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Full Length Research Paper

Spatial distribution of maximal earthquake effects in the Red Sea region

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Two maps of estimated maximum intensity distribution have been prepared for the Red Sea region by applying appropriate intensity attenuation and conversion equations, without considering the probability of exceedance. The maps are represented in two parametric elements, which are: the maximal earthquake effects and the period of observation. The significance of these maps is due to their contributory aspect of providing supplemental earthquake information pertaining to simple, but necessary seismic hazard representation of the Red Sea area. Basically, the maps are illustrative of the areas that are likely and susceptible to experience the possibility of hazardous earthquake effects as shown and indicated. The importance of this study is to give some high light on the maximal earthquake effects in the Red Sea which is one of the most important plate boundaries with frequent occurrence of moderate earthquakes. It is one of the most important passages of world trade with some important commercial ports on each flank.

Key words: Red Sea region, spatial distribution, earthquake effects.

INTRODUCTION

Earthquake-affected countries have to confront the importance of implementing measures of protection against seismic effects. In the near future, there will be an increase of population, urban expansion and rapid growth of industrialization. These elements will be exposed to seismic vulnerability and risk, not unless mitigation measures are imperatively undertaken. One protective and preventive measure for mitigating earthquake disaster is the aseismatic design of infra-structures. However, a common basic limitation toward this endeavor is the scarcity and uncertainty of essential earthquake information. However, not withstanding these hindrances, it is substantially imperative that the required information about seismic hazard be provided, even if drastic assumptions are taken in the establishment of standards in mitigating earthquake disaster.

A simple representation of seismic hazard in a particular region is the map of earthquake effects. It reflects the spatial distribution of the hazard parameter on the surface within a known period of observation.

Such a map may be designated as two parametric seismic hazard representations, because it indicates the relation between earthquakes effects and observation time. Even if the probability of exceedance is not included, still, the effects and manifestations remain within the period of observation. As such, it is known to be included in national building codes. The map provides the basis of introducing measures toward seismic resistant design of building structures, for mitigation of earthquake disaster (Schenk, 1992; Petrovski, 1992; Grunthal, 1992).

It is known from observation and experience that most damage to building structures during occurrences of destructive earthquakes is due to the severity and duration of seismic vibrations. It is presumably acceptable, that the loss of lives is not directly due to the occurring earthquake, but to its disastrous effects to physical man-made structures, such as, buildings, lifeline facilities, dams and others. If the physical facilities are not properly designed and constructed to withstand the seismic vibrations affecting the infra-structures, the situation may lead to the collapse of the facilities, and

