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Potential Seismogenic Source Model for the Red Sea and Coastal areas of Saudi Arabia

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Abstract: Seismogenic source models are unavoidable and a crucial element in seismic hazard studies. A seismogenic source model for Red sea and surrounding areas was constructed. The source model was built up taking into consideration various scientific data sources and logical opinions. A comprehensive model for Red sea and coastal regions of western Saudi Arabia was generated. This model is based on regional geological and tectonic studies, already published seismogenic source models, historical seismicity, recent seismicity, and finally adding up gravity and magnetic studies to construct the final layout of our model. The evaluation of the resources available led to a conclusion for dividing the study area into 23 seismogenic source zones.

Keywords: Red sea, seismic hazards, seismogenic source zones, coastal areas.

Introduction

One of the essential elements in seismic hazard assessment is the delineation of seismogenic sources. The contribution of seismogenic source model for hazard calculation is unavoidable (Rehman et al., 2018). The hazard assessment studies are based upon input seismogenic source model and their identification is a key factor in hazard studies. The seismic activity including historical and recent events and their patterns, and active faults seismic potential contributes crucial role in seismogenic source delineation (Rehman et al., 2016a). A noteworthy explanation behind anxiety emerges from the seismic vulnerability of urban structures along coastal areas in developing countries. The most imperative component in the earthquake-resistant design of the structure is accurate determination of seismic hazard. The seismogenic source model is key element in determination of accurate hazard assessment (Rehman et al. 2016b).

In the current study an attempt is made to construct a comprehensive seismogenic source model. This comprehensive source model will assist in seismic hazard studies for western Saudi Arabia and Red Sea coastal areas. A seismogenic source model for Red sea and west coast of Saudi Arabia after careful consideration of various input parameters was constructed to assist the seismic hazard studies along Red coastal areas, especially western Saudi Arabia. There was no complete comprehensive source model available for the Red Sea and west coast of Saudi Arabia.

Materials and Methods

Construction of Seismogenic Source Model

In seismic zone the temporal and spatial occurrence of seismicity is considered uniform (Sinadinovski, 2004). Seismic source zones delineation is largely based upon interpretation of seismological, geophysical, geological and tectonic data (Al-Malki and Al-Amri, 2013). Seismogenic source zones can be defined on various criteria. The basic division is done on the basis of present-day geological and tectonic setting, historical and recent seismicity, the location of known faults and heat flow measurements for crustal studies (Musson 2009, Burkhard and Grünthal, 2009, Pailoplee et al., 2010, Ares, 2010, Al-Arifi et al., 2013).

In this research seismogenic source model was developed very carefully by taking into account the geological and tectonic studies, seismicity and seismotectonics, previously established models, historical and recent seismicity, gravity and magnetic studies.

Geology and Tectonics

The Arabian plate stands among one of the youngest crustal fragments (Sadek, 2004). This juvenile lithospheric fragment is surrounded by active plate margins in all directions. Approximately ~25 Ma ago rifting of Arabian plate from NE Africa resulted in creation of Gulf of Aqaba and Red sea (Stern and Johnson, 2010).

The Arabian plate is principally comprised of the two distinct eastern and western provinces divided on the basis of geology and tectonics. Arabian platform lies in eastern part and the Arabian shield is present in eastern part. The Arabian platform is characterized by thick sedimentary cover. The Arabian shield area is devoid of sedimentary covers and has mainly igneous and metamorphic rocks exposed. The major tectonic provinces of Arabian shield, that are present mainly in the vicinity of western part, are illustrated in Figure 1.

The Arabian shield separated from the Nubian shield in early Tertiary age by Red sea rifting. The generation of the sea floor by approximately 5 Ma in the southern part of Red sea was followed by continental lithosphere rifting beginning in Oligocene (Rehman et al., 2017).

