A New Tidal Gravity Station at Hurghada, Red Sea, Egypt

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Abstract

The Red Sea region is one of the seismically active regions in Egypt due to the tectonic movements in the Red Sea. The evaluation of the seismic activity and recent crustal movements in this region is an important point of scientific interest. The LaCoste and Romberg gravimeter D-218 was installed in the tidal gravity station on the ground floor of the main building of the Seismological Centre at Hurghada, Red Sea, Egypt. One year of continuous gravity observations (February 2008 to February 2009) are available to conduct the current study. The main objectives are to determine the response of the crust to the tidal forces and, in consequence, to supply reductions for the geodetic observations, which were initiated due to the continuous seismological activities in this region. The tidal parameters of Hurgada station have been determined by least squares adjustment and the standard deviation of the analysis is ±5.6 nm/s^2. The residuals reach about 20 nm/s^2. The amplitude spectrum shows a noise level in the diurnal band of 5.5 nm/s^2 and 6 nm/s^2 in the semidiurnal band.

1. Introduction

Hurghada city is located in a seismically active area close to the triple junction of the African plate, Arabian plate and Sinai sub-plate. The boundaries of these three plates are seismically active and are represented by three seismic source zones: the northern part of Red Sea, the southern part of Gulf of Suez and the Gulf of Aqaba seismic zones (Fig. 1). The National Research Institute of Astronomy and Geophysics (NRIAG) has established a seismic network (ENSN) to study the seismic activity and a geodetic network to monitor the recent crustal movements. Thus, a tidal gravity station at Hurghada is of great importance in this region. In the gulf areas and shelf regions usually a lateral change of the tidal constituents is observable due to the complicated tidal wave propagation against the boundary of the shelf and the influence of the bottom and coastal friction in shallow water areas. The anomalous behavior of the tidal constituents in Gulf regions has made the accurate prediction of tides in these regions of considerable importance for various geophysical, geodetic and oceanographic applications. NRIAG has successfully established tidal gravity stations at both Cairo (Zahran et. Al, 2004) and Aswan (Hassan, 2007 ; Hassan et al., 2009 a & b). An additionl tidal gravity station has been established at the ground floor of the main building of Hurghada seismological center to achieve a higher accuracy for geodetic and geophysical observations, so high precaution in the observation and advanced analysis technique has to be applied.

2. Objectives of Hurghada Tidal Gravity Station

The objectives of Hurghada tidal gravity station are summarized as follows:

a- Carrying out continuous gravity observations to determine the local elastic parameters of the Earth's crust to the tidal forces;

b- Providing Earth tide reductions for gravity measurements and other precision measurements (satellite positioning and leveling);

