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Estimation of crustal movements using the Global Positioning System (GPS) measurements along Nile Valley area, Egypt from 2007 to 2012

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Abstract The Nile Valley in Egypt is located to the west of the Red Sea Rift and to the south of the Mediterranean Sea. Recently, some moderate earthquakes were occurred along the Nile Valley at the eastern and western side. Tectonically, the Nile Valley is controlled by NW–SE, NE–SW, E–W and N–S tectonic trends due to the exerted forces and stresses.

A program of studying the recent crustal movements in Egypt has been started since 1984 to cover some areas which are characterized by the occurrence of felt Earthquakes. One of these areas is the Nile Valley. About 6 moderate earthquakes with magnitudes more than 4 were occurred on both sides of River Nile.

The present study aimed to determine the recent crustal movement parameters along the Nile Valley using the Global Positioning System (GPS) measurements. To achieve this mission, a GPS network consisting of ten geodetic stations has been established on both sides along the Nile Valley area. GPS measurements have been collected from 2007 to 2012. The collected data were processed using Bernese 5.0 Software. The result of the data analysis indicates that the rate of local velocity is small ranging from 1 to 4 mm/year. This rate is consistent with the low rate of occurrence of recent earthquakes activity along the Nile Valley area. But, the results obtained from the calculation of the regional velocity indicated that the velocity of the GPS stations including the African Plate motion is about 25 mm/year in the northeast direction which is consistent with the African Plate motion direction.

1. Introduction and tectonic setting

Nowadays, Great efforts are devoted for the development of the Nile Valley because this area is highly populated and includes many tourism places, which are very important for the Egyptian national income. Also, it contains different factories and strategic projects such as dams, electric power stations

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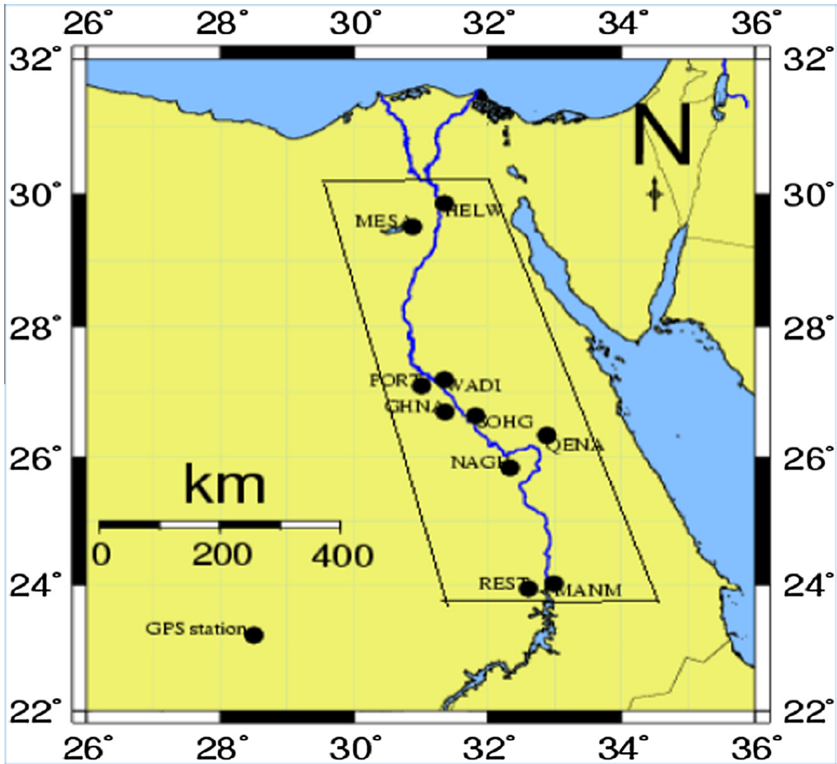

Figure 1 The study area and distribution of the GPS Stations.