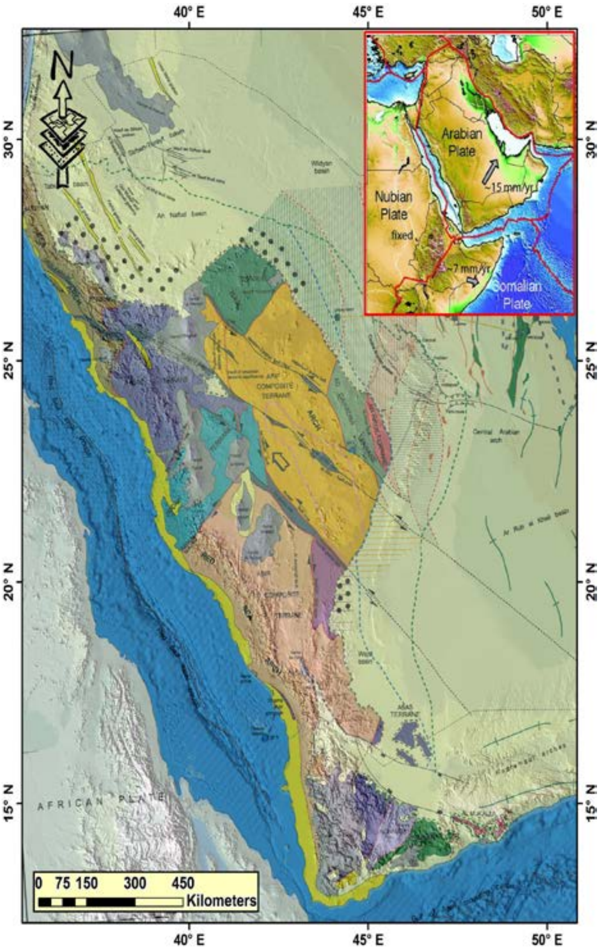

Fig. 1: Major tectonic provinces with geological terrain (Rehman 2016).

The Arabian shield can be divided into five terrains on the basis of tectonics and geology (Fig. 1). In western part, Madyan, Hijaz, Assir, ArRayn and Afif continental terrains are present in eastern part (Al-Shanti 2009). A group of various strike-slip faults dissects and crosses these terrains. Few of these strike-slip faults are major and extend from the southeast to northeastern Arabia with approximately 300km width and 120km length. These faults are supposed to be linked with Proterozoic age (Stern, 1985, Agar, 1987, Al-Shanti, 2009).

A volcanic eruption around 24 Ma; mainly comprised of basaltic dikes, layered gabbro and granophyre bodies, emerged almost concurrently all over the entire Red sea, from Yemen and Afar to the northern part of Egypt. This magmatism phase was accompanied by extension, normal to rifting direction. This circumstance directed the deposition of marine and marginal marine sediments of syn-tectonic origin (Keir et al. 2013).

The composition and structure of Arabian lithosphere are fashioned by a comprehensive set of geophysical data. The crustal thickness from west to east varies from 22 to 53 km across the plate (Fnais et al. 2013). The difference in thickness is modest at Central Arabia which ranges from 35 km to 50 km in the east to 32 km to 46 km in the west (Al-Damegh, et al., 2005, Rodgers et al., 1999).

Red sea, bounded by uplifted edges of the African shield and Arabian, is twisting escarpment-bound elongated basin. The Red sea tectonics reveals that at first rift-normal extension occurred. This oblique rifting was substituted later by this extensional process. The continental rift altered to oceanic rift entirely (Rehman et al., 2017).

Previous Seismotectonic Models

The northwestern regions of Saudi Arabia were assessed by Al Arifi et al. (2013). The author divided study zone into twelve seismogenic source zones on the basis of earthquakes, spatial distribution and tectonic setting of the study area and vicinity. The author used two alternate models to incorporate uncertainty (Fig. 2 a,b). The constraints from this seismogenic source model were aroused by not taking the consideration of background or diffused seismicity into account. While taking into account seismic hazard studies, the diffused seismicity should be incorporated.

