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SEISMICITY AND SEISMIC HAZARD ANALYSIS IN AND AROUND THE PROPOSED TUSHKA NEW CITY SITE, SOUTH EGYPT

Raafat E. FAT-HELBARY [1]*, Hussein M. El KHASHAB [2], Dragi DOJCINOVSKI [3], Karrar O. El FARAGAWY [4] and Abdel-nasser M. ABDEL-MOTAAL [1]

[1] *Aswan Earthquake Research Center, P.O. Box 152 Aswan, Egypt*
[2] *Geology Dept., Sohag University, Sohag, Egypt*
[3] *Institute of Earthquake Engineering and Engineering Seismology (IZIIS), Skopje, Macedonia*
[4] *Geology Dept., Aswan Faculty of Science, South Valley University, Aswan, Egypt*
**Corresponding author's e-mail:* fat_helbary@yahoo.com

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ABSTRACT

For the last decade the Egyptian government has planned to implement the Tushka project at the southeastern part of the western Desert. This project includes the construction of a number of new cities. Tushka New City is one of these cities. Tushka area has a complex tectonic and geological history. Although no historical earthquakes are known to have occurred in the Tushka area, five large earthquakes of magnitude between 5.1 and 6.2 were recently observed from four active zones located around Tushka area. In addition to these four zones many microearthquakes have been detected in and around Tushak area. The main purpose of this research is to elucidate the seismicity and estimate the seismic hazard due to this activity in the study area.

According to the spatial distribution of earthquakes that located in and around the study area, 9 seismic zones are defined on the seismotectonic map. For each seismic zone the seismic hazard parameters are estimated and used as input data for seismic hazard analysis. The resulting probability distributions are taken to produce iso-acceleration map for specific periods and economic life of public structures. The hazard at the proposed Tushka New City site is given by the hazard curve that is represented by the relationship between the peak ground acceleration and its annual exceedance probability. The maximum peak ground acceleration is 49, 137, 157 and 177 cm/s^2 (gal) for zones Z-1, Z-6, Z-9 and Z-4 respectively. Although the values of PGA in zones Z-4, Z-6 and Z-9 are almost the same, Z-4 has a significant effect on the proposed Tushka New City site due to its location about 140 km northeast to the study area, while the calculated maximum acceleration with 90 percent probability of not being exceeded in 50 years of exposure time (475 years return period) at the proposed Tushka New City site was about 22 cm/s^2.

KEYWORDS: seismic hazard, proposed Tushka New City site, Kalabsha, acceleration

1. INTRODUCTION

Tushka area located at the southeastern part of western Desert, in the distance between 200 to 260 km south of the Aswan High Dam. This area is characterized by a complex tectonic and structural history. Tushka New City (Figure 1) is an urbanization project that is relatively large-scale regional development project and it will be good if the assessment of seismic hazard being incorporates in the planning stage.

Seismic hazard is defined as the probability that the ground-motion amplitude exceeds a certain threshold at a specific site. The hazard-relevant quantity calculated is the Peak Ground Acceleration (PGA), a commonly used parameter in earthquake engineering. The methodology applied is based on the generally accepted concept by Cornell (1968).

In this study the main target is to study the seismicity and to calculate the seismic hazard due to this activity in the study area and surrounding area based on probabilistic seismic hazard computation using the seismic source models in the area.

2. SEISMICITY IN AND AROUND THE PROPOSED TUSHAK NEW CITY SITE

Instrumental earthquakes during the period 1900 to 2006 were collected from Mamoun et al., 1984, International Seismological Center Bulletin (ISC), National Earthquake Information Center (NEIC), Preliminary Determination of Epicenters (PDE) and Aswan seismic Bulletin.

Earthquake recording in Egypt has started since 1899 with Helwan station. Instruments of this station have been upgraded several times and in late 1975 two other stations were added at Aswan and Abu-Simbel. Kalabsha earthquake had a magnitude of 5.6 and occurred on 14 November, 1981 in Kalabsha area. Microearthquake monitoring of the region began in December 1981, when MEQ-800 field recorders were installed after the Kalabsha earthquake. In July 1982