c- Determining the observed ocean tide loading parameters

d- Comparing the recent ocean tide models with the observed ocean tide loading

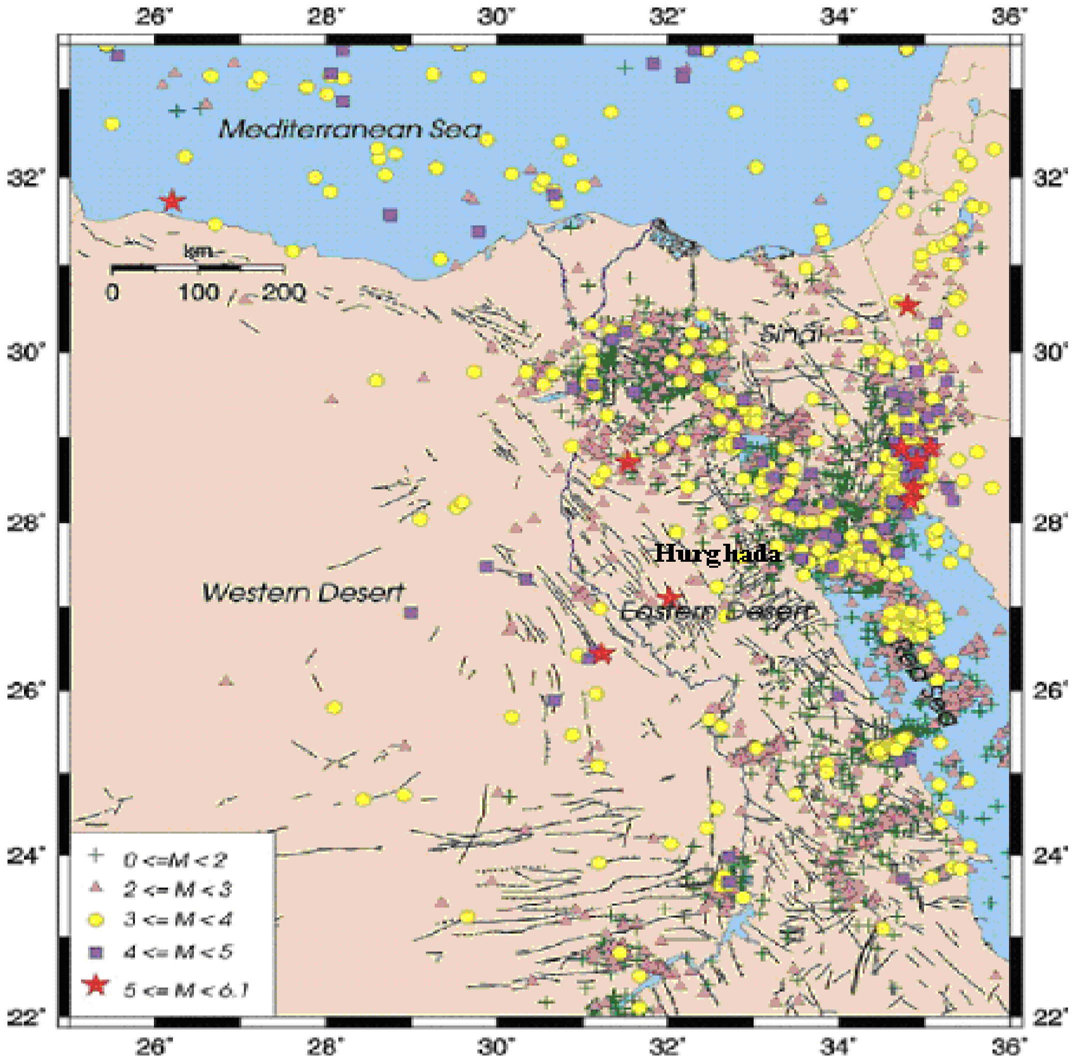

Figure 1. Local earthquakes recorded by ENSN from Aug. 1997 to Dec. 2004.

3. Hurghada Station

Hurghada tidal gravity station is located in Hurghada city (Fig. 2) at the ground floor of the main building of the Seismological Centre at Hurghada, which is close to the shore line of the Red Sea (about 250 meters). The station coordinates are 27.313° N and 33.832° E, and the elevation is 77.25m. A wooden box chamber that consists of double walls of wood and insulation material between the double walls was designed to keep the sensor (gravimeter) isolated from the surroundings. The sensor was installed on a pillar connected to the bedrock, inside the wooden box room, which is separated from the construction of the building. The gravimeter used is the LaCoste-Romberg meter D-218 with electrostatic feedback. The temperature stability in the sensor room is better than 1°C per day. The recording system consists of a multi-channel A/D-converter to provide the feedback output to the computer (Fig. 3). Besides, an UPS (uninterruptible power supply) guarantees for safe power supply and a Laptop is used to download the data.