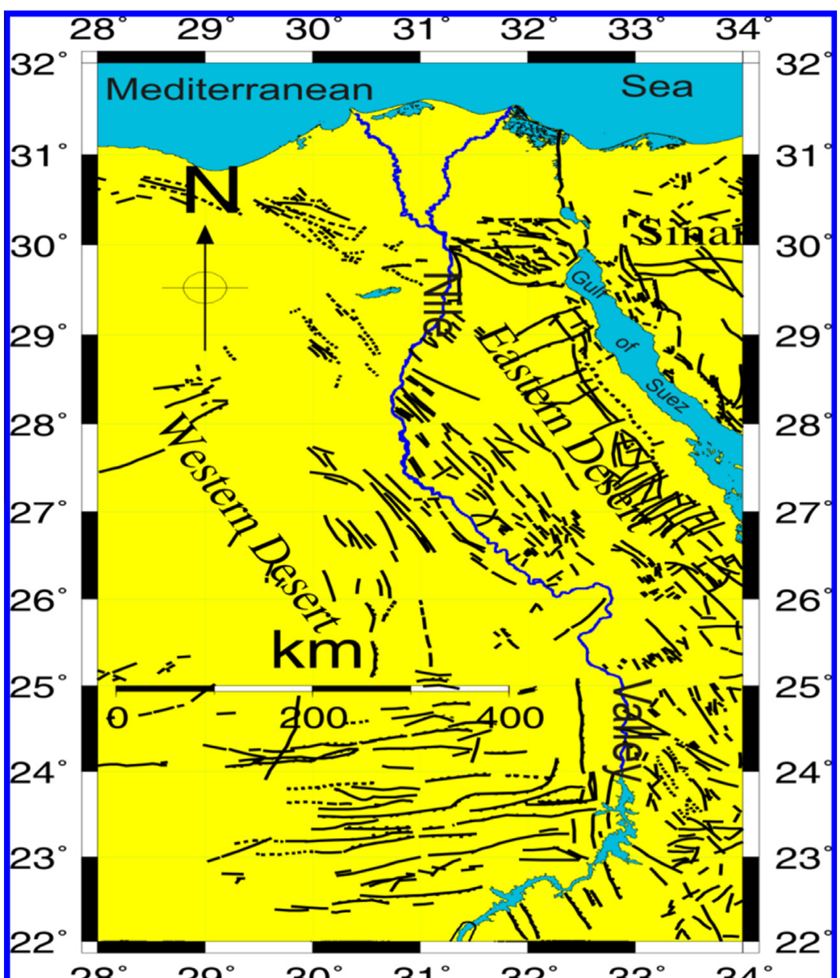

Figure 2 Main structural pattern of the study area (modified after the Egyptian Geological Survey and Mining Authority "EGSMA", 1984).