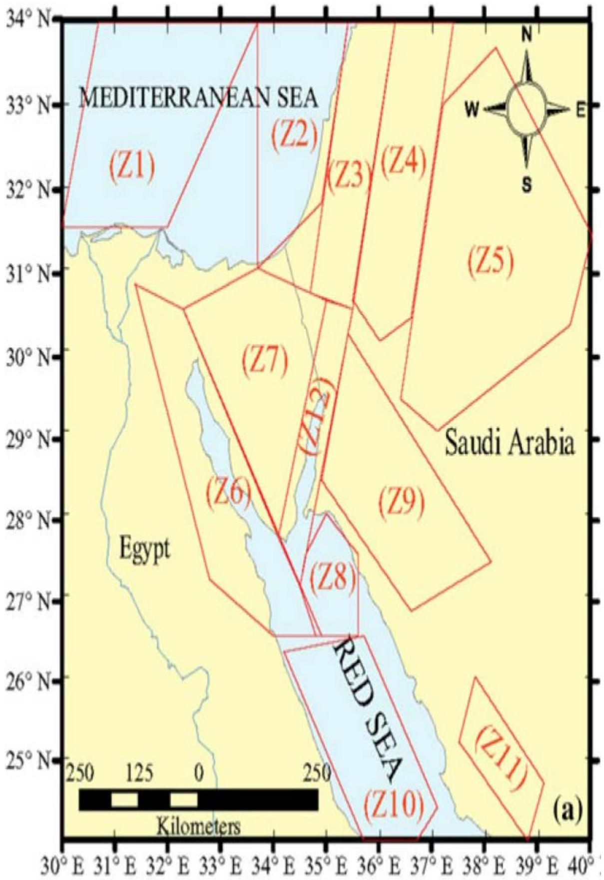

Fig. 2a Major tectonic provinces with geological terrains (Rehman, 2016) .

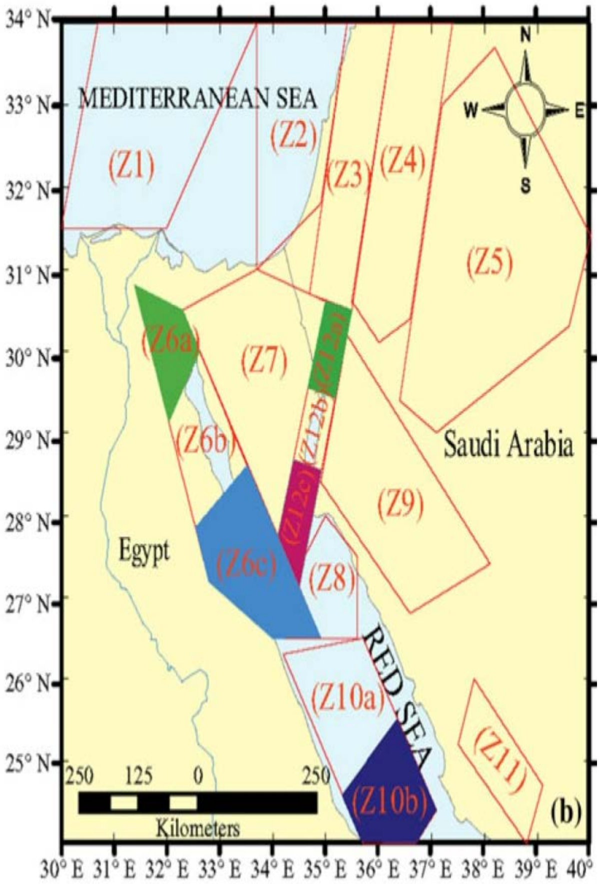

Fig. 2b Two alternative earthquake source models (a and b) used by Al Arifi et al., (2013).

The seismic hazard studies were carried out by Al-Amri (2013) for the Arabian platform to construct seismogenic source model for Saudi Arabia and Red sea regions. However, the study emphasized on central and eastern Arabian hazard. The material published did not discuss in particular the western Arabian source zones in detail. The source model constructed by Al-Amri (2013) which incorporated all coastal areas in Red sea active seismic zones (Fig. 3). Especially for central Red sea Jeddah city and surroundings are incorporated in zone 8. The eastern coastal area is passive margin. The major activity is going along the Red sea rifting axes (El-Isa and Shanti, 1989).