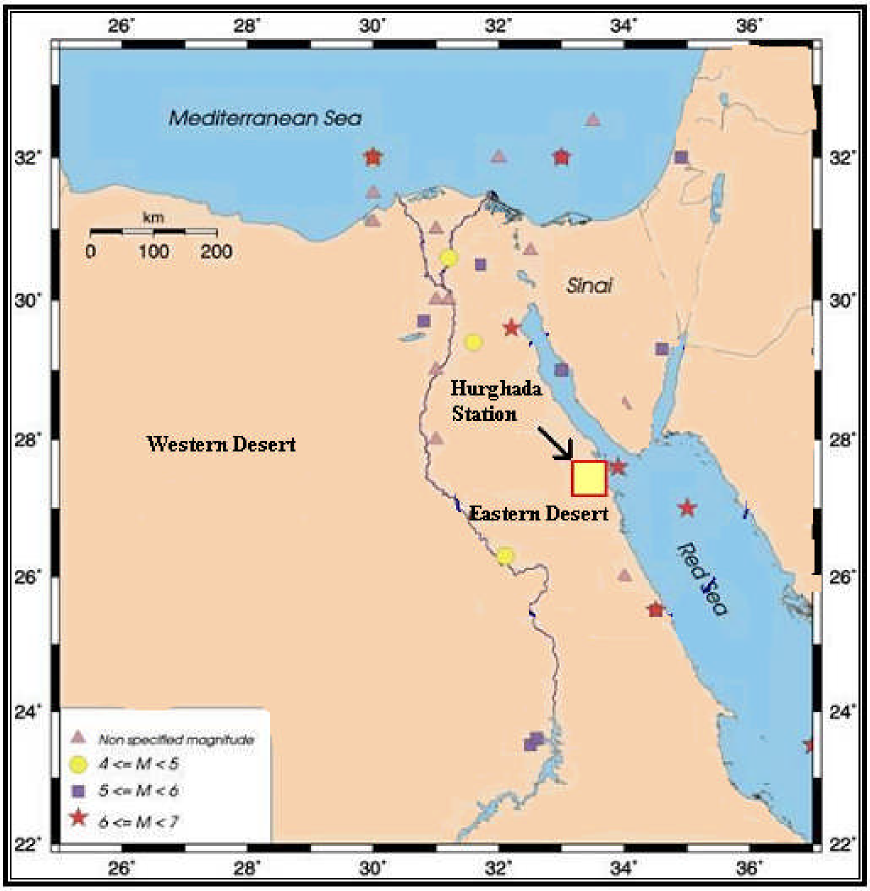

Figure 2. Location of Hurghada tidal gravity station.

Figure 3. Lacoste and Romberg Gravimeter D-218 in the measuring room of Hurghada station (left) and recording system (right).

4. Recording of Data

The recorded data were stored in a computer using software which was designed under Q-basic. Because of the response time of the feedback system there was no additional anti-aliasing filter. The data comprise three channels: two channels for the long and cross levels of the gravimeter and the third one for the feedback output. Data were logged in a high resolution sampling interval of 5 seconds. The data were stored in files, each of one hour capacity. The ETERNA format used was described by Wenzel (1994). It was adopted for the exchange of high precision and high rate Earth tide data by the working group on High Precision Tidal Data Processing at its meeting in Bonn 1994 (Jentzsch, 1995). The recording of tidal gravity data started in February, 2008, and is still going on. The changes in air pressure and temperature affect the quality of the recorded data. Besides, the data contain some gaps due to power failure. The raw data, with all noise and local perturbations, are shown in Fig. 4. The data contain, in general, a high drift. Because the station is located in a region of seismic activity, any seismic activity is clearly observed in the raw data. A period of one year (Feb. 2008 to Feb. 2009) was used for the tidal analysis.