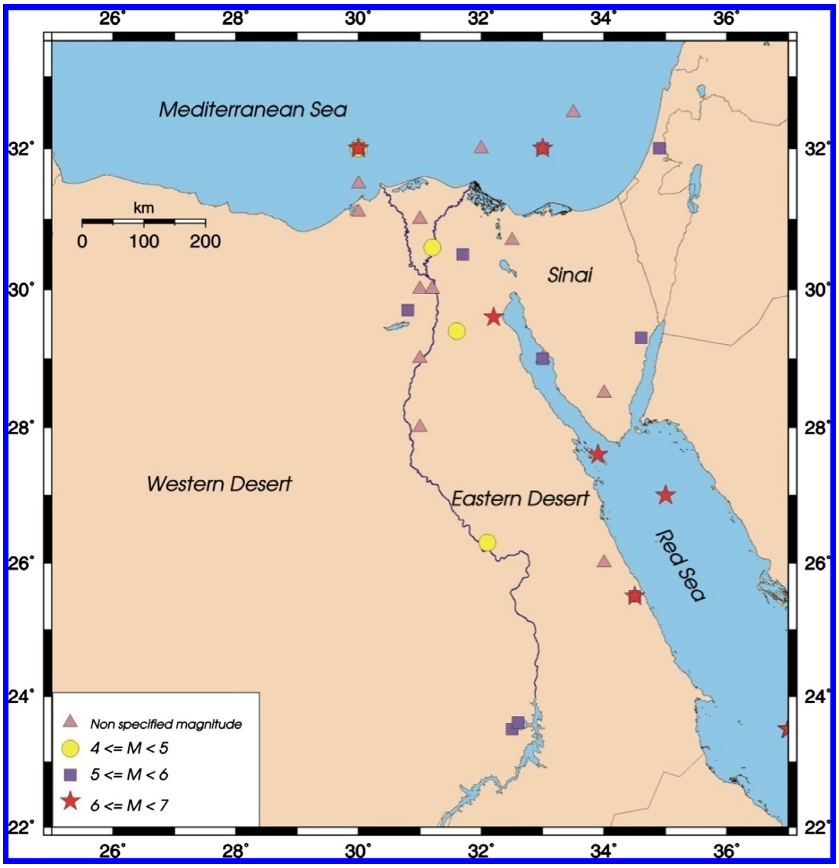

Figure 3 Review of historical earthquake activity (2200 B.C. to 1900 A.D.) Data collected from Poirer and Taher (1980), Maamoun et al. (1984) and Ambraseys et al. (1994).

Table 1 Some moderate earthquakes occurred around the Nile Valley with magnitude more than 4.

No.	Location	Date	Magnitude
1	Kalabsha earthquake	November 14, 1981	5.6
2	Dahshour earthquake	October 12, 1992	5.9
3	Gehyna (west Nile)	December 14, 1998	4.8
4	Gehyna (west Nile)	April 30, 1999	4.5
5	East Beni sueif	October 11, 1999	➢4
6	East Cairo	December 25, 1999	➢4

and settlements of new cities in different sites on both sides of the Nile Valley.

So, the study of crustal movements and seismicity is important along this vital area. The study area is located along the Nile Valley in Egypt between the latitudes 23° 56′ and 29° 51′ and longitudes 30° 33′ and 32° 59′ as shown in Fig. 1. The major tectonic trends in this area are the NW–SE and NE–SW lineaments of which the Nile Valley has been distributed (Philobbos et al., 2000; Omran et al., 2001). The lineaments are parallel and sub-parallel to the Red Sea. The geological Survey of Egypt determined the main structural elements of Egypt as shown in Fig. 2. A plateau of the Eocene sediments occupies the Eastern and Western bank of River Nile characterized by low relief topography with general inclination toward the west direction (Said, 1962, 1981, 1990). Elevation of the plateau ranges between 210 and 280 m above the sea level distributed on its eastern and western sides with a sharp scarp facing the Nile Valley area (Issawi, 1978, 1981).

For studying the crustal movements and its relation to the earthquake occurrence around the Nile Valley, geodetic points were established and measured by GPS technique at seismoactive parts since 1999 (Rashwan, 2012). In this work, additional geodetic points were distributed on both sides of River Nile from Helwan at the Northern part of the study area to Aswan at the southern part.

2. Nile Valley seismicity

The Nile valley is considered as one of the few regions of the world where evidence of historical earthquake activity has been recorded during the past 4800 years. According to Sieberg (1932), Maamoun (1979), Poirier and Taher (1980), Savage (1984), Maamoun et al. (1984) and Ambraseys et al. (1994), about 83 historical events were reported to have occurred in and around Egypt and have caused damage of variable degrees in different areas. The uneven distribution of population in Egypt creates inaccuracy in the proper identification of the origin and effects of Egyptian historical earthquakes. This yields some of the events to be spurious or to be due to other effects, which are not of seismic origin. Fig. 3 shows the location of the historical earthquakes.

As a consequence to the October 12, 1992 earthquake southwest of Cairo, the Egyptian government financed the construction of the Egyptian National Seismic Network (ENSN), covering the whole Egyptian territory. ENSN can now detect the majority of the local and regional earthquakes as well as teleseismic events (ENSN Bulletin, 2012).