Seismicity and Seismotectonics

The seismicity map for the Arabian shield and it is neighboring areas was prepared based on magnitudes above 3 ranging in time from 1900 to 2013 (Fig. 4). A homogenized earthquake catalog was constructed, from 827 AD to August 2013 keeping in view various earthquake data sources, comprising of historical and instrumental events. The catalogs helped to characterize the seismicity region. The seismicity of Arabian plate evolved along the boundaries of African, Arabian and Eurasian plates. Most of the seismic activity is restricted to the spreading centers of the Red sea; the divergent boundaries to the west and south, strike-slip Dead sea fault zone in northwest and Gulf of Aden in the south. The Arabian peninsula's lack of seismicity in the interior, which suggests that presently at Arabian plate very small-scale internal deformation is taking place (Rehman, 2016).

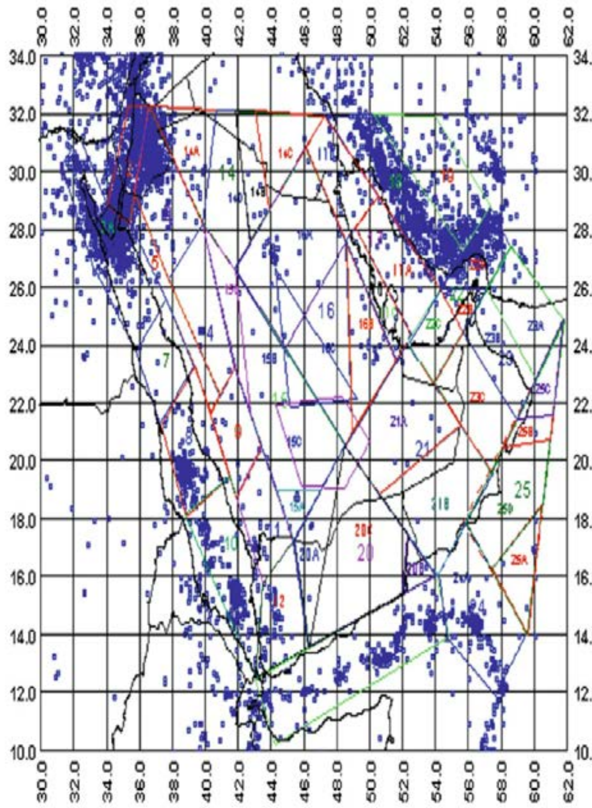

Fig. 3 Seismogenic source model for Saudi Arabia and Red sea regions (Al-Amri, 2013).

The focal mechanism solution map was created by applying Harvard Centroid Moment Tensor solution (Fig. 5). The pure normal faulting is associated with East African rift system. The orientation direction of tension axis is nearly NNE-SSW. The normal faults and strike-slip faulting system is exhibited by Gulf of Aden. Strike-slip faults accompanying existing normal and transform faulting are the product of spreading. The focal mechanism solution describes pure normal faulting style present Yemen. In Red sea strike-slip, faulting trend changes to normal faulting from southern part towards central. The normal faulting can be attributed to extension or sea floor spreading while strike-slip behavior at the southern part is an attribute of the counter-clockwise movement. Two styles of faulting: normal and strike slip are observed in Gulf of Aqaba with tension axis in NNE-SSW direction.

Gravity and Magnetic Studies

Published gravity and magnetic survey data along Red sea and Arabian shield was collected. The gravity anomaly trend is near to some extent similar in Arabian shield part. However, along coastal zone of Red sea and southern Red sea, there is high gravity anomaly observed. The gravity anomaly along the Red sea rifting axis is high as compared to coastal areas (Al Hosani et al., 2012) (Fig. 6, 7).