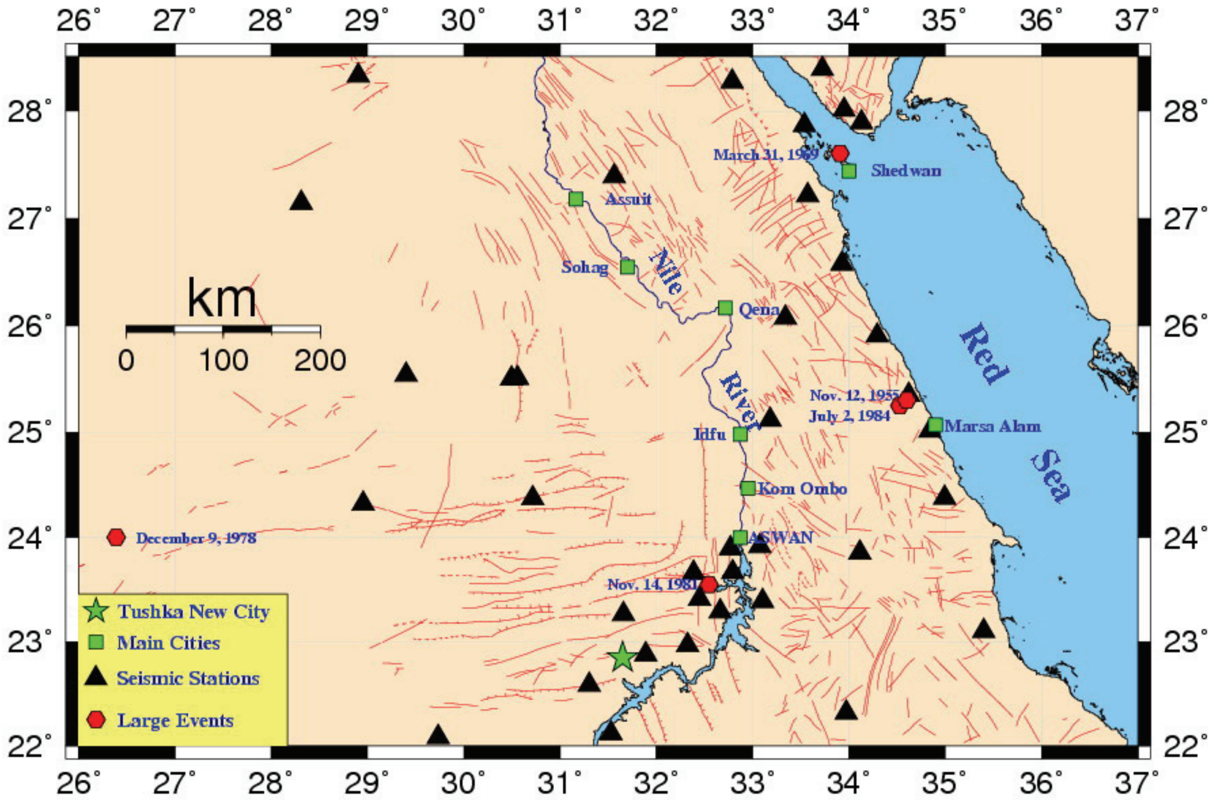

Fig. 1 Location map of the proposed Tushka New City site and surrounding area.

a radio-telemetry network of thirteen stations erected by Helwan Observatory and High and Aswan Dam authority was operated for monitoring microearthquake activity around the northern part of Nasser Lake. After October, 12, 1992 earthquake in Dahshour area, 35 km to the southwest of Cairo, the Egyptian Government manipulated the investment in the National Research Institute of Astronomy and Geophysics (NRIAG) and constructed the Egyptian National Seismic Network (ENSN). The ENSN covered the whole Egyptian territory based on satellite communication to detect and record the majority of local and regional earthquakes as well as teleseismic events.

On November 12, 1955 an earthquake with magnitude of 5.6 occurred in Abu- Dabbab area and was felt in Upper Egypt at Aswan, Qena and as far as Cairo but no damage was reported. Also on July 2, 1984 an earthquake of magnitude 5.1 occurred in the same area, it was the maximum magnitude of the earthquake swarms observed since 1970. Shedwan Island earthquake occurred on March 31, 1969 with magnitude 6.2 in a small part of Shedwan Island. In the southern part of the western Desert, Gilf El-Kabir earthquake was occurred on December 9, 1978. This event had a magnitude of 5.3 and a focal depth of about 7 km.

In addition to the collected earthquakes from National and International Bulletins, the regional data used in this study during the period from 1982 to 2006 mainly was located using Aswan, Abu–Simbil, Marsa Alam seismic stations, Aswan seismic network and Egyptian National Seismic Network.

According to the spatial distribution of earthquakes that were located in and around the study area as shown in Figure 2, several areas having different seismicity level have been represented around Tushka New City site and known as: Shedwan Island, Red Sea, Abu Dabbab, East southern corner of the Eastern Desert, Kalabsha, Abu Simbel and southern part of the Western Desert area. Due to the location of Kalabsha and Abu-Simbel near to the study area, so the seismicity of these areas will be discussed in details as follow.

2.1. SEISMICITY OF KALABSHA AREA

No earthquakes (except the 5.6 M 14, November 1981) had been reported in the Kalabsha area in the catalogue of the International Seismological Center (ISC) since its inception in 1920. Because of the lack of the continuous and reliable data during the early stages of filling Nasser Lake, it is not possible to determine exactly when low-magnitude activity might start. Following the main shock, portable