The seismic monitoring capability is increased in Egypt by the establishment of the national seismograph network. The space distribution of the earthquakes constructing the seismicity map of the Nile Valley area shows that the earthquakes of the study area take almost a parallel trend to the Red Sea which is also one of the main fault trends at the Nile Valley area.

Recently, some earthquakes with moderate magnitudes occurred close to the Nile Valley area as shown in Table 1 and Fig. 4. The earthquakes are mainly concentrated in the northern part of the study area. Fig. 5 shows the earthquakes that happened from 1997 to 2012. It can be noticed that the recent earthquakes which happened during this period take the trend parallel to the Red Sea. More earthquakes in northern part of the study area may be attributed to the Mediterranean Sea and Northern Red Sea seismic activity. Majority of these earthquakes have magnitudes less than 5.0.

3. GPS measurements

In 2006, the GPS geodetic network which was established around the middle part of the Nile Valley in 1999 has been extended to cover the whole area of the Nile Valley.

In this study, GPS campaigns were carried out from May 2007 to September 2012 as shown in Table 2.

For carrying out the geodetic measurements using GPS techniques, there were a lot of field equipments that were needed in the collection of the data including the receiver units and auxiliary devices such as compass, batteries and other ancillary equipment as shown in Fig. 6.

The Geodetic receivers which perform precise baseline measurements were Dual-frequency Trimble receivers 4000 SSI and 4000 SSE. The antenna at all sessions of measurements was centered above the marker, directed to the North and fixed vertically on the benchmark as shown in Fig. 6. The

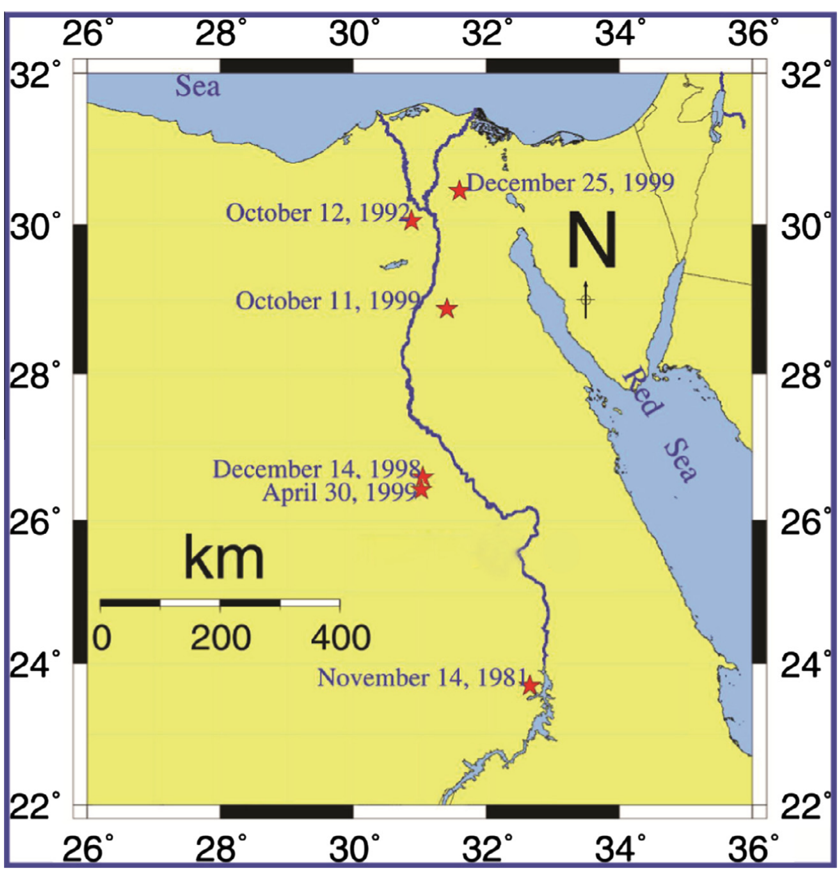

Figure 4 Recent earthquakes occurred along the Nile Valley (1980–2012).