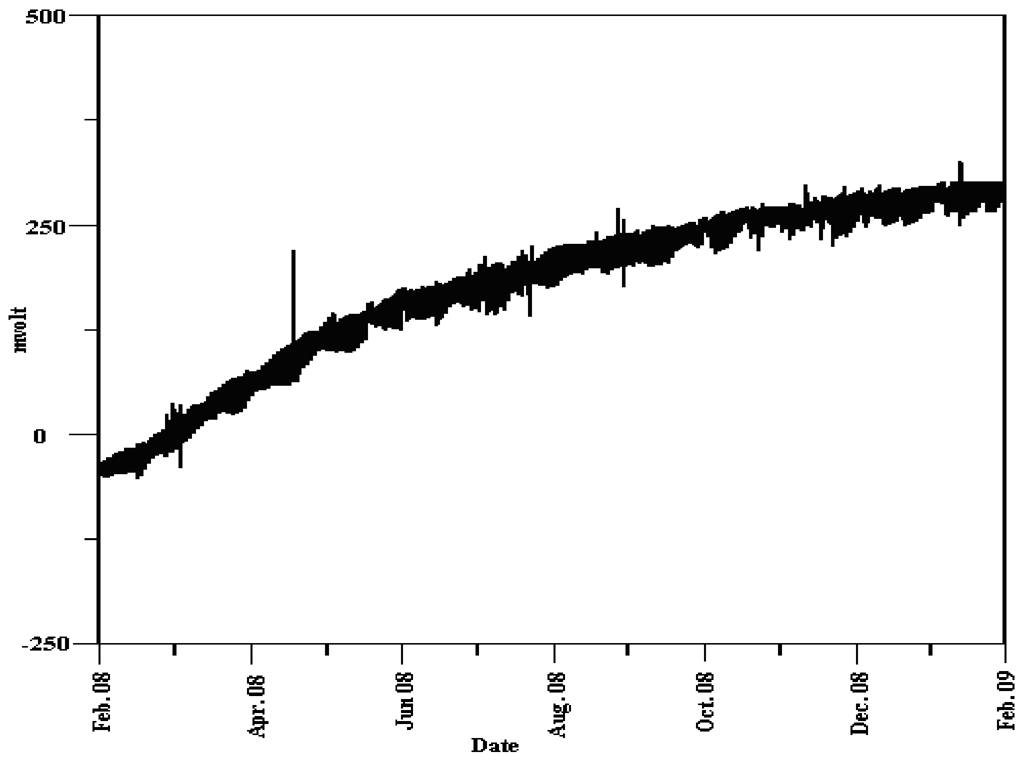

Figure 4. Raw data recorded from Feb. 2008 to Feb.2009 at Hurghada station (calibration factor 1mvolt = 12.88 nm/s^2) .

5. Analysis of Hurghada Tidal Gravity data

The tidal analysis was carried out using the program ANALYZE of the ETERNA 3.4 package (Wenzel, 1996, 1997), using the Hartmann and Wenzel (1995a, b) tidal potential catalogue. A numerical digital high-pass filtering was applied in order to eliminate the long periodic drift of the instrument. The analysis of data contained two main steps, first: data pre-processing and second: data analysis. In the first step the 5 second data files for each day were combined to one single file per day, and then, all files were combined to one file. The data were numerically filtered and sampled at 1 min interval. Afterwards, the 1 min data were calibrated and corrected for drift. The corrected one minute samples were finally numerically filtered and decimated to one hour sampling interval, using the program DECIMATE. The hourly samples have been used for tidal analysis. Fig. 5 shows the pre-processed hourly samples of the recording period.