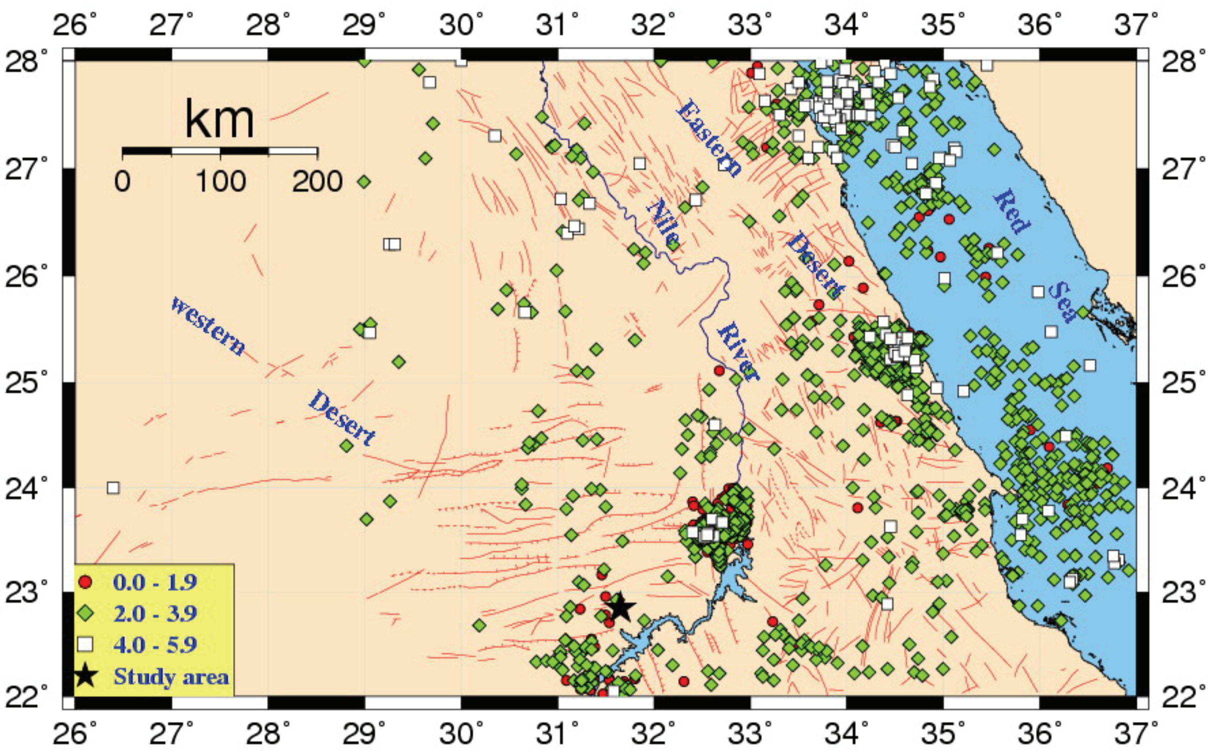

Fig. 2 Earthquake epicentral distribution in and around the study area during the period 1900 to 2006.

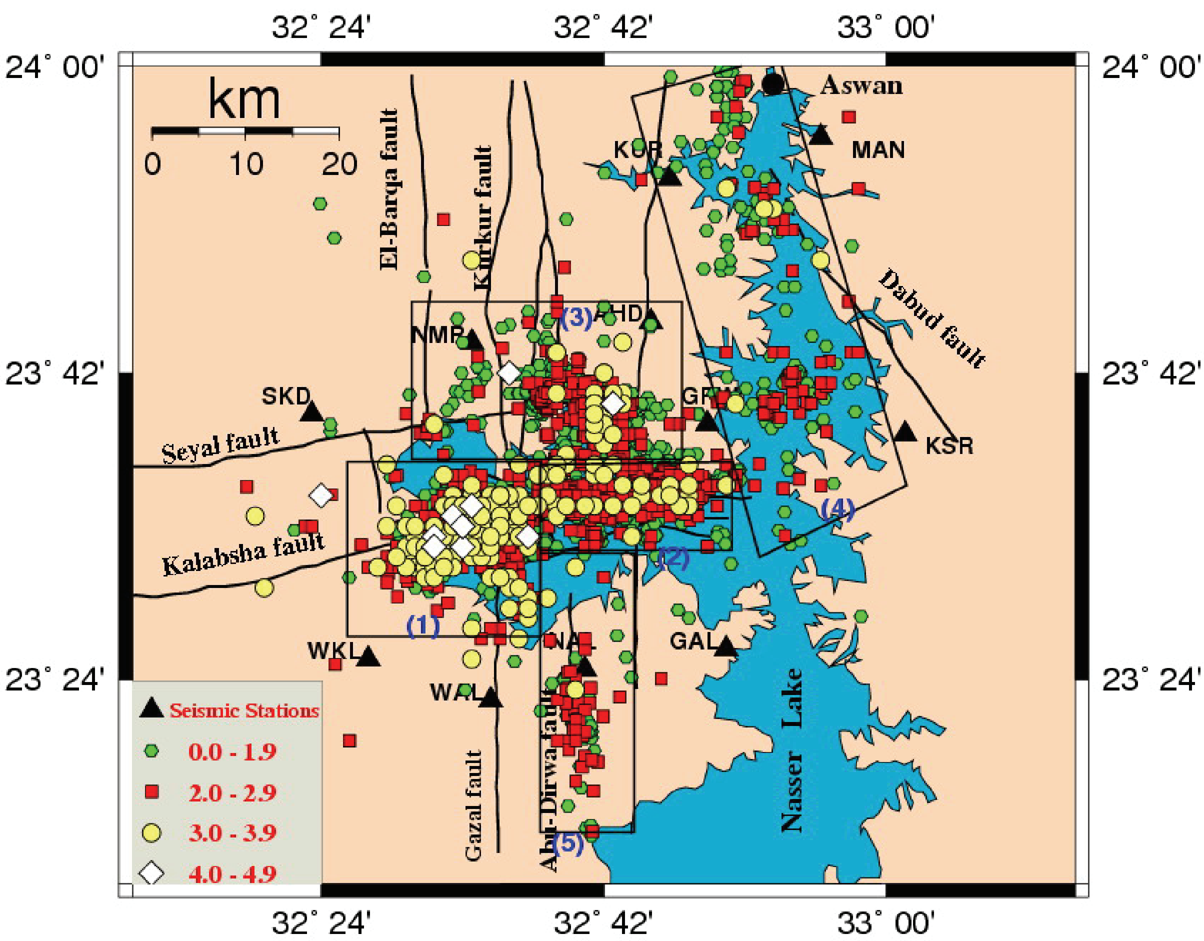

Fig. 3 Earthquake epicentral distribution in Kalabsha area during the period.

microearthquake stations were installed in the northern part of reservoir area by Egyptian Geological Survey from December to June 1982. In late June 1982 the portable seismic field stations were replaced by a telemetry network erected by Helwan Observatory and Lamont-Doherty Geological Observatory (USA). The purpose of the telemetry network is to monitor the induced seismicity along the Kalabsha fault, which continues to occur in the area of the November 14, 1981 earthquake (Kebeasy et al., 1987).