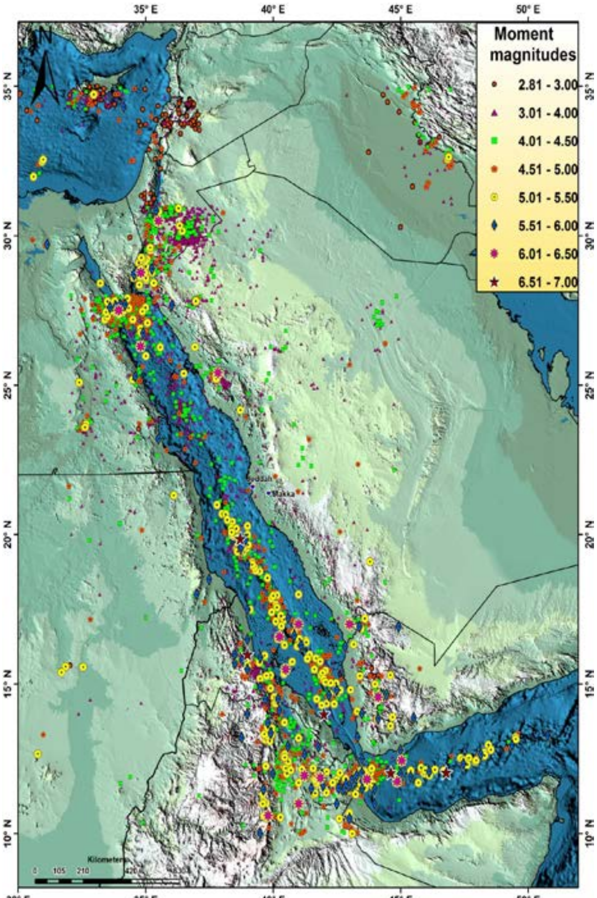

Fig. 4 Arabian peninsula and its surrounding regions instrumental seismicity map from1900 to 2016 (Rehman, 2016).

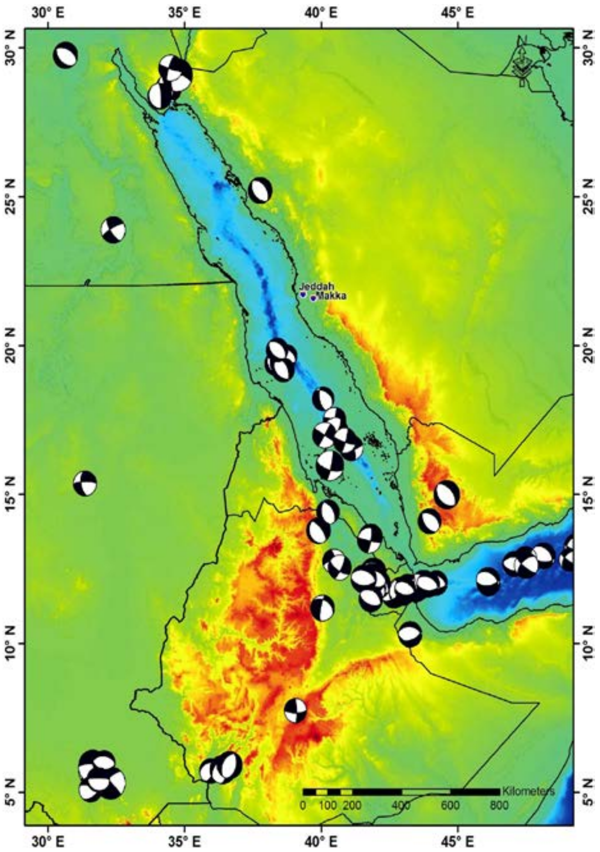

Fig. 5 Focal Mechanism solution for earthquakes magnitudes greater than 5 (Rehman 2016).

Results and Discussion

Seismogenic Source Model

The methodology adopted to construct the source model is shown (Fig. 8). Keeping in view all above mentioned sources of information and various types of maps, the geological and tectonic maps were used as the base maps. In next stage previously constructed seismogenic source models were superimposed over the base map. Later, historical and recent seismicity distribution was analyzed over that layout. Finally, boundaries of each source zone were drawn by the overall pattern of seismicity distribution, geological and structural trends and focal mechanism solutions.

