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Investigation of the Effects of Earthquake Swarms in the Seismic Hazard in the Gulf of Aqaba, Northern Red Sea

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ABSTRACT

The seismic hazard potential in the Gulf of Aqaba has been assessed in this study. The probabilistic approach has been utilized to produce a seismic hazard map in the mean of maximum peak ground acceleration, in cm/sec^2, with 90% probabilities of not being exceeded in 50 years. The seismicity of the Gulf of Aqaba is characterized by seismic swarm's activity. To determine the sensitivity of the calculated hazard map to the seismic swarm's data that occurred in the 1983, 1990, 1993, and 1995, another hazard map is performed and presented in this study. The first group of data has indicated that the maximum hazard values occur in the central part of the Gulf, whereas the values decrease north- and southwards. The maximum peak ground accelerations, with 90% probabilities that will not be exceeded in 50 years, for the first group in Aqaba, Hagel, Nuweiba, Dahab, Magna, and Nebek cities are 260, 300, 270, 275, 275, and 260 cm/sec^2, respectively, while for the second group are 210, 205, 175, 175, 175, and 180 cm/sec^2, respectively for the same cities mentioned above. The seismic hazard coming from the swarms represent 24% of the total for Aqaba city. For the other cities, it ranges among 45% to 57% such as for Nuweiba in Egypt and for Hagel in Saudi Arabia.

KEYWORDS: seismicity of Jordan, seismic hazard, seismotectonic, Gulf of Aqaba.

1. INTRODUCTION

The Gulf of Aqaba is located between latitude 28.0° and 29.6° N, and longitude 34.4° and 35.0° E, its length is about 230 km. It is part of the Jordan -Dead Sea transform fault system (hereafter, DST) (Bayer et al., 1989). There are some cities lying around the Gulf such as Aqaba, Eilat, Hagel, Magna, Nuweiba, Dahab and Nebek, (Figure 1). Aqaba city is located in the most northern part of the Gulf. This city has suffered from many earthquakes' causalities through the previous centuries. Most of these earthquakes are documented in the historical manuscripts and literatures. Examples of these earthquakes are: 48 A.D., 1068, 1212, 1261, and 1588, which have had local magnitudes (M_L) of 6.3, 6.5, 6.3, 6.3, and 6.3, respectively (Al-Tarazi, 1994; Abou Karaki, 1987).

Seismic activity has dramatically increased during the last two decades, in comparison with the previous several decades (Abou Karaki, 1987; 2001). This activity comes in a swarm form, so hundreds to thousands of micro and intermediate earthquakes occurred in swarms such as the earthquake swarms of 1983, 1990, and 1993 (El-Isa et al., 1984; Abou Karaki, 2001). On 22 November 1995 at 4 (hr): 15(min.): 11 (sec) (GMT) an intermediate earthquake occurred on the central part of the Gulf of Aqaba with M_L equal to 6.2 (M_W=7.3) (Klinger et al., 1999). More than 3 thousand aftershocks occurred after the main one according to the Jordan Seismological Observatory (hereafter JSO) (JSO, 1983-2002). The reports talked about 10 persons killed; several hundreds were injured, and accompanied with minor destruction on the cities that locate on the shores of the Gulf (Al-Tarazi, 2000).

In Aqaba city and since its port is the only one in Jordan, intensified urbanization and an enormous increase in population density has substantially enhanced vulnerability to strong regional earthquakes in the Gulf of Aqaba. Therefore, the assessment of earthquake's hazard is of great practical importance in Aqaba city and in the

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other main cities that lie along the Gulf, such as Nuweiba, Dahab and Nebek cities that lie in Egypt, Hagel and Magna cities in Saudi Arabia (Figure 1).

The seismicity of the Gulf of Aqaba is characterized by seismic swarm's activity. In the last 100 years, this part of the DST seems the most active part of the whole transform, only because of the 1983, 1990, 1993, and 1995 seismic swarms (Abou Karaki, 2001).