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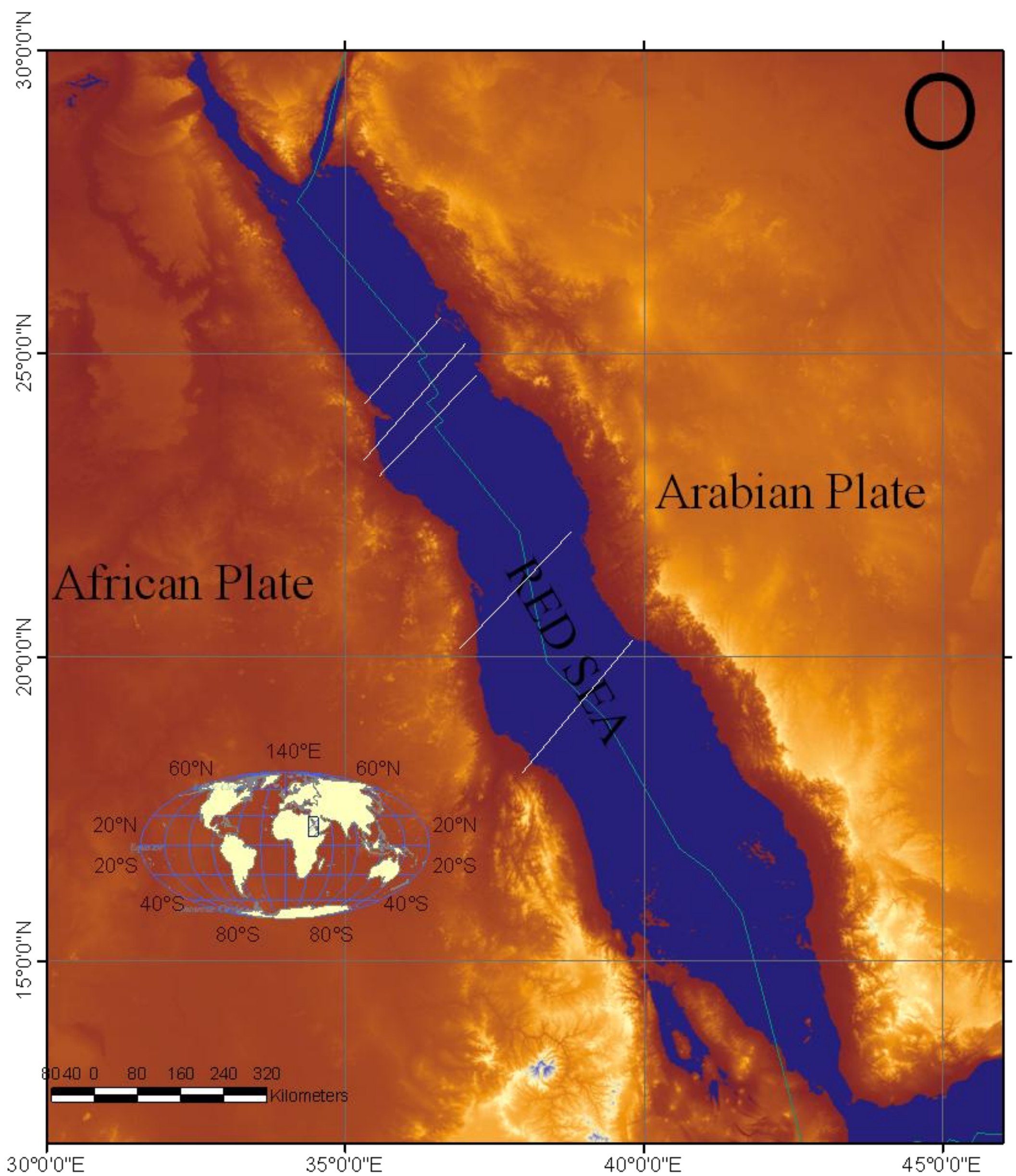

Figure 1. Index map of the study area in addition to the main rift and transforms of the Red Sea.

thereby, crushing the occupants to inevitable injuries or worse-loss of lives and properties. Likewise, it may be presumed further, that seismic energy releases are stable, but population and urbanization are increasing in time. It follows that earthquakes have tended to become increasingly destructive, since these phenomena affect larger and wider concentrations of national population and property (Petrovski, 1983, 1992; Hays, 1986).

Hence, it is a worthwhile endeavor, to provide maps of maximal earthquake effects for the Red Sea region. This area is observed to be seismically active (Figure 2). As shown in studies (Neumann, 1960; Medvedev and Sponheuer, 1969; Trifunac and Brady, 1975; Espinosa, 1977; Grunthal, 1992) that intensity is better correlated to seismic vibrations/particle velocities. The maps of maximum intensity, therefore, are a necessity in the present and future socio-economic developments in the Red Sea area, particularly in Western Saudi Arabia.