The space in the distribution of the earthquakes comprising the seismicity map of Kalabsha area in Figure 3 shows that the seismicity is concentrated in five main cluster zones, (1) Gebel Marawa, (2) East of Gebel Marawa, (3) Khor El-Ramla, (4) Old Stream and (5) Abu Dirwa zone (Fat-Helbary and Tealb, 2002).

Gebel Marawa Zone: This is the most active zone and located around the place of the November 1981 main shock on the Kalabsha fault. The seismicity at this zone is almost between depths of 15 and 26 km. The composite fault plane solution of the earthquakes indicates a nearly pure strike-slip faulting with a normal-fault component (Fat-Helbary and Tealb, 2002).

East of Gebel Marawa Zone: This zone, north east of Gebel Marawa zone, is located along Kalabsha fault and the focal depths of the events are shallow (between 3 and 7 km depth). The composite fault plane solution indicates strike-slip faulting with normal fault component (Fat-Helbary and Tealb 2002).

Khor El-Ramla Zone: This zone includes shallow activity (between 0 to 10 km) located north east of Gebel Marawa, and on the Khor El-Ramla fault. The fault plane solution indicates reverse left-lateral faulting (Fat-Helbary and Tealb, 2002).

Old Stream Zone: All the epicenters, which have been located in the River Nile channel, are located along one segment (40 km (extends from Khor El-Ramla in the south to Khor Kurkur in the north. They may be associated with a major North-South fault, which extends from Kalabsha to Idfu. The fault plane solution indicates reverse left lateral faulting in strike 160 degree (Ali, 1992).

Abu Dirwa Zone: This is only North South trend of activity recorded south of Kalabsha fault and it associated with the Abu Dirwa fault. Compared with the other Kalabsha activity zones, this is the only active zone located away from the reservoir, in an area that has not been covered with the reservoir water. The focal mechanism of this zone is reverse left lateral with strike 177 degree from the north (Ali, 1992).

2.2. *SEISMICITY OF TUSHKA AND ABU SIMBLE AREAS*

During the period 1982–2006 after the installation of Aswan seismic network around the northern part of Nasser Lake many earthquakes were recorded and located in this area. The epicentral distributions of the recorded earthquakes in Tushka area and its vicinity are shown in Figure 4. Thirty four events with magnitude range from 2.5 to 3.7 are located in this area. Five of these events had expressed

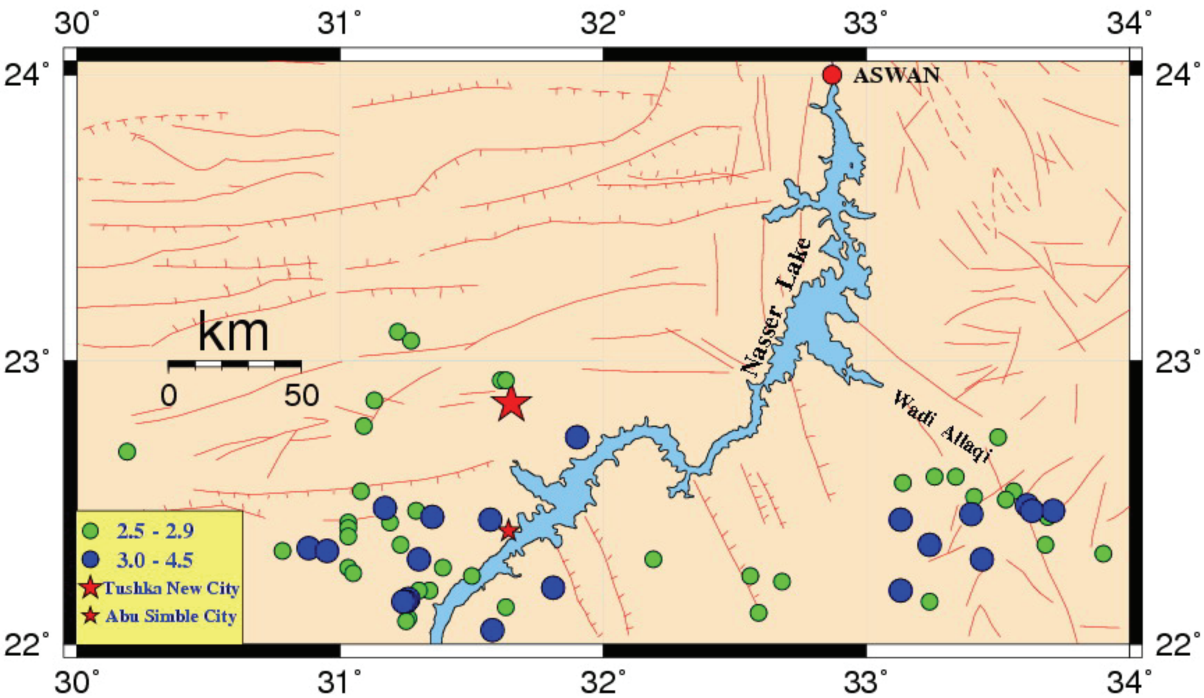

Fig. 4 Earthquake epicentral distribution in and around the proposed Tushka New City site from 1982 to 2006 (magnitude greater than 2.5).

magnitudes greater than 2.5 and less than 3.0 are located in the northern part (2 events) and to the West of the proposed Tushka New City site. One of these earthquakes with magnitude 3.1 is located directly southeast of Tushka New City site (at distance about 25 km). To the South of Tushka area 28 events are located in and around Abu Simbel City; one of these events with magnitude 3.7 is located directly to the northwest of Abu Simble City (7 km). As shown in the map most of the activity is located to the south and southwest of Abu Simble area.