Many previous studies in other regions in the world that characterized by seismic swarms activity as in the Gulf of Aqaba have concluded that the seismic swarms are a major factor in increasing the seismic hazard potential in the studied regions (Giner et al., 2002; Gruenthal and Wahlstroem, 2001; McGuire, 1995; and Barbano et al., 1989). Therefore, this study aims to produce a seismic hazard map for the Gulf of Aqaba. On the other hand, to determine the percentage of sharing of the seismic swarms that occurred in the Gulf on the total hazards of the Gulf (Wahlstroem and Gruenthal, 2001). Furthermore, to determine the effect of the earthquakes that occurred in the other DST faults on the seismic hazard in the Gulf.

2. Tectonic Setting

The Gulf of Aqaba as part of the DST is connected to the East African rift (Quennell, 1959). The system bifurcated from the Red Sea; this last is recognized as continuation of a mid-oceanic ridge (Badawy and Horvath, 1999). The movement between Africa and the Arabian Peninsula is taking place and accompanied by a system of regional transform and normal faults that run along and across the Red Sea. The opening of the Red Sea took place during two stages, the first stage occurred during the Late Eocene to Early Oligocene time, whereas the second stage started from about 5 Ma. onwards (Bayer et al., 1989).

Freund and Garfunkel (1976) suggested that the horizontal movements along the DST also occurred in two stages: 60 km of displacement in the Early Miocene and 40 km of displacement started in the Late Miocene or in the Early Pliocene. Bartov et al. (1980) suggested that the opening of the Red Sea and the horizontal movement along the DST began after Early Miocene, from 22 to 19 Ma. (Figure 2a).

The Gulf of Aqaba has a depth of about 2.5 km and has a maximum width of about 17 km. The Gulf is made up of three in-line, pull apart basins, namely Dakar-Tiran deep, Aragonese deep, and Eilat deep, in southern, central, and northern parts, respectively (Figure 2b) (Ben-Avraham, 1985). The Precambrian rocks are exposed on both banks of the Gulf. The crust in the northern part of the Gulf is continental and has a thickness of 32 km (Bayer et al., 1989).

The fault plane solution for the main earthquake that occurred in February 3, 1983 earthquake, with M_L 5.1, indicates a left lateral strike-slip mechanism that accompanied by reverse component (Abou Karaki, 1987; Figure 2b). For the August 3, 1993 earthquake, with M_L 5.6, a normal mechanism with a slight left lateral component (Figure 2b) is indicated. While for the November 22, 1995 earthquake, with M_L 6.2, a pure strike-slip movement is determined (Figure 2b). The fault plane solutions of the three main earthquakes occurred in seismic swarms of 1983, 1993, and 1995 indicate complex tectonical setting and lateral heterogeneous crust in the Gulf of Aqaba (Abou Karaki, 2001; Salamon et al., 1996).

3. Data Base

The Seismicity of the Gulf of Aqaba and the other seismic sources, which lie at about 300 km from the Gulf area have been considered in this study. These include the area between latitudes 27.0°-34° N and longitudes 32.0°-39.0°E, and covers the period from 2100 B.C. to 2002 A.D. The data are divided into two parts:

I- Historical earthquakes: this part covers the period from 2100 B.C. to 1899 A.D. It includes 62 earthquakes. Their local magnitude (M_L) is in the order of $5.5 \le M_L \le 7.3$. The parameters of these earthquakes (i.e., location, magnitude, and intensity) are compiled from the unified catalogue of MERC project (Amrat et al., 2003). This catalogue compiled depending on previous studies and catalogues prepared for the area such as Abou Karaki (1987) and Al-Tarazi (1992).

II- Instrumentally recorded earthquakes: it covers the period from 1900 to 2002. The earthquake data of this period are taken from different sources, namely the bulletins of the International Seismic Center (ISC), the Preliminary Determination of Epicenter (PDE) and the Jordan Seismological Observatory, and the unified catalogue of MERC project (Amrat et al., 2003). This part includes all earthquakes, which fall in the order of $3.0 \le M_L \le 6.25$.

The epicenters of the historical and instrumental earthquake data used in this study are shown in Figure (3).