Related to this endeavor are field studies done for the March 30, 1969 earthquake in the Northern Red Sea by Maamoun and El-Keshab (1978); the December 13, 1982 earthquake in Dhamar, Yemen by Shehata et al. (1983); the October 12, 1992 earthquake in Dashour, Egypt by Ibrahim (1994); the November 22, 1995 earthquake in Gulf of Aqaba by Osman and Ghobarah (1996) and Al-Arifi (1996); Al-Arifi and Al-Humidan (2011) and the paper

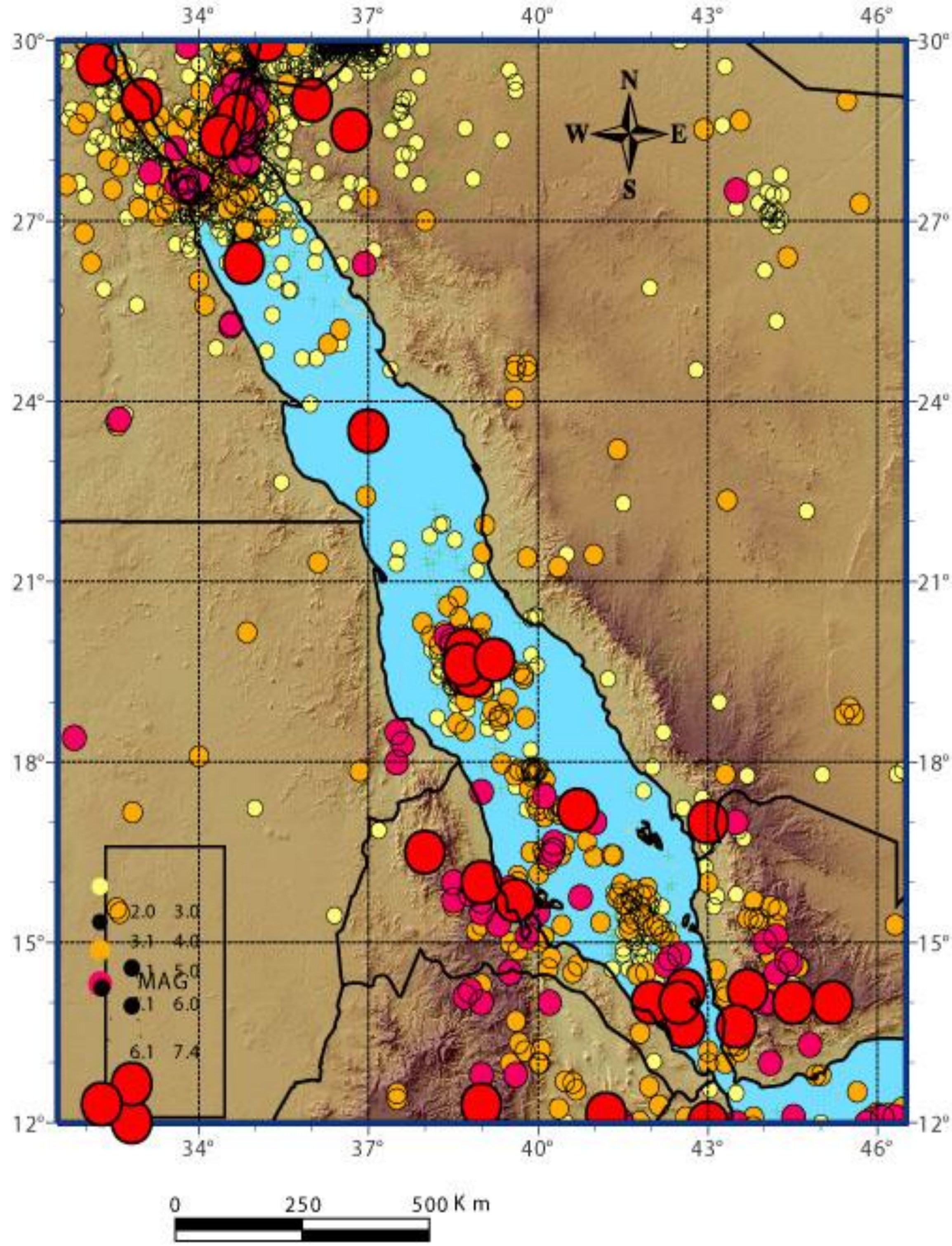

Figure 2. Seismicity map of the Red Sea (study area).

by Al-Sinawi (1988). Nevertheless, these informative manuscripts are insufficient to provide the essential seismic data that are required in preparation for the maps of maximum intensity in the Red Sea region.