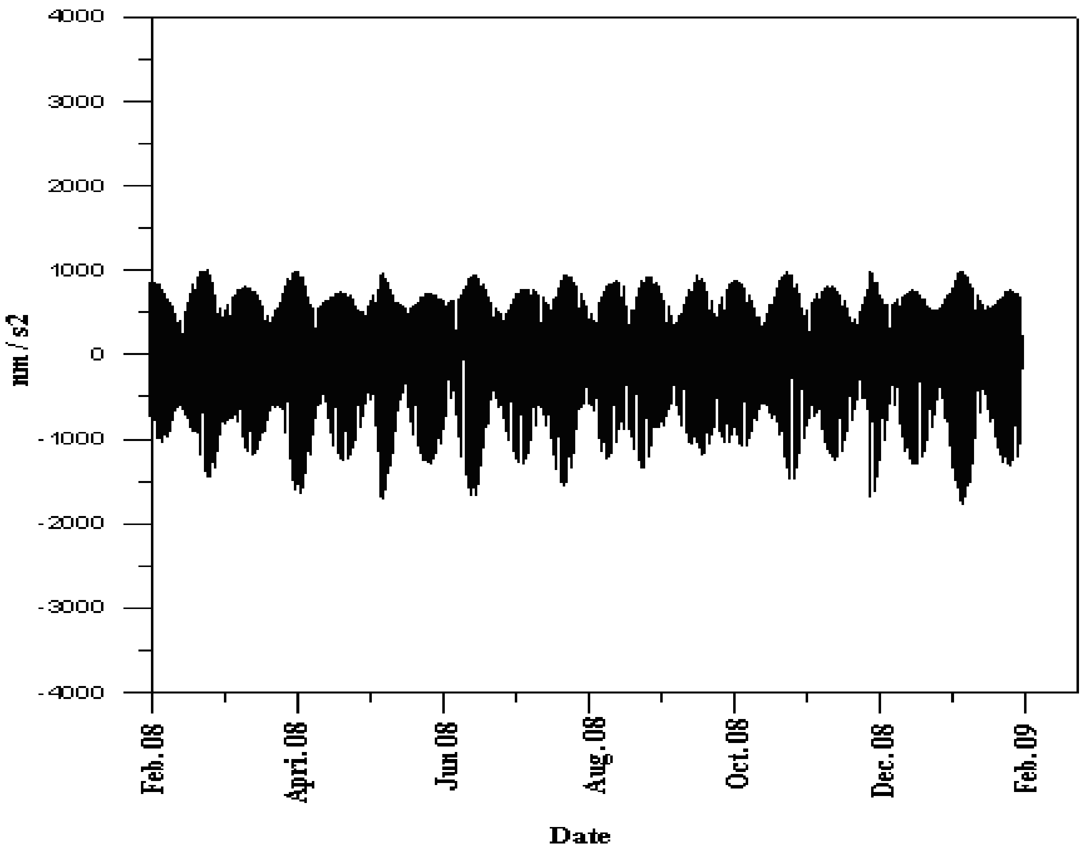

Figure 5. Hourly data at Hurghada station after pre-processing and high pass filtering.

6. Results of Tidal Analysis

The adjusted tidal parameters, using ETERNA 3.4, are given in Tab. 1. It can be noticed that some waves show an amplitude factor close to the global amplitude factor, i. e., 1.16. Most of the wave groups have a phase shift close to zero except S1, because S1 is strongly affected by thermal variations. Generally, low errors can be recognized in the semidiurnal band, especially for wave groups of large amplitudes as M2, both in amplitude factor and phase shift. The standard deviations are high for M1, S1 and L2 in phase shift. This could be due to the strong air pressure variation and the high thermal variation during the day which is very clear in S1. The standard deviations of all phases are affected by the error in the quartz clock. Also the standard deviations are very high for most of the tidal waves of higher frequencies (>2.4 cpd) because of the small amplitudes.

Table 1: Adjusted tidal parameters of Hurghada station.

Tidal Wave	From cpd	To cpd	Amplitude Th. nm / s²	Amplit. Factor	Stand. dev. %	Phase shift (degree)	Stand. dev. (degree)
Q1	0.501370	0.911390	48.4448	1.1354	0.351	-0.252	0.204
O1	0.911391	0.947991	253.0250	1.1289	0.076	0.058	0.044
M1	0.947992	0.981854	19.8995	1.1029	1.358	-0.931	0.787
P1	0.981855	0.998631	117.7320	1.1321	0.213	0.154	0.122
S1	0.998632	1.001369	2.7830	1.1706	12.551	20.35	6.964
K1	1.001370	1.880264	355.8535	1.1121	0.064	-0.047	0.036
N2	1.880265	1.914128	113.4428	1.1477	0.232	-0.010	0.136
M2	1.914129	1.950419	592.5144	1.1489	0.049	0.005	0.029
L2	1.950420	1.984282	16.7475	1.1624	1.702	0.142	0.961
S2	1.984283	2.002885	275.6689	1.1384	0.100	0.024	0.058
K2	2.002886	2.182843	74.9228	1.1222	0.004	0.164	0.058
2MK3	2.451944	2.869714	2.8350	0.7927	0.035	-7.793	2.503
M3	2.898264	2.903887	10.3383	1.1538	1.104	0.370	0.667
MK3	2.927107	2.940325	0.5859	1.5732	0.142	-1.371	5.172
S3	2.965989	3.001000	1.3475	1.0898	0.058	-0.294	3.065
MN4	3.791510	3.833113	0.0601	2.8219	1.911	157.346	38.786
M4	3.500000	4.499999	0.1671	2.1661	35.356	-151.520	22.490
SN4	3.875000	3.901458	0.0144	10.5698	6.946	-164.754	37.656
MK4	3.936000	6.00000	0.0292	69.1009	25.398	113.794	21.056