Regarding the earthquake swarms, of 1983, 1990, 1993, and 1995 the date, magnitude range and number of earthquakes in each swarm are listed in Table (1). For the earthquake of November 22, 1995 the epicenter determined by Abou Karaki (2001) is considered in this study (Figure 2b). Since it has been calculated depending on optimal covering of stations that recorded it, with 81° azimuth gap. These stations were located in epicenter range less than 175 km (Abou Karaki, 2001).

Depending on the seismicity and the tectonic map of the studied area (Figure's 2a, b and 3), and previous studies such as Bouhadad and Laouami, 2002; Al-Tarazi, 1999, and 2000; Badawy and Horvath, 1999; Bayer et al., 1989; Barbano et al., 1989; Arieh and Rabinowitz, 1989; and Erdik, 1984, twelve seismic sources have been delineated and considered to assess the seismic hazard in the Gulf of Aqaba as shown in Figure (3). It's important to mention that source no. 6 is determined depending mainly on the earthquake epicenters found in that area and this may indicate for the presence of an inferred fault passing the area. On the other hand, the seismic activity located to the north of latitude 34.0 N namely (Palmyrides folds and south Orontes valley, Fig. 2a) does not considered in this study because it's far away from the Gulf of Aqaba and their effect is negligible (Al-Tarazi, 1992).

4. Seismic Hazard Parameters

The Seismic Hazard Parameters (hereafter, SHP) are the annual rate of occurrence of earthquakes (λ), the b-constant of Gutenberg-Richter formula (1965), and the maximum expected magnitude (M_{max}). Determination of these parameters for every source is the second step to achieve the goals of this study.

The problems of inhomogeneity, incompleteness and uncertainty in the epicenter location, magnitude, and focal depth of the historical earthquakes as well as the earthquakes that occurred in the first 7 decades of this century for the DST area, are well known (Al-Homoud and Amrat, 1998; Al-Tarazi, 1994; Arieh and Rabinowitz, 1989). The traditional methods to determine the SHP, such as the least-squares method, are used to calculate the b-constant. The rupture length-magnitude relation is used to determine the M_{max} for a given area. These methods give untrue results, since they depend on incomplete earthquake catalogs and the data used have a high degree of uncertainty as mentioned above. Moreover, using recent data for the last ten years of the instrumentally recorded earthquakes is not an accurate method for these areas, which are characterized by low-to intermediate-activity, such as the DST sources, and may lead to misleading results (Al-Tarazi, 1992). To overcome this problem, Kijko and Sellevoll (1992) have developed a relevant method to determine the SHP with their standard deviations. This method henceforth is called the KS-method. The KS-method combines data of the largest historical earthquakes with the complete instrumental data of variable threshold magnitude, i.e., variable quality instrumental data.

The KS-method assumes the Poisson occurrence of earthquakes with the activity rate (λ) and the doubly truncated Gutenberg-Richter distribution F(y) of earthquake magnitude y. The doubly truncated exponential distribution can be written following Kijko and Sellevoll (1992):

$$F(y) = Pr\,(Y \leq y) = A_1 - A(y) / A_1 - A_2,\ m_{min} \leq y \leq m_{max} \qquad (1)$$

Where $A_1 = \exp(-\beta m_{min})$, $A_2 = \exp(-\beta m_{max})$ and $A(y) = \exp(-\beta y)$, m_{max}, is the maximum regional magnitude value, m_{min} is the threshold magnitude and β is a parameter equal to b ln10.

This method has been used in many previous studies (e.g., Bouhadad and Laouami, 2002; Malkawi et al., 1995; and Al-Tarazi, 1994). In this study, the low magnitude threshold is taken to be 4, since the earthquakes with magnitude < 4.0 are not significant from seismic hazard point of view. Also, it proved that both the historical and the first 7 decades of the instrumental recorded earthquakes of the DST are incomplete for earthquakes with Magnitude <4.0 (Al-Tarazi, 1994). Therefore, λ_4 is the annual activity rate of earthquakes ≥ 4, is calculated for each source. β is used in the study and equals to b ln10 as defined in equation (1). The focal depth for every source determined is taken as the average for all focal depths in the source (Table II).