In addition to this activity, (150 km southeast Tushka area) 26 events with magnitude range from 2.5 to 4.3 are located in Allaqi area (East southern corner of the Eastern Desert). Most of these events are located in the main wadi of Allaqi (QabQaba area) and they range in magnitude from 2.5 to 3.8. The other events are located between the East bank of Nasser Lake and Qabqaba area. Two of these events with magnitude 3.0 and 4.3 are located to the south and southeast of Abu Simble City (about 40 km) on the Eastern side of Nasser Lake.

3. SEISMIC HAZARD ANALYSIS:

Approaches to seismic hazard assessment can be grouped into to broad categories: (1) deterministic and (2) probabilistic (Reiter, 1990). In this study we will use the Probabilistic Seismic Hazard Analysis (PSHA) to estimate the seismic hazard in and around Tushka New City site. Probabilistic Seismic Hazard Analysis (PSHA) is the most favourable today. It covers a wide range of seismic hazard assessment including the compiling of seismic zoning maps, microzoning and seismic hazard assessment for engineering structures.

The goal of PSHA is to quantify the probability of exceeding ground-motion levels at a site (or sites) given by all possible earthquakes (Field, 2000).

The strongest point of any deductive type procedure of PSHA is its ability to account for all sorts of deviations from the standard model, i.e. it accounts for phenomena such as migration of seismicity and seismic gaps.

According to Cornell (1968), the basic elements of PSHA are:

1. Earthquake catalogues.
2. Seismotectonic and earthquake source zones: the creation of a master seismic source model to explain the spatial-temporal seismology; mapping of active faults, geodetic estimates of crustal deformation, remote sensing and geodynamic models to constrain the earthquake cyclicity in different tectonic provinces.
3. Strong seismic ground motion: the evaluation of ground shaking as function of earthquake size and distance, taking into account propagation effects in different tectonic and structural environments and using direct measures of damage caused by the earthquake (the seismic intensity) and instrumental values of ground acceleration.
4. Computation of seismic hazard: the computation of the probability of occurrence of ground shaking in a given time period, to produce maps of seismic hazard and related uncertainties at appropriate scales.

3.1. MODELLING OF SEISMIC SOURCES:

The first step in seismic hazard analysis is to characterize the various seismic sources in the area which may affect the site of a structure. The seismic sources are generally defined from the spatial distribution of past earthquakes or from knowledge of various faults and lineaments in the area or both. A source zone may be an idealized point source, a line source, a diffused area source, a volume source or dipping plane (Lee and Trifunace, 1985). The general seismological setting in South Egypt was described. In this way, the spatial (epicentral map) and the temporal (earthquake catalogue) distribution of events provide a sufficient basis for modeling the seismicity of South Egypt, i.e., definition of the seismic sources. This was done on the basis of existing seismological data, geophysical and geological data. The elaboration of model of seismic sources, i.e., seismogenic zones around Tushka area was produced by a lot of discussion and critical analyses. After the performed analyses and critical reviews of the obtained results and based on the existing available data, we found that model presented in Figure 5 is the most appropriate considering the seismological conditions in South Egypt. Therefore, it has been adopted as a representative model of seismic sources in and around the study area. All further analyses are based on this model. As can be seen in Figure 5, the adopted model consists of 9 seismic sources.

The main characteristics of the individual seismic sources are described as follows:

1. **Zone - 1:** This source represents the Western Desert system where a relatively moderate-magnitude earthquake (M_b 5.3) with focal depth about 7 km. was instrumentally recorded in Gilf El-Kebir area in 1978. After the installation of Aswan seismic network in the northern part of Nasser Lake several small events from this area and the area to the northwest of Aswan were detected.
2. **Zone - 2**: This source is located on the West bank of the River Nile in the area between Assuit to the North and Kom Ombo to the South. Several events were recorded in the West Kom Ombo area, where on March 22, 2003 an earthquake (Md 4.0) occurred. This activity in Kom Ombo may be related to the Gebel El-Barqa fault that is one of western desert fault system (Fat-Helbary and Mohamed, 2004).
3. **Zone - 3 and Zone - 4:** These sources represent Kalabsha and Tushka zone in south-eastern corner of the Western Desert. Kalabsha source zone is the most active zone in South Egypt where 14 Nov. 1981 earthquake (M_b 5.6)