EARTH SEISMIC BULLETINS

Within the disposal in this work for database references are the compilation works of Ben-Menahem (1979), Poirier and Taher (1980), Riad and Myers (1985), Ambraseys (1974) and seismic bulletins from the United States Geological Survey (USGS) and the International Seismological Center (ISC). However, most of the seismic data utilized in this endeavor comes from Ambraseys (1988) compilation work for Saudi Arabia and adjacent areas for the historical earthquakes events before 1965, while post 1966 comes from the USGS seismic bulletins (NEIS/NEIC, EDR, PDE). Preference is given to the USGS values when duplicate earthquake events are encountered in the overlapping years of seismic data from all the references.

Two types of magnitude scale are considered in this study. These are the surface wave (M_s) and the body wave (M_b) magnitude. Preference is given to the M_s, since it almost reflects the total seismic energy release. It is assumed that the other types of magnitude scale known as local (M_L) and duration (M_d or M_c) are equivalent to M_b, since presumably, the calibration of these magnitude scales are based on M_b as the standard magnitude value. This assumption is due to the observation that the bulk of magnitude data in the study area is given in M_b and only few earthquake events have $M_b \geq 6.5$.

The reliability range for the historical earthquakes is within 1°C for the intensity and 0.5°C for the magnitude (Ambraseys, 1974). These are due to sparse population and few numbers of buildings, and limited seismic instrumentation, respectively. It also follows that the given locations of these events may incur error of 100 km. On the other hand, instrumental data may have error range from 0.3 to 0.2 unit for the magnitude and 30 to 20 km for the location.

METHODOLOGY

The study area is limited to the Red Sea region (Figure 2) and is subdivided into grid/mesh points also known as sites. The grid points are located at every half-degree (0.5) latitude and longitude. At every mesh point, the intensity that is induced by each of the surrounding earthquake events affecting the sites is determined by using the following empirical equations:

$$I = I_o - 2.2\log(D+6) + 1.7 \quad (1)$$

$$M_s = 0.65 I_o + 0.9 \quad \text{focal depth (h) = 10 km} \quad (2)$$

$$M_s = 1.07\, M_b - 0.48 \quad (3)$$

and

$$\cos(D) = \sin(X_i)\sin(X_e) + \cos(X_i)\cos(X_a)\cos(Y_e\text{-}) \quad (4)$$

where I is the intensity in the Medvedev et al. (1964) intensity scale at epicentral distance (D) in km, I_o is the intensity at the epicenter, M_s and M_b are the surface wave and body wave magnitude, respectively and X_i, X_e and Y_i, Y_e are the latitude and longitude of sites (i) and epicenter (e), respectively. Equations 1 and 2 are empirically determined by Punsalan and Al-Amri (2003), while Equation 3 is from Al-Amri (1994). The 3 relations are determined based on local data, particularly, from the Red Sea region, and therefore, appropriately applicable in the study area. The focal depth of 10 km is assumed for each earthquake event in the compiled seismic data, since this depth is commonly and mostly observed for events occurring in the Red Sea region. M_b values are converted to M_s from Equation 3 for substitution in Equation 2, and the resulting equation to relation (Equation1), when the I_o is not directly given in the data. In this manner, I_i is determined in every site from magnitude data.

The class range of I as estimated from Equation 1 is from $0.4 + I_i > I > I_i - 0.5$, where I_i is the center of the class inferred from the MSK assigned grade/degree of classification. The estimation of I is computer aided-work. The respective I_i as determined from the computed I are compiled and stored at respective sites for retrieval. The highest I_i at each site can be retrieved from the stored data of respective I_i, for plotting and contouring purposes.