7. Ocean Tide Loading Computation

Hurgada tidal station is of relatively small distance to the shore line, so precise computation of the ocean tide loading is needed. In order to compare the observed tidal parameters with the theoretical tidal signals, the ocean tide loading contribution has to be subtracted from the observed tidal parameters. The computation of ocean tide loading requires a model of ocean tides (Zahran et al., 2006). Nowadays, there is a great progress on ocean tide models, based on the data from TOPEX/POSEIDON. Ocean tide loading has been predicted for the coordinates of Hurghada tidal station, using the FES2004 ocean tide model (Lyard et al., 2006) and the online computation with the program OLMPP, M. S. Bos and H. G. Scherneck. The resolution of the ocean tidal model (FES2004) is 0.125°x0.125°. The computations were carried out applying the SPOTL-program (Agnew, 1996) at the coordinates of Hurghada tidal station. Table 2 shows the results of the ocean tide loading vectors and the corrected tidal parameters for the main tidal waves.

8. Discussion of Tidal Analysis Results

The evaluation of the discrepancy between observed /corrected and the theoretical parameters was obtained by computing the residual vectors (Table 3) which are in the range from 0.39 nm/s² for Q1 to 15.3 nm/s² for M2. The theoretical tidal parameters were estimated using the Dehant (1987) Earth model (Eanes, 1994). A systematic bias is existing in the ratio between the theoretical amplitude factors (Table 3) and the corrected ones (Table 2). This bias reaches 1.5% when considering the main diurnal and semi-diurnal tidal constituents. It is difficult to explain such an effect only by the insufficient resolution of the ocean tides model in the Red Sea, as the ocean loading values associated with that bias represent twice the amplitude of the computed ocean loading for the diurnal waves and 50% of it for M2. One can suspect perhaps a change of the calibration factor of the instrument.

Table 2: Ocean tide loading computation at Hrghada station.

Wave	Amplitude nm / s²	Phase shift (degree)	Amplitude Factor corrected	Phase Shift corrected
Q1	0.7	-179.1	1.1109	-0.244
O1	1.9	176.9	1.1364	0.037
P1	0.8	145.2	1.1377	-0.042
K1	2.8	147.9	1.1188	-0.261
N2	4.4	-96.6	1.1528	1.905
M2	15.2	-76.2	1.1431	1.254
S2	4.4	-47.9	1.1278	0.626

Table 3: Discrepancies between theoretical and observed tidal parameters at Hurghada station.

Wave	Amplitude Theoretical	Amp. Factor Theoretical	Residual Vector nm / s²	Phase of residual vector
Q1	48.4448	1.1561	4.78	142.48
O1	253.0250	1.1559	5.01	177.89
P1	117.7320	1.1504	1.51	176.71
K1	355.8535	1.1349	5.96	162.34
N2	113.4428	1.1596	4.44	101.74
M2	592.5144	1.1596	18.02	124.68
S2	275.6689	1.1596	9.53	159.04

9. Gravity Residuals and Conclusions

The tidal gravity residuals are given in Fig. 6. The residuals have a general range of about ± 10 nm/s². No significant anomalies can be recognized in the residuals. The amplitude spectrum of residual gravity is very important to prove if the tidal waves are completely approximated or not. It can be noticed that tidal signals are still contained in the gravity residuals. The ANALYZE program allows the computations of the Fourier amplitude spectrum of the residuals (Fig. 7). It shows a noise level in the diurnal band of up to 5.5 nm/s² and in the semidiurnal band of 6 nm/s². Also at higher frequencies a noise level of 4.7 nm/s² can be recognized. The peaks correspond to shallow water components probably caused by ocean tide loading in the Red Sea. The significant energy in the residual spectrum may be due to the timing problem of the quartz clock, and air pressure variation, which was not considered during registration and analysis.