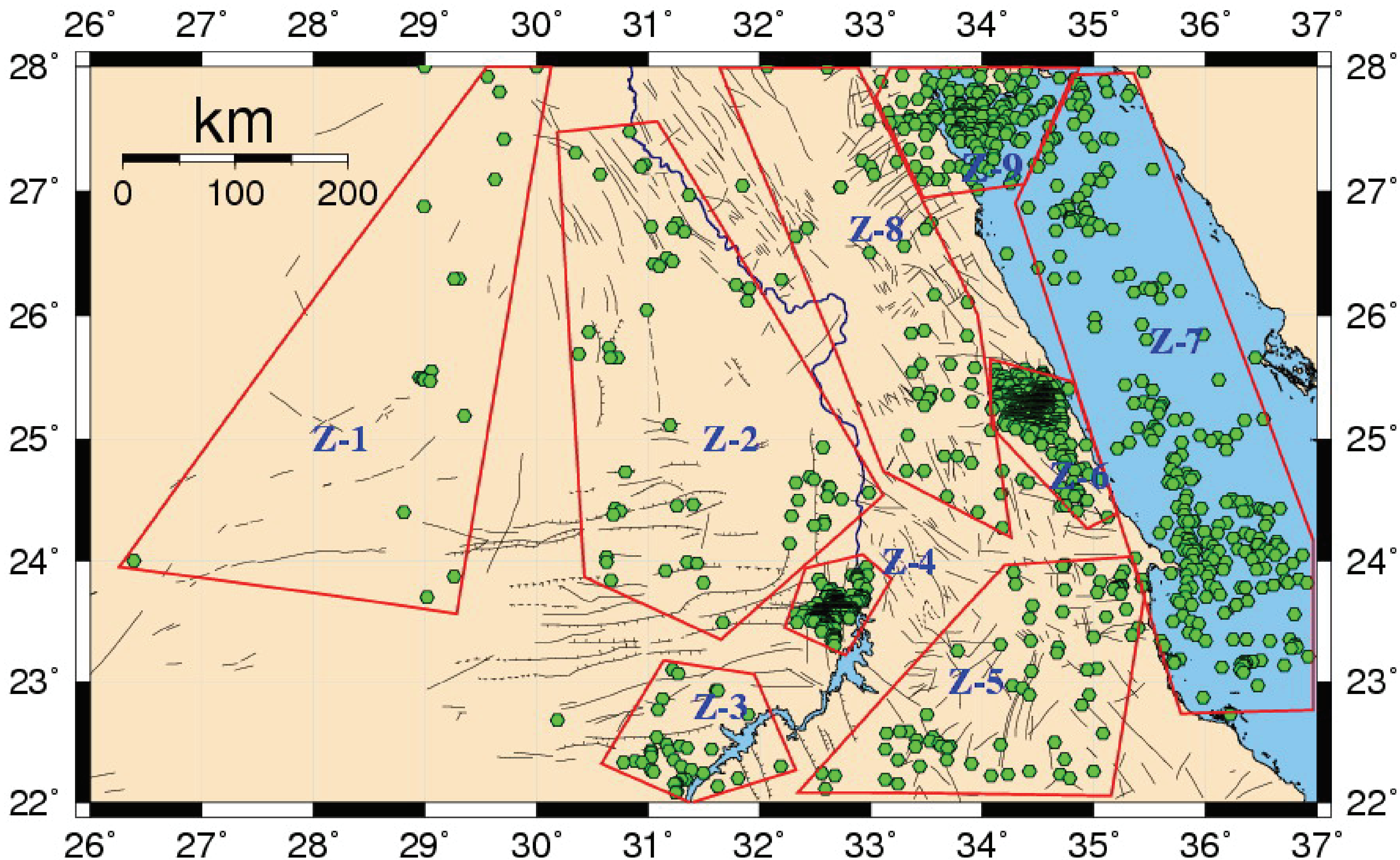

Fig. 5 Proposed seismic source models in and around Tushka area.

Table 1 Parameters of seismic recurrence for sources in and around Tushka area.

Source name	Min. Mag. (m_b)	Max. Mag. (m_b)	Average Depth (km)	No. of earthquakes	b-value	β = (b ln 10)
Z-1	3.0	5.8	22	20	0.536	1.234
Z-2	2.5	5.2	8.1	53	0.678	1.561
Z-3	2.5	4.2	6.2	35	1.219	2.807
Z-4	2.5	6.1	15.6	1000	1.125	2.590
Z-5	2.5	4.8	6.2	75	1.060	2.441
Z-6	3.0	6.1	7.5	537	1.103	2.540
Z-7	3.0	5.5	12.5	270	1.080	2.487
Z-8	3.0	4.7	7.9	43	0.907	2.088
Z-9	3.0	6.7	15.3	202	0.711	1.637

occurred at Kalabsha fault with epicentre of about 25 km. (Southwest Aswan City). This zone is a part of the western Desert fault system. This consists of two sets of faults, East-West faults and North-South faults.

4. **Zone - 5, Zone - 6, Zone - 7 and Zone - 8:** These sources represent the Red Sea zone, Abo Dabab zone, North Abo Dabab and the south-eastern corner of the Eastern Desert (Allaqi zone). The fault systems in this area parallel to the fault systems in the Red sea where the Arabian plate is continuing to rotate away from the African plate along the Red Sea spreading center (Cochran, 1983). Abo Dabab zone is the most active zone in the Red Sea area. Several earthquakes were recorded in this area and along the Red Sea coast mainly after the installation of Aswan Seismic Network and the Egyptian National Seismic Network (ENSN). Several events were recorded in South-eastern corner of the Eastern Desert (Allaqi area) using Aswan Seismic Network and ENSN during the period 1982 to 2006.
5. **Zone - 9:** This zone represents a part of the Red Sea faults system (Gulf of Suez fault North of the Red sea) where Shedwan area is one of the most active zones in the Red Sea coast.

3.2. *SIZE OF THE MAXIMUM CREDIBLE EARTHQUAKES*

The maximum credible earthquake is defined as the largest earthquake that appears along a fault in the existing tectonic stress environment (Shah, 1985; Milutinovic, 1995). From the seismic hazard point of view the smaller earthquakes are not interesting, so the lower bound magnitude at m = 2.5 for near seismic zones (2, 3, 4 and 5) has been set, while for far seismic zones the lower bound magnitude was m = 3.0. In the present study, for each seismic source area, the cut-off magnitude is taken to be the observed maximum magnitude known for the source plus 0.5 (Al-Hadad et al., 1992).

3.3. *EARTHQUAKE RECURRENCE RELATIONSHIP*

Recurrence earthquakes are formulas relating the frequency of occurrence and the size parameter of the seismic event. The most commonly used size parameter is the Richter Magnitude. The relationships are empirically obtained by curve fitting or regression analysis for each seismic source (Mihailov, 1978).