Two maps of maximal intensity are intended to be prepared from the plotted data of I_i in the area of study. For the first map, the highest I_i that is calculated at each site are plotted and contoured. The frequency of occurrence of the highest I_i at the different grid points is not taken into consideration. The intention is to generate the map of maximal earthquake effects in the study area without considering the probability of exceedance. The second map considers elevating the highest I_i determined at each site into the next higher I_i when the frequency of the highest I_i is more than 2. Presumably, the incurred frequency of more than 2 is due to the influence of neighboring seismic source zones or aftershocks or swarm events. Reasonably, even these phenomena are also contributory to seismic hazard. Since the independency of earthquake events is not necessarily required in this endeavor, the contribution of these phenomena in the intensity-frequency relation is to give higher estimate of the value of the maximum intensity. The inclusion or non-inclusion of aftershocks and swarm types of earthquake events in seismic hazard assessment seems to be an issue that is still debatable. Hence, the preparation of the two maps of maximal earthquake effects in the study area is presumed to be staying in the safe side of the controversy.

RESULTS

The results that are obtained from the application of Equations 1 to 4 seem to divide the Red Sea region into three portions as indicated in Figures 3 to 4. The highest I_i, characterizing the two figures is intensity 9. This is found in the Northern, Central and Southern portion of the Red Sea region. Both flanks of the Red Sea are encompassed by lower intensities from intensity 6 to 4 in an outward direction from the main trough. The main directions of the spatial distribution of the maximal earthquake effects seem to be aligned to the orientation of the Red Sea rift systems and to the trend of tectonic and transform fault (Figure1). Figure 3 shows the spatial distribution of the maximal earthquake effects when the frequency occurrence of the highest I_i at each site is not considered. On the other hand, Figure 4 is the spatial distribution map when the estimated maximum intensity at each site is elevated to the next higher I_i when the frequency of occurrence is more than 2.

Except for the widening of the area of coverage of intensity from 7 to 5 in Figure 4, there is no much difference in the two figures. Probably, the essential indication is to give attention to the implication of Figure 4 when earthquake hazards are considered. Uncertainties