The KS-method described above is used in this study to determine the SHP for every determined seismic source in the area. The results are listed in Table (II).

For the Gulf of Aqaba source, the seismic hazard parameters have been determined using all the earthquakes including the swarm's data. The seismic hazard parameters are calculated for the same area after excluding earthquakes of the four seismic swarms except their main shocks. The resulted SHP's for the Gulf of Aqaba are listed in Table (III).

It is important to note that KS-method (1992) was derived assuming that the earthquakes are independent. On the other hand, the earthquake swarms have their own distribution and are usually dependent events. This is considered as a limitation in this study (Table III).

The values of the seismic hazard parameters determined for the seismic sources in this study (Table II) match well with previous studies such as (Shapira and Hofstetter, 2003; Malkawi et al., 1995).

For the Gulf of Aqaba source, the values of the SHP decrease sharply after excluding the swarm's data. The b-value decreases from 0.9 to 0.66. The annual rate of activity λ_4 decreases from 0.56 to 0.202. The Mmax decreases from 6.25 to 5.3. Similar values of b, λ_4, and Mmax for the Gulf area were determined by previous studies (Abou Karaki, 2001; and Al-Tarazi, 1999). The effect of the variations in the SHP values on the seismic hazard values will be determined in the later section.

5. Probabilistic Analysis and Results

The distribution of the Peak Ground Acceleration (hereafter, PGA) with distance is essential to assess the seismic hazard in the studied area. Al-Homoud and Amrat (1998) have derived a new attenuation equation of PGA for Jordan depending on local strong motion data. This equation is in the following form:

$$\log PGA\,(R, M_L) = 0.5 + 0.367\,M_L - 0.011R - 0.020\,\log\,(R + 20) \qquad (2)$$

Where, PGA (R, M_L) is the maximum peak ground acceleration on bedrock as a function of epicentral distance R (in km) and certain local magnitude M_L. The standard deviation of the natural logarithm of the ratio of the observed to the computed PGA for equation 2 equals to (0.50). Equation 2 has been used in this study to describe the attenuation of PGA with distance and magnitude in the studied area.

To determine the rupture Length (L), which resulted from a certain magnitude (M_L), a relationship is needed. Ambraseys and Barazangi (1989) have derived the following equation for the Middle East region (rewritten):

$$Log_{10}\,(L) = 0.70\,M_S - 3.24 \qquad (3)$$

To use the local magnitude (M_L) instead of the surface wave magnitude (M_S) of equation (3), Al-Tarazi (1992) had derived the following equation for DST and Middle East region:

$$M_S = 1.43\,M_L - 2.6 \qquad (4)$$

Combining equations 3 and 4 give:

$$log(L) = 1.001\,M_L - 5.06 \qquad (5)$$

Equation (5) can be used for the different seismic sources in the Middle East and is used for all sources under consideration in this study.

The maximum peak ground accelerations (in cm/sec^2) with 90% probability of Not Being Exceeded (NBE) in an economic life of a structure of 50 years is calculated for each point of the network. The economic life of a structure (T), the Return Period (R_P) and the Probability of not being exceeded (P) are related after the following equation (Makropoulos and Burton, 1985):

$$R_P = 1/\,(1-(1-P)^{1/T}) \qquad (6)$$

The seismic hazard estimation for a given site is determined by calculating the probability that a certain ground motion (here PGA) will be exceeded at a given site by numerical evaluation of the total probability theorem.

The probability that ground motion (PGA) is exceeded given one event of a random size (M), Rupture Length (L_r) and location (X) on a fault is McGuire (1978):

$$P[Z>z] = \int\int\int P[Z>z \mid m, l_r(m), x]\, f_M(m)\, f_L(l_r)\, f_X(x)\; dm\, dl_r\, dx \qquad (7)$$

Where P[Z>z] = probability that a random ground motion (Z) at a site will exceed a certain intensity (z). Given the location (x) and length of the rupture (l_r), the closest distance from the rupture to the site is calculated. Integration over m, l_r, and x gives the total probability that Z will be exceeded due to a single event of random M, L_r and X.