Basically, the recurrence relationship is represented in functional form given by equation:

$$\log N(m) = a - bm$$

where: N (m) = cumulative number of earthquakes equal and larger size m
a and b = are constants

A recurrence relationship for each source is obtained by fitting a regression line through all earthquakes with $M \geq 2.5$. For each zone separately, the regression constants have been determined (Table 1), while results along with the other main characteristics of seismic sources are computed.

3.4. *ATTENUATION RELATIONSHIPS:*

The determination of the attenuation relationship for the considered region is an important part of seismic hazard analysis. However, in most regions, as in Egypt, there are no sufficient or some times not all, strong ground motion data to perform statistical and regression analysis and determine its own PGA attenuation relationship. Therefore, in applications, it is very common practice to use world-known attenuation relationships of the PGA. To develop a seismic hazard at a site in terms of Peak Ground Acceleration (PGA), the attenuation relationship of Makropoulos and Burton (1985) was found to be the most adequate for the region (Elamin, 2004) and used for seismic hazard in this study.

This relationship is:

$$\ln(A) = 2164\ e^{0.7M}\ (R + 25)^{-1.8}$$

where A is the Peak ground acceleration in cm/s^2,
M is the earthquake magnitude and
R is the distance from point of energy release to site in km.

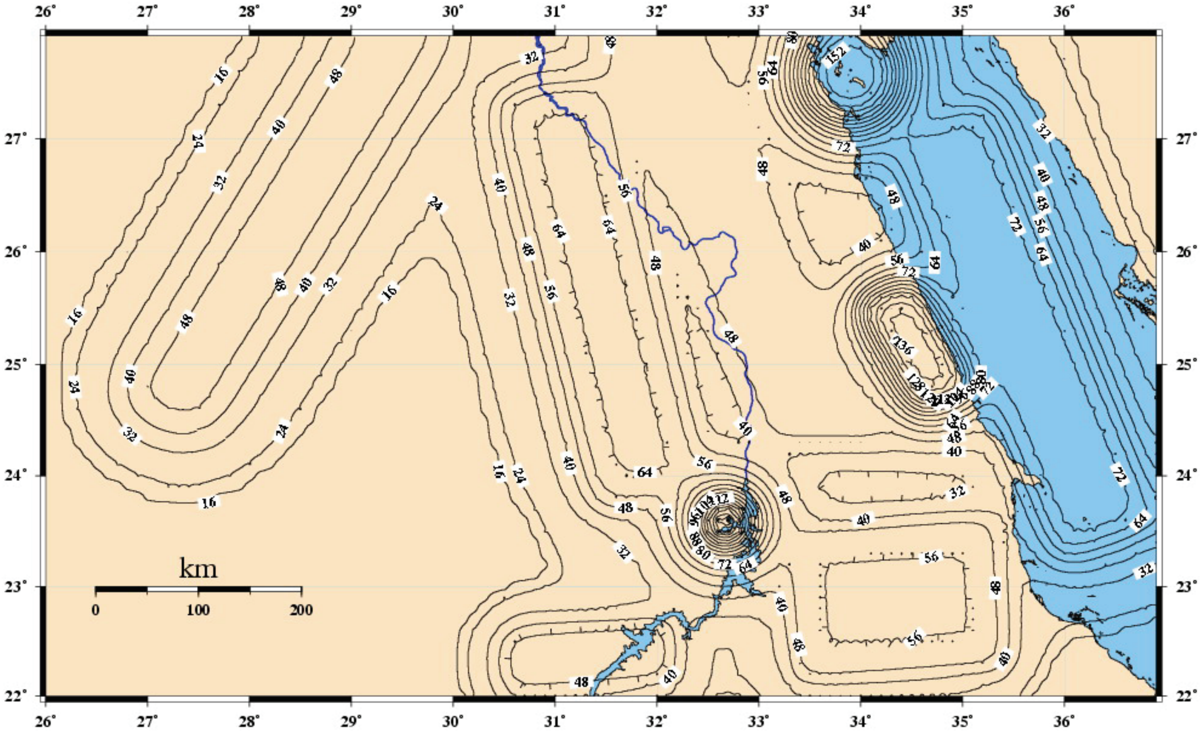

Fig. 6 Seismic hazard map in and around Tushka area for 475 years return period.

The logarithmic standard deviation was assumed to be 0.8 to account for its uncertainty, as indicated by Donovan (1973) for worldwide data.

4. SEISMIC HAZARD MAPS

Poisson model together with the available seismic data for study area was presented. Based on these data, various seismic source models were formulated and the recurrence relationship for each of these sources was developed. Then, using the attenuation relationships probabilistic information on peak ground acceleration was derived.

The main parameters for definition and elaboration of seismic hazard maps were computed using specially created computer programs, (Petrovski et al., 1983) and presented as:

1. Cumulative distribution function of peak ground acceleration for different time periods;
2. Peak ground acceleration for different time periods and different levels of probability that shall not be exceeded within the defined time period;
3. Diagrams of return periods of peak ground acceleration;
4. Seismic hazard maps.

The seismic hazard maps (maps of distribution of peak ground acceleration) were elaborated using HAZ81 program (Petrovski et al., 1983) as:

1. The study area and the surrounding area were divided into a network of squares with sides of 0.05° latitudes and 0.05° longitudes.
2. The cumulative distribution function of peak ground acceleration and the peak ground acceleration for different return periods were computed for all the intersecting points of the network.
3. Between the closest intersecting points, peak ground acceleration values were interpolated geometrically and then the acceleration isolines were drawn. An interval of 9.81 cm/s^2 was adopted between the individual isolines for maps of the different return periods.