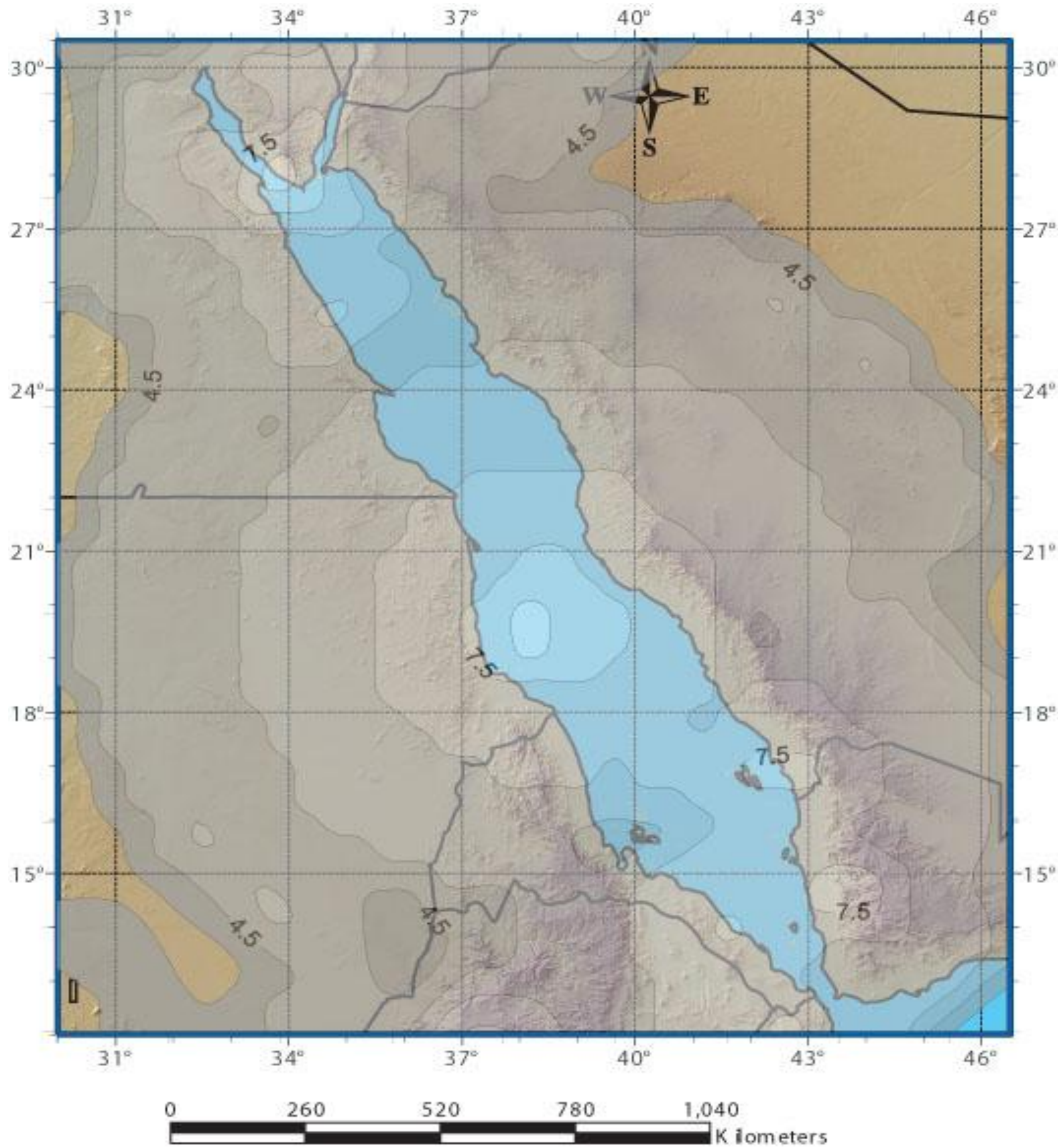

Figure 3. The distribution map of the estimated maximum intensity in the Red Sea region without considering the frequency of occurrence at each site.

of results are to be expected in the representation of seismic hazard. Some of the uncertainties are bound to be due to unreliability of historical seismic data, scatter of the scaling relations among earthquake parameters and the dependency of seismic wave motions on ground characteristics. These factors may influence the out-comes of the study to conservative estimates.

DISCUSSION

Various difficulties appear to be encountered in the assessment of earthquake effects. Inherent in any intensity scale is the basis of utilizing the same physical elements which are: the impact on human beings and their environment, effects to infra-structures and effects