The hazard at the site for peak ground acceleration Z (that is the probability that Z is exceeded) under the Poisson assumption is determined as in the following equation:

$$\text{HAZARD} = 1 - \exp\,(-N_T) \qquad (8)$$

Where N_T the total expected number of events causing $Z \geq z$ at the site is obtained by summing the expected number of events from each source area.

The computations carried out using the algorithm FRISK written in 1978 by McGuire.

In order to show the results in iso-acceleration maps, the studied area is divided into a network 25X25 km.

Some modifications to FRISK program by the author of this paper are made to include the form of attenuation equation used in this study (eqn. 2).

The output of this program is then written into an output file according to the specified lifetime (here it is 50 years). This output is then used to draw the iso-acceleration map. The Surfer™ program is used to draw these iso-lines on the digitized geographical map of the Gulf of Aqaba.

The corresponding seismic hazard map is shown in Figure (4a).

Another map is derived, in which the earthquake swarms of 1983, 1990, 1993, and 1995 of the Gulf of Aqaba are not considered in the analysis. This map is shown in (Figure 4b).

6. Discussion

The produced seismic hazard maps (Figures 4a and b) show that the greatest seismic threat is expected in the Gulf of Aqaba and the seismic severity decreases as we go away from the Gulf. The first group map which includes the swarm's data (Figure 4a) shows that the maximum hazards' values are in the central part of the Gulf. The PGA in cm/sec^2 for the main cities along the Gulf of Aqaba namely Aqaba, Hagel, Nuweiba, Dahab, Magna and Nebek cities are 260, 260, 300, 270, 275, 275 and 260 for lifetime of 50 years, respectively (Figure 4a). The second group, in which the seismic swarms data are excluded (Figure 4b), shows generally lower values for PGA in the area. The PGA's for the cities mentioned above are 210, 210, 205, 175, 175, 175, and 180 cm/sec^2 for lifetime of 50 years, respectively. The difference between the two groups of maps has been interpreted according to the effect of the earthquake swarms of the 1983, 1990, 1993 and 1995. The northeast shorelines and central part of the Gulf has higher hazard threat than its west bank (contour line 300 cm/sec^2 in Figure 4a). The Aqaba, Nuweiba, Dahab, Nebek, and Magna cities have hazard range between 250 to 275 cm/sec^2, while Hagel city has higher hazard, about 300 cm/sec^2. This can be explained as the effect of the Gulf of Aqaba source (No. 3), since it passes near Hagel city, while it lies away from the other cities mentioned above (Figure 3). Another factor is the location of the major earthquake of 22 November 1995 that occurred during the swarm of 1995 that is located in the eastern part of the Gulf (Figure 3).

The percentages of sharing of the seismic swarms on the hazard values in the cities mentioned above are 24%, 24%, 46%, 54%, 54%, 57%, and 45%, respectively. This means that for the cities that lie in the most northern part of the Gulf, for example Aqaba, the swarms of the Gulf represent 24% of the total seismic hazard and the rest are represented by the other sources near to the Gulf such as the Dead Sea and Wadi Araba sources, with no's 1 and 2, respectively. In addition to the normal seismic activity along the Gulf (Figure 3). For the cities laying in the central part of the Gulf, such as Hagel, Nuweiba, Dahab, and Magna the swarms represent 53% (average value for these cities). For the most southern part of the Gulf, the swarm's activity represents 45% from the total seismic activity, as for Nebek city (Figures 4a and b).

This indicates that the seismic swarm activity of 1983, 1990, 1993, and 1995 are major factors responsible for increasing the seismic hazard potential in both the central and southern parts of the Gulf.

The comparison of the resulted PGA values with these obtained from previous studies shows a good agreement (Leonov, 2003; and Al-Tarazi, 1999). In Leonov (2003) seismic hazard map, the assigned PGA for the northern part of the Gulf is equal to 200 cm/sec^2 that is similar to the results calculated in this study (Figure 4b). Another regional hazard map performed for the Jordan Dead Sea Transform shows that the maximum PGA contour line (300 cm/sec^2) goes along the central part of the Gulf (Al-Tarazi, 1999) is similar to the results assigned in this study (Figure 4a).