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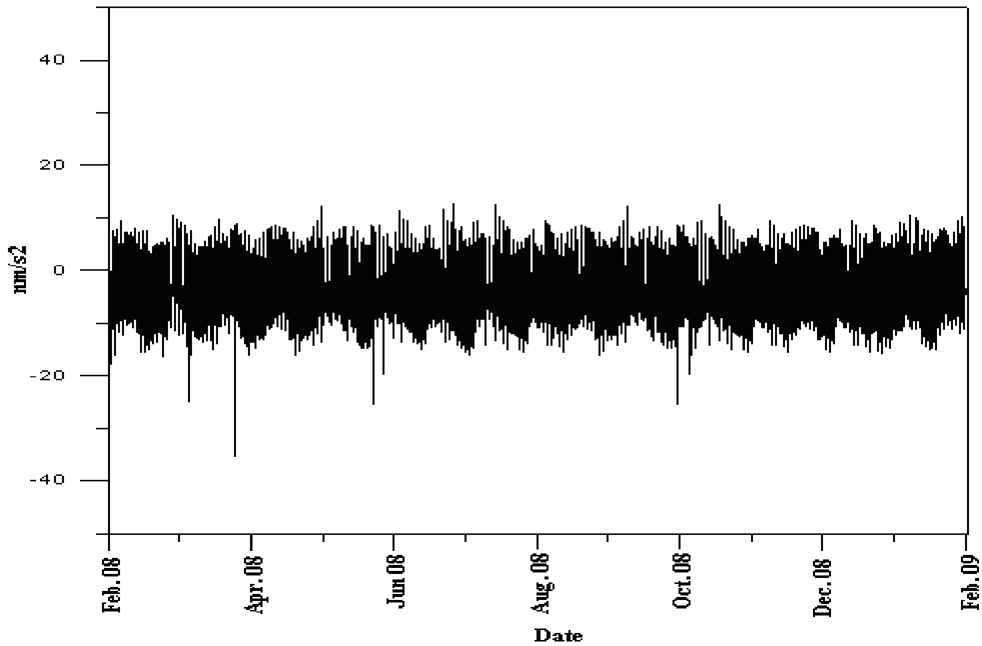

Figure 6.Residual gravity at Hurghada station after tidal analysis.

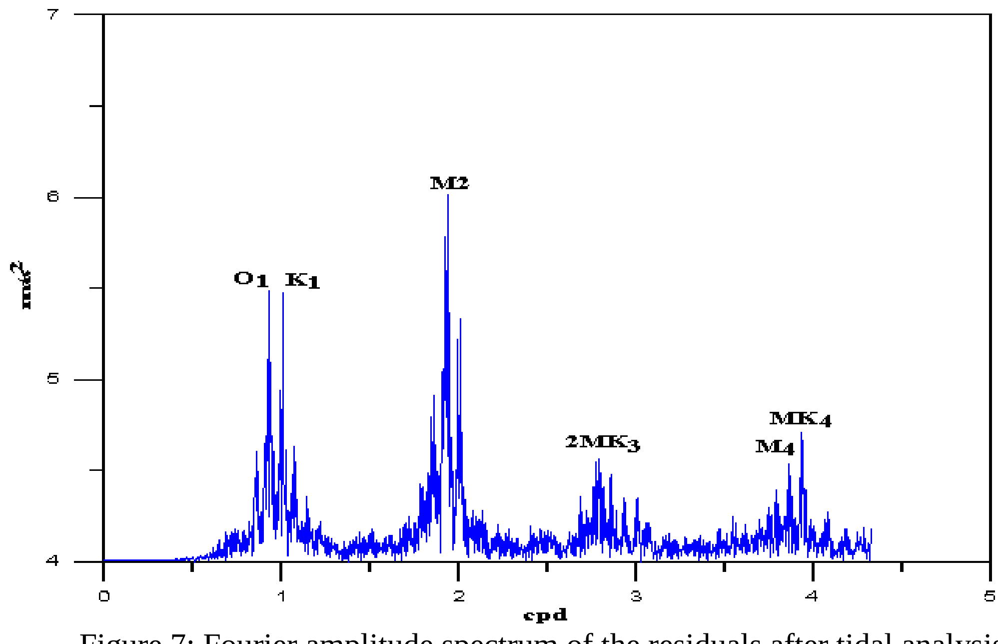

Figure 7: Fourier amplitude spectrum of the residuals after tidal analysis at Hurghada station.

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