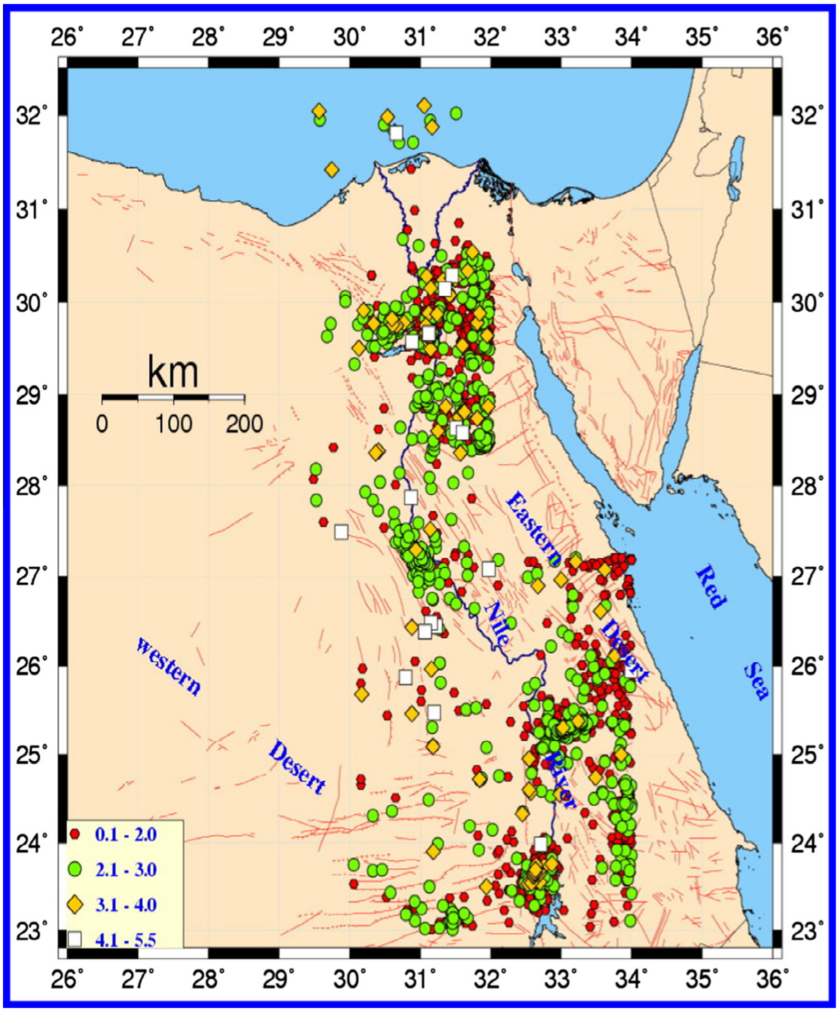

Figure 5 Earthquakes of the Nile Valley area from 1997 to 2012 by (ENSN Bulletin, 2012).

measurements were performed under constant conditions such as: the minimum elevation mask angle was 15°, the sampling data rate interval was 30 s at all stations, and the observation time of all sessions at all station was fixed as shown in Table 2.

4. GPS data processing and results

The collected data were processed using the Bernese software version 5.0 (Dach et al., 2007). Precise orbits from the International GNSS Service (IGS) stations were used throughout the processing and all the network solutions were constrained individual solution. An absolute antenna PCV correction tables for satellite and receivers were applied to correct all the phase observations, the elevation cutoff angle was set to 15° and sampling rate in the pre-processing was 30 s while the sampling rate in calculation of the network solution was reduced to 180 s. An OBS–MAX strategy was used as a strategy for ambiguity resolution, which was done through two steps; the first was fixing wide lane ambiguities with wide lane phase observations, and the second was fixing narrow lane ambiguities by using ionosphere free phases and fixing the wide lane ambiguities.