7. Conclusions

From this study the following points are concluded:

1. The seismic swarms occurred in 1983, 1990, 1993, and 1995 represent a main factor responsible for increasing the seismic hazard in the Gulf region.
2. The earthquake swarms increase the hazard potential 24% in the northern part of the Gulf, while it has increased to 53% and 46% in the central and southern part of the Gulf, respectively.
3. For Aqaba city the Jordan Dead Sea transform seismic sources, mainly Wadi Araba (no. 2) and the Dead Sea (no. 1), represent the second potential hazard sources, after the Gulf of

Aqaba source.

4. The maximum peak ground acceleration isoline is equal to 300 cm/sec^2, which lies in the northeastern part of the Gulf and ends at the central and southern parts of the Gulf (Figure 4a).
5. The northeastern shoreline of the Gulf of Aqaba is much more active than the northwestern part (Figure 4b).
6. The highest seismic hazard values in the studied area are in the Gulf of Aqaba basin, which decrease rapidly on going away from the Gulf.

Table I. The date, magnitude range and number of earthquakes of the four seismic swarms, that occurred in the Gulf of Aqaba.

Swarm no.	**Date**		**Magnitude range (M_L)**	**No. of earthquakes**
	Begin	**End**		
1	21/1/1983	11/4/1983	$2.0\le M_L\le 5.3$	184
2	11/3/1990	5/7/1990	$2.0\le M_L\le 4.2$	53
3	30/7/1993	28/12/1994	$2.0\le M_L\le 5.8$	1400
4	22/11/1995	27/2/1998	$2.0\le M_L\le 6.2$	2278

Table II. The calculated seismic hazard parameters for eleven seismic sources out of the twelve delineated in this study. The parameters for Aqaba source (no.3) are in Table III.

No.	**Source**	**b-parameter**	**β**	**λ_4 (Yearly)**	**M_{max}**	**Focal depth (km)**
1	Dead Sea	0.86 ± 0.03	1.98	0.299 ± 0.003	7.6 ± 0.83	15
2	W. Araba	0.77 ± 0.05	1.77	0.125 ± 0.005	6.7 ± 0.5	15
4	Northern Red Sea	0.64 ± 0.05	1.47	0.25±0.008	6.0±0.6	24
5	Suez Gulf	0.67 ± 0.07	1.54	0.476 ± 0.006	6.5 ± 0.26	24
6	Northeast Sinai	0.70 ± 0.08	1.61	0.051 ± 0.004	5.5 ± 0.5	15
7	Jordan River	0.86 ± 0.04	1.98	0.31 ± 0.007	7.6 ± 0.7	15
8	Northern Faults	0.66 ± 0.03	1.52	0.331± 0.003	7.7 ± 0.5	15
9	Central Lebanon	0.83 ± 0.02	1.91	0.25 ± 0.006	7.5 ± 0.5	15
10	W. Sirhan	0.78 ± 0.06	1.79	0.054 ± 0.003	7.8 ± 1.81	10
11	Carmel Faults	0.75 ± 0.04	1.73	0.200 ± 0.003	5.9 ± 0.50	10
12	SE-Mediterranean	0.54 ± 0.04	1.24	0.189 ± 0.004	7.2 ± 0.4	15

Table III. The seismic hazard parameters of the Gulf of Aqaba with or without the earthquakes of the swarms, that occurred in 1983, 1990, 1993 and 1995.

No.	Source	b-parameter	β	λ_4 (Yearly)	M_{max}	Focal depth (km)	Remarks
3	Gulf of Aqaba	0.90 ± 0.14	2.70	0.56 ± 0.08	6.2 ± 0.47	15	Including the swarms data
3	Gulf of Aqaba	0.66 ± 0.04	1.52	0.202 ± 0.004	5.3 ± 0.20	15	Excluding the swarms data

Figure 1. The Gulf of Aqaba and the main cities that lay along it.