In this study iso-acceleration map in and around Tushka area is represented with 90 percent probability of not being exceeded for return periods of 475, Figure 6. This map refers to use area seismic model presented in Figure 5 which has been adopted as a representative model of seismicity in and around Tushka area.

4.1. SEISMIC EXPOSURE HAZARD LEVELS FOR THE PROPOSED TUSHKA NEW CITY SITE:

The hazard curve relates the peak ground acceleration with its annual excedance probability at a selected site in the proposed Tushka New City with coordinates (31° 33\ 00\\ E and 22° 49\ 48\\ N) is carried

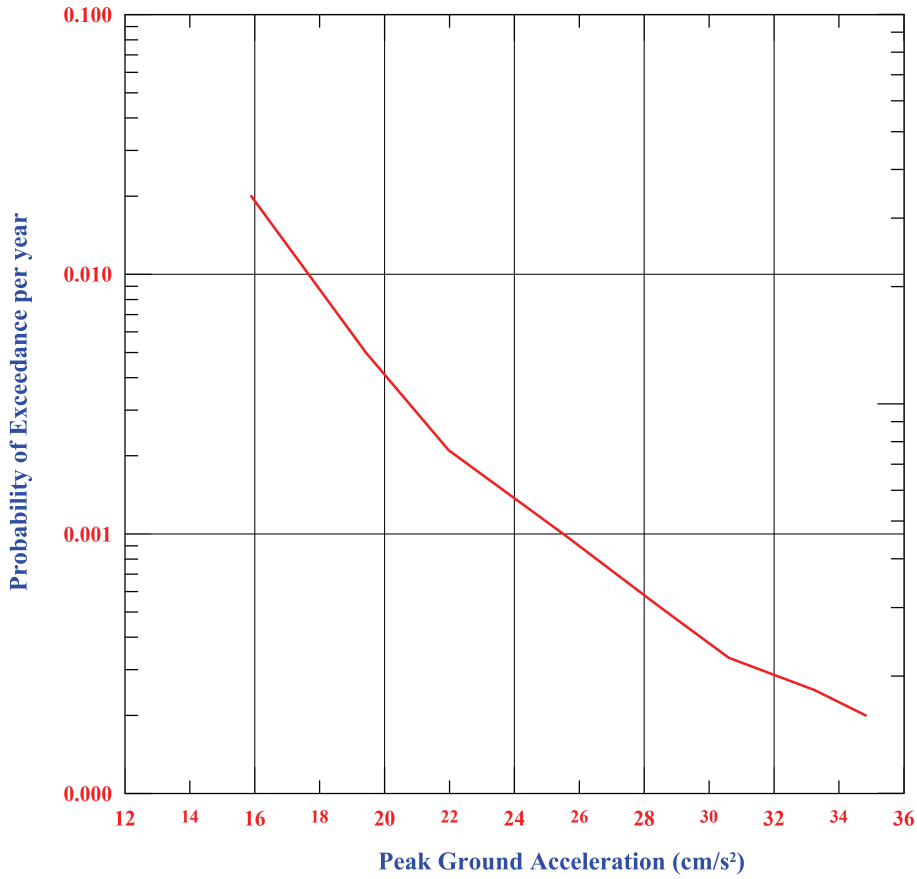

Fig. 7 Seismic hazard curve at the proposed Tushka New City site.

out, employing the same parameters and assumptions as those used in the previous section. The resulting hazard curve was calculated for the proposed site as shown in Figure 7. The figure shows the computed probabilities of exceeding various levels of peak ground acceleration area source model is normalized on an annual basis**.**

5. SUMMARY AND CONCLUSIONS

The seismic characteristic and definition of the boundaries and the regime of individual seismic sources was carried out based on the existing tectonic, geological and seismological data. Therefore, the model shown in Figure 5 was elaborated and used in this study as the most representative model.

Variations in computed peak ground acceleration forecasts produced different attenuation relationships, different levels of maximum magnitude (M_{max}) for seismic sources and different depths. Attenuation equation of Makropoulos and Burton (1985) was used in this study as the most adequate for the seismotectonic characteristics of Egypt.

Seismic hazard curve, which describes peak ground acceleration values as function of annual probability of exceedance, was developed for the proposed Tushka New City site. From this graph risk consistent parameters can be developed for earthquake resistant design and analysis of structures. Seismic hazard map was elaborated for return period of events of 475 years.

The seismic hazard map showed that the maximum peak ground Z-1, Z-6, Z-9 and Z-4 respectively acceleration in the four significant seismic zones is 49, 137, 157, 177 cm/s^2, although the values of PGA in zones Z-4, Z-6 and Z-9 are almost very close to each other. Zone 4, however has a significant effect on the proposed Tushka New City site as being located about 140 km northeast to the study area.

From the seismic hazard curve the calculated maximum acceleration with 90 percent probability of not being exceeded in 50 years of exposure time (475 years return period) at the proposed Tushka New City site was about 22 cm/s^2, that means the proposed Tushka New City site has a low seismicity is comparison with comparing the other sites in South Egypt.

The methods and models used in this study are capable of incorporating objective as well as subjective data for engineering planning (and not for geological information) and provide seismic hazard information for Tushka area and surrounding areas. The models are such that the results could be updated at regular intervals of time, as more and more knowledge about the seismicity of Egypt is made available.

In conclusion, the seismic ground shaking hazard information in the form of iso-acceleration maps and the seismic hazard curve developed in this study represents one of the most used method of seismic hazard analysis. The results are consistent with the available information. Thus, the shortcomings of the results are the same as the shortcomings of the input data.

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