Analysis of the GPS observations was carried out during a four days campaign in all epoch observation from May, 2007 to September, 2012. Processing of baselines analyses were performed using Bernese (V.5.0) software packages and other programs for adjustment. We used six European GPS Permanent stations and the abbreviations of the stations correspond to their 4-literal ID and stand for the following sites: Ankara (ANKR), Turkey; Matera (MATE), Italy; Noto (NOT1),Italy; Nicosia (NICO), Cyprus; Sofia (SOFI), Bulgaria ; and Mitzpe Ramon (RAMO). The IGS precise ephemeris was applied in the calculation of the baselines and the displacement vectors at each GPS station were determined. Horizontal components at each station were computed from the difference of adjusted coordinates of the stations from one epoch to another and from the last epoch to the first. The displacement vectors between each two epochs of observations were calculated from the coordinate changes. Considering the confidence limit, most of these displacement vectors can be mainly attributed to the crustal movement within the study area during the campaigns of measurements.

Rashwan, 2012 calculated and concluded that the local horizontal velocity vectors with 95% confidence error ellipses

Table 2 The available data of the GPS sites from 2007 to 2012 around the Nile Valley.

Campaign	Date	Day of year (DOY)	GPS week day of week	Sampling (s)	Mask angle (°)
May, 2007	26.05.07	146	1428 – 6	30	15
	27.05.07	147	1429 – 0		
	28.05.07	148	1429 – 1		
	29.05.07	149	1429 – 2		
August, 2008	11.08.08	224	1492 – 1	30	15
	12.08.08	225	1492 – 2		
	13.08.08	226	1492 – 3		
	14.08.08	227	1492 – 4		
March, 2009	26.03.09	85	1524 – 4	30	15
	27.03.09	86	1524 – 5		
	28.03.09	87	1524 – 6		
	29.03.09	88	1525 – 0		
November, 2009	17.11.09	321	1558 – 2	30	15
	18.11.09	322	1558 – 3		
	19.11.09	323	1558 – 4		
	20.11.09	324	1558 – 5		
September, 2012	17.09.12	261	1706 – 1	30	15
	18.09.12	262	1706 – 2		
	19.09.12	263	1706 – 3		
	20.09.12	264	1706 – 4		
	21.09.12	265	1706 – 5		

Figure 6 GPS antenna connected with Trimble receiver 4000SSI.

during 2007–2009 ranging from 1 to 5 mm/yr. Geodetic data show that the African plate is moving NE with respect to Eurasia with a velocity of 6 mm/year (McClusky et al., 2003). In this work, analysis of the geodetic data in the region along the Nile Valley in Egypt indicated that the regional velocities of the GPS stations with respect to the regional tectonic plate were calculated with value between 18 mm/yr in the north direction and 23 mm/yr in the east direction, these values of regional velocities include also the African plate motion, it can be noticed that all stations move to the northeast direction which agrees quite well with the direction of the African plate motion as shown in Table 3 and Fig. 7.

On the other hand, the local horizontal velocity vectors of the stations with respect to each others are small magnitude and in the range of 1–4 mm/yr in East direction and 1–3 mm/yr in North direction as shown in Table 4 and Fig. 8.

5. Conclusions

Analysis of four GPS campaigns of the Nile Valley network was carried out from May 2007 to September 2012. Bernese version 5.0 software package has been used to analyze GPS measurements. In this study, we can conclude that, the rate of local velocity is small ranging from 1 to 4 mm/year. This rate is consistent with the occurrence of recent earthquakes activity along the Nile Valley area. Some stations of the network indicate significant changes while other stations indicate no significant changes through the period of observations. The magnitudes of the movements are distributed inhomogeneous over the area of study.

The results obtained from the calculation of the regional velocity indicated that, the velocity of the GPS stations

Table 3 The regional horizontal velocity from May 2007 to November 2012 relative to ITRF 2008.

