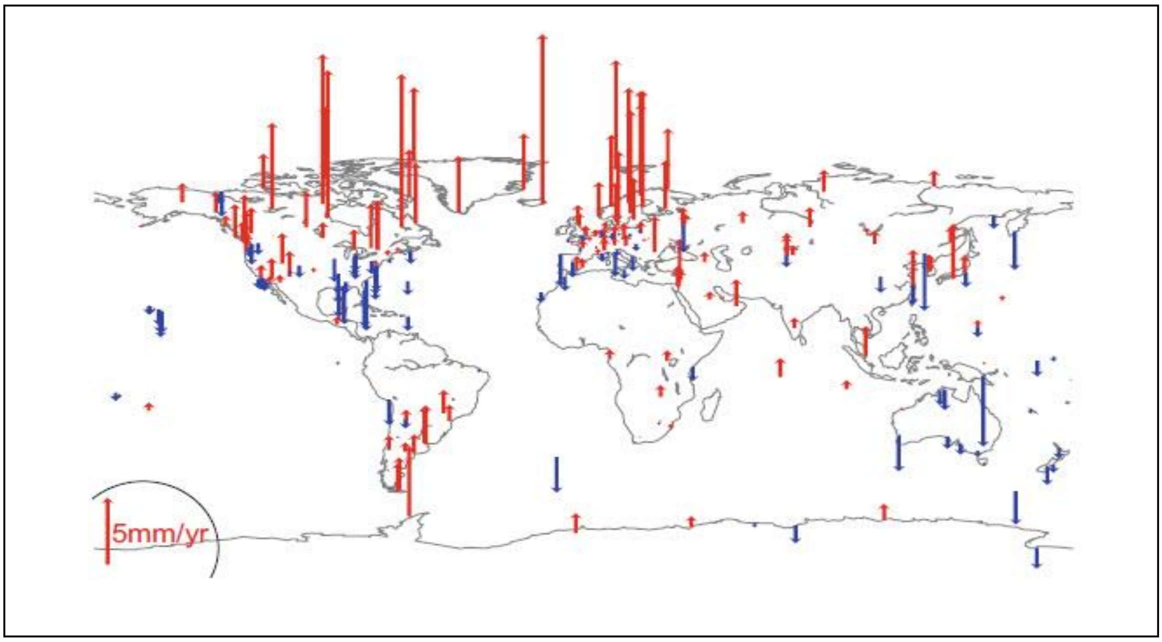

Fig. 5 ITRF2008 vertical velocities, Positive velocities are shown in red and negative in blue

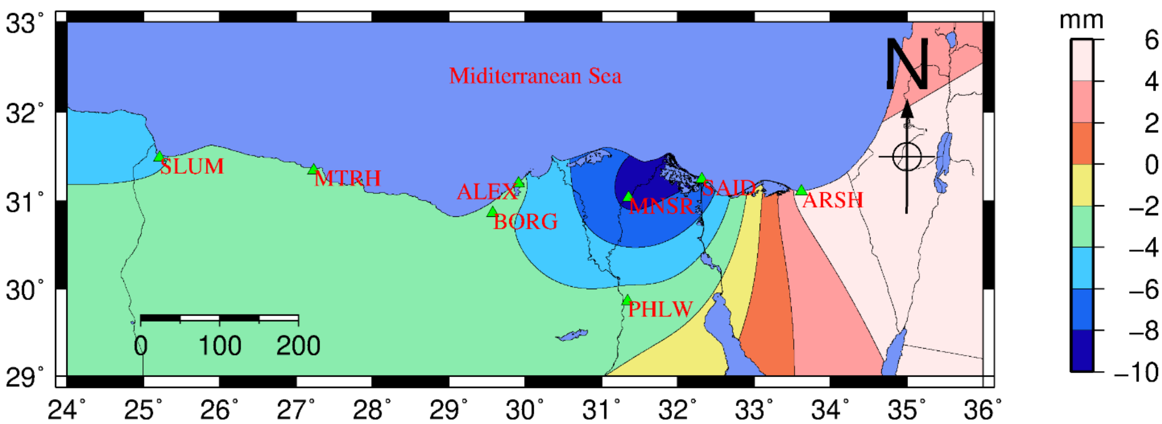

Fig. 6 The contour map of vertical velocity distribution of the north Egypt network

Conclusions

Ground deformation in general and land subsidence in particular significantly influence urban areas on environmental, development, and human basis. This research study has applied recent high precision GNSS datasets for monitoring and detecting both vertical ground movements in the north Egypt region. Repeated GNSS observations for eight stations over the North covering the period 2013 to middle of 2015 have been combined in thirteen campaign in three days RINEX file, processed, and analyzed. Ellipsoidal heights have been computed for each station at each session. The attained results show that subsidence exist in all station except Al Arish shows uplift. Furthermore, it can be seen that the GNSS station at Port Said and Mansoura shows the maximum subsidence annual rate with almost 8.5 mm/year. It should be highlighted that eight GNSS stations over the entire area might not be the optimum number of stations to precisely monitor ground deformation over that large area. More GNSS monitoring stations are recommended to fulfill a homogenous spatial distribution. The proposed stations should agree completely with the international geodetic standards for such a high-precision activity. In addition, further investigations should be carried out in the future utilizing longer time-span datasets in order to accurately map the time-dependent vertical movements in the study area.

Based on the attained primarily findings, few recommendations could be made. Firstly, although geodetic techniques, such as GNSS, can monitor and detect ground deformation by a high-accuracy level, they observe such deformation at specific point locations. Performing GPS monitoring at large number of points over a large area might be time-consuming and expansive. Hence, for the Nile Delta region, it is recommended to integrate GPS with SAR satellite imagery method in order to spatially portray the ground deformation pattern with adequate precision. Furthermore, it is a matter of fact that ground deformations are often caused by human activities such as water and oil pumping, and are influenced by natural characteristics particularly the geological, hydrological, and soil conditions. Hence, it is recommended that further detailed multi-disciplinary studies should be carried out to detect the soil compaction features of the Nile Delta, along with the recent variations of groundwater levels. Finally, the accomplished results should be taken into consideration by decision makers in any future development plans of the Nile Delta.

Appendix

Table 3: Egyptian Permanent GPS Network (EPGN) in Nile Delta and its equipment

Station	4-ID character	Antenna	Receiver	Organized by
Alexandria	ALEX	LEIAT504GG NONE	LEICA GRX1200GGPRO	CEALX
Al Arish	ARSH	TRM55971.00 NONE	TRIMBLE NETR5	NIRAG
Borg El Arab	BORG	TRM55971.00 TZGD	TRIMBLE NETR5	NIRAG
Mansoura	MNSR	TRM55971.00 TZGD	TRIMBLE NETR5	NIRAG
Matrouh	MTRH	TRM55971.00 NONE	TRIMBLE NETR5	NIRAG
Helwan	PHLW	TRM41249.00 NONE	TRIMBLE 5700	NIRAG
Port Said	SAID	TRM55971.00 TZGD	TRIMBLE NETR5	NIRAG
Saloum	SLUM	TRM41249.00 NONE	TRIMBLE 5700	NIRAG

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