Figure 2a. Regional tectonic map of the study area (modified after Salamon et al. 1996). Note the plates: Africa, Arabia, Anatolia and Sinai; and the plate borders: Cypriotic arc, Dead Sea transform, Gulf of Aqaba and Gulf of Suez. Other elements: EAFZ-East Anatolian fracture zone; ESM-Eratostenes sea mount; NEMTJ-Northeast Mediterranean triple junction; NSZ-Negev shear zone; SAFB-Syrian arc fold belt (including P-Palmyrides); STJ-Sinai triple junction, and volcanic flood basalts. Localities: A-Arava valley; B-Baniyas; BA Bay of Antalyia; BI-Bay of Iskenderun; BL-Bitter

Lakes; Carmel fault; F-Farah fault; H-Hasbaya; fault; G-Galilee; Hb-Hula basin; JV-Jordan valley; J-Jericho; O-Orontes valley; R-Roum fault; Ra-Rachya fault; S-Shadwan; Se-Serrhaya fault; SL-South Lebanon; Y-Yammouneh bending.

Figure 2b. The seismo-tectonic setting of the Gulf of Aqaba. The Eilat, Aragonese, and Dakar deeps. Note the fault plane solutions of the main earthquakes occurred in the seismic swarms of 1983, 1990, 1993, and 1995. The epicenter of the 1995 major earthquake determined by Abou Karaki 2001 (light star), and its location determined by NEIC (bold star) (Modified from Abou Karaki, 2001).

Figure 3. The seismicity of the Gulf of Aqaba for period from 2100 B.C. to 2002 July. Twelve seismic-lines sources delineated to assess seismic hazard in the Gulf of Aqaba. To know the names of the sources according the given numbers see Table's (II and III).

Figures 4a, b. Maximum peak ground accelerations (cm/sec2) with 90% probability of not being exceeded in 50 years for the Gulf of Aqaba. In a) with including the earthquake swarms of 1983, 1990, 1993 and 1995 in b) with excluding the swarm's data.

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تحديد تأثير العواصف الزلزالية على الخطر الزلزالي في خليج العقبة، شمال البحر الأحمر

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ملخص

في هذه الدراسة تم تقييم الخطر الزلزالي في خليج العقبة. لقد تم اتباع الطريقة الاحتمالية لانتاج خارطة الخطر الزلزالي التي تحوي اكبر تسارع ارضي بوحدة (سم/ث^2) واحتمالية 90% أن قيم التسارع الأرضي لن تزيد عن القيم المبينة في الخارطة خلال الخمسين سنة القادمة.يمتاز خليج العقبة بحدوث العواصف الزلزالية مثل تلك التي حدثت خلال الأعوام 1983، 1990، 1993 و1995. لأغراض هذه الدراسة، تم إنتاج خارطتين للخطر الزلزالي؛ الأولى أخذت بعين الاعتبار الزلازل التي حدثت خلال العواصف الزلزالية المذكورة وفي الثانية تم إهمالها. الخارطة الزلزالية الأولى بينت أن اكبر قيم للخطر الزلزالي تتركز في وسط الخليج وتقل القيم كلما اتجهنا إلي شماله وجنوبه إضافة إلى أن اكبر تسارع ارضي متوقع لكل من مدن العقبة، حقل، نويبع، ذهب، مقنى، والنبك يعادل 260، 300، 270، 275، 275، و260 سم/ث^2، على الترتيب، بينما للخارطة الثانية فان اكبر تسارع ارضي يعادل 210، 205، 175، 175، 175، و180 سم/ث^2 على الترتيب ولنفس المدن المذكورة أعلاه. إن العواصف الزلزالية تشكل 24% من مجموع الخطر الزلزالي في مدينة العقبة، بينما تبلغ هذه النسبة 45% و57% لكل من مدينتي نويبع وحقل على الترتيب.

الكلمات الدالة: زلزالية الأردن، المخاطر الزلزالية، سيزموتكتونيك، خليج العقبة.

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