Station name	HELW	MESA	WADI	PORT	SOHG	GHNA	QENA	NAGH	MANM	REST
V_e (mm/yr)	21.7	22.9	24.2	22.9	23.3	23.1	24.6	28.0	21.5	20.8
V_n (mm/yr)	16.9	18.2	17.3	17.7	17.5	18.5	18.8	16.6	19.6	18.3

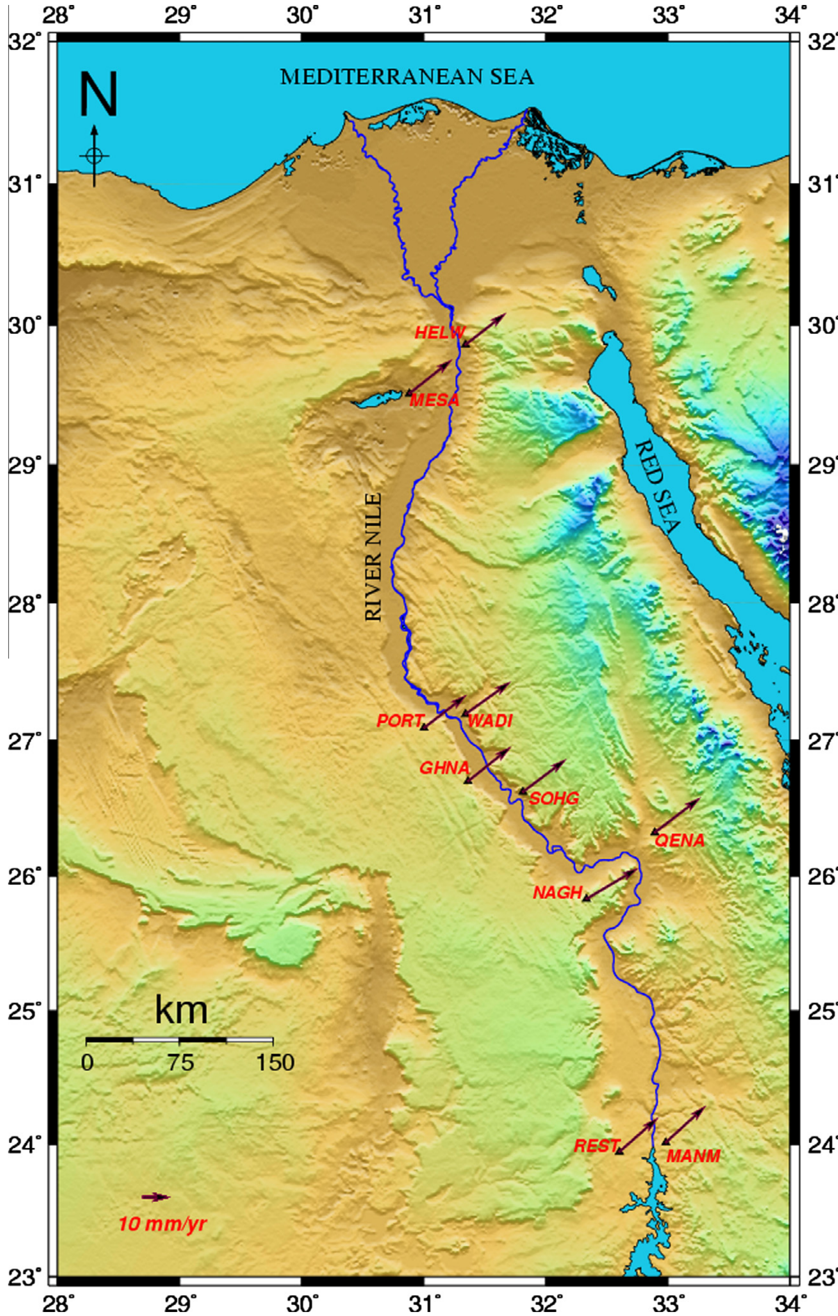

Figure 7 The regional horizontal velocity field from May 2007 till September 2012 relative to ITRF 2008.

Table 4 Local horizontal velocity recorded on the geodetic stations along the Nile Valley from May 2007 to September 2012 relative to ITRF 2008.