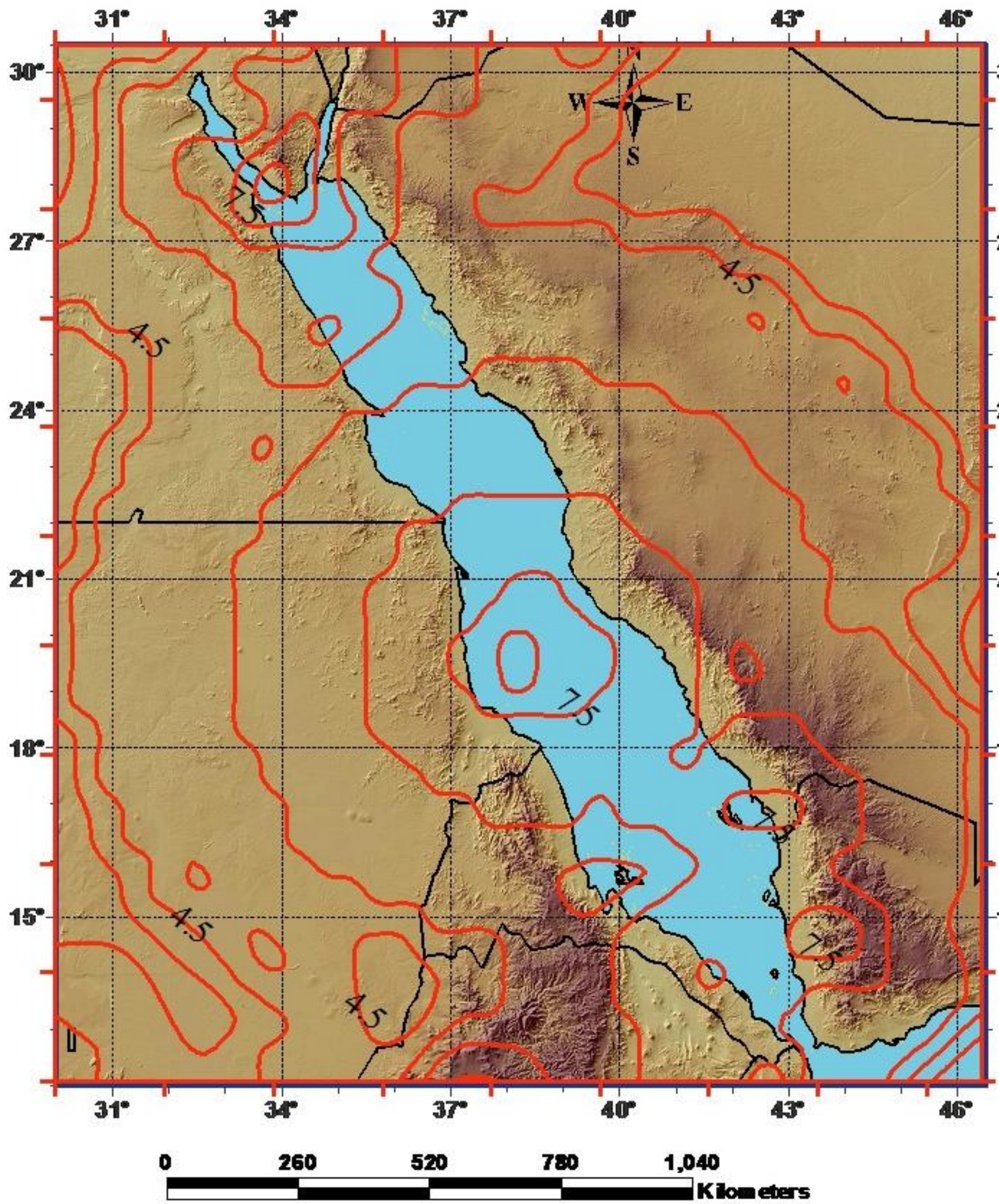

Figure 4. Map of the maximum intensity in the Red Sea region when the frequency of occurrence at each site is considered.

to free nature, in the assessment and differentiation of each degree in the scale. Consequently, when the affected areas are inaccessible, the determination of the degree of earthquake effects, especially the intensity at the epicenter will be problematic. This problem includes as well in drawing the boundary lines that separate the different iso-intensity curves that characterize the shape and trend of the isoseismal map. Probably, one of the reasons in preparing Isoseismal maps is for correlated studies of loss of lives and damage to properties to degree of seismic effects at affected areas during occurrence of an earthquake. Intensity scales are also correlated on physical variables, such as ground acceleration and particle velocity. Nevertheless, studies have shown that intensity shows better relation with particle velocity (Grunthal, 1992). Since the damage to structures is mostly due to severity and duration of ground vibrations, intensity maps become valuable materials in the aseismatic design of buildings for the mitigation of earthquake disaster.

The constraints in the assessment of intensity can be minimized if instrumental data are available. The instrumental magnitude of an earthquake can be correlated empirically with the I_o with respect to the focal depth when sufficient isoseismal maps are utilized. Correspondingly, isoseismal maps show the attenuation of intensity with respect to epicentral distance, and hence, can be used in the empirical determination of the relation between these two entities. The two relations can be applied in the approximate estimation of intensity distribution. Specifically, Equations 1 to 3 are empirically determined from seismic data occurring in the Red Sea region, and these equations are applied correspondingly for the maximum intensity distribution in the study area, for appropriate outcomes.

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