Station	V_e (mm/yr)	δ_e (mm/yr)	V_n (mm/yr)	δ_{n1} (mm/yr)
HELW	−2.7	0.20	−2.9	0.20
MESA	−1.4	0.20	−1.6	0.20
WADI	−1.4	0.10	−2.5	0.20
PORT	−1.7	0.10	−2.1	0.10
SOHG	−1.6	0.10	−2.3	0.20
GHNA	−1.7	0.10	−1.2	0.10
QENA	−1.5	0.10	−1.8	0.10
NAGH	2.9	0.20	−3.2	0.20
MANM	−3.8	0.20	−1.1	0.20
REST	−4.4	0.20	−1.3	0.20

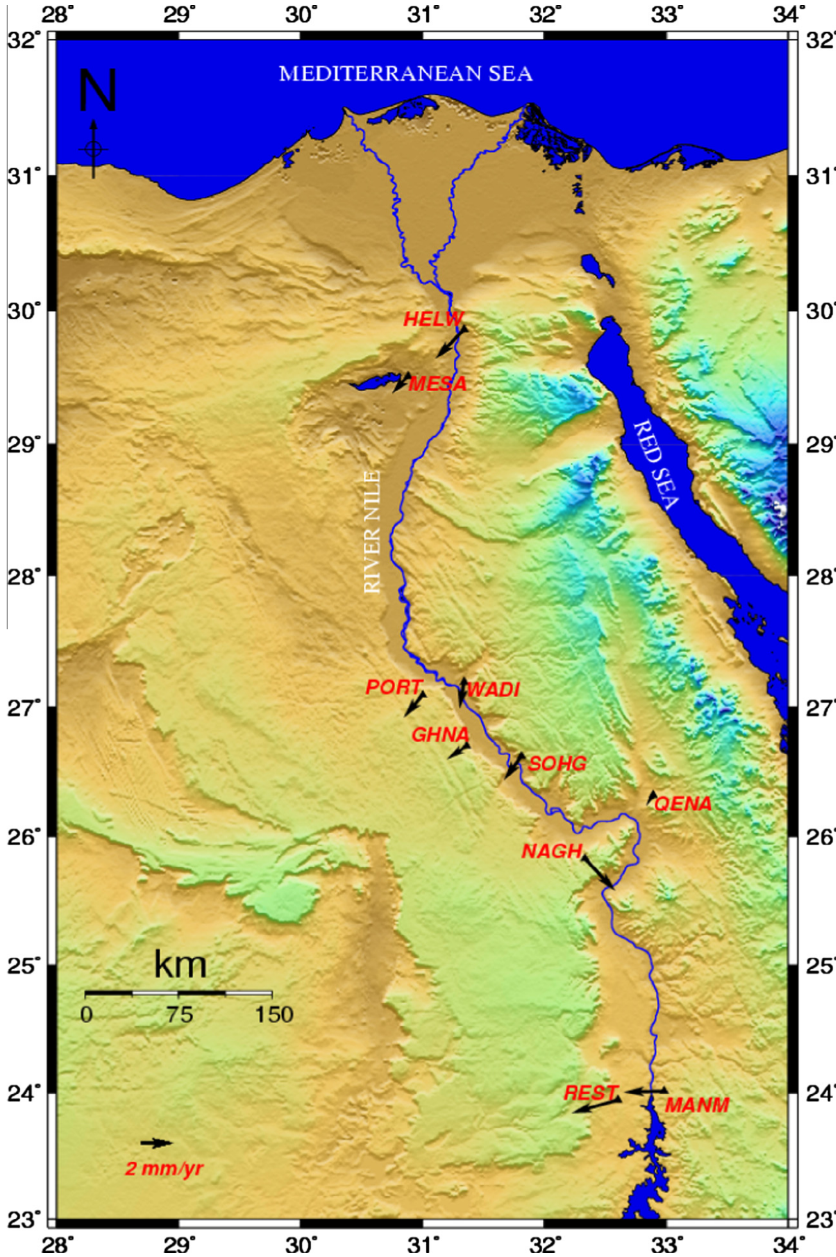

Figure 8 The local horizontal displacement of Nile Valley network from May 2007 to September 2012 relative to ITRF 2008.

including the African Plate motion about 25 mm/year taking the northeast direction which is consistent with the direction of the African plate notion.

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