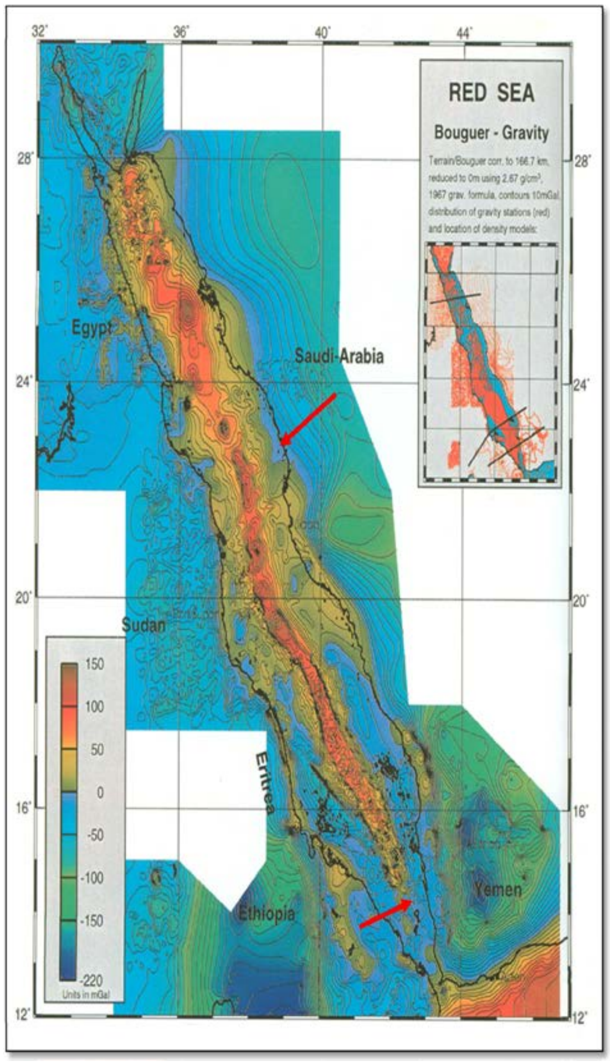

Fig. 6 Gravity anomaly map for the Red Sea and adjacent areas (Al Hosani et al. 2012). (Red arrows indicating low gravity anomaly).

The gravity and magnetic anomalous observations help to make decisions to incorporate coastal zones in the separate seismogenic zone and divide the southern Red sea into two different seismogenic source zones (Fig. 6). The magnetic map (Fig. 7) supported the decision for dividing southern part of Red sea into two seismogenic source zones indicated by yellow arrows.

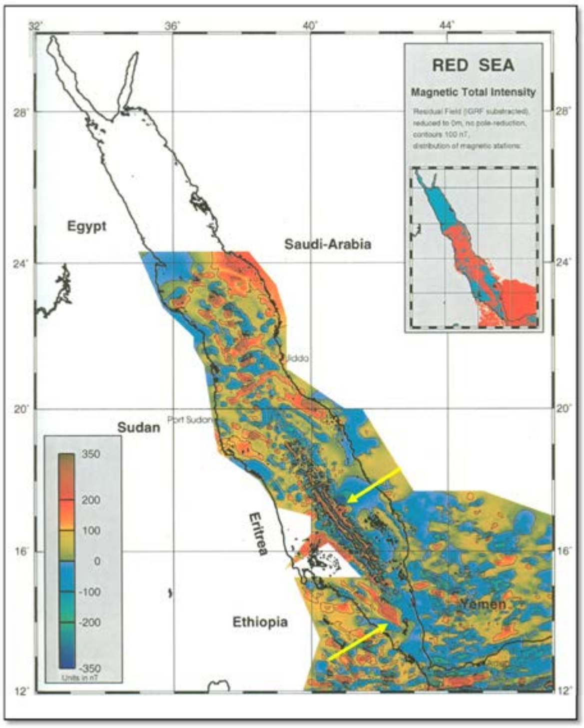

Fig. 7 Total residual intensity magnetic map (yellow arrows indicating magnetic behavior for southern part of Red sea) (Al Hosani et al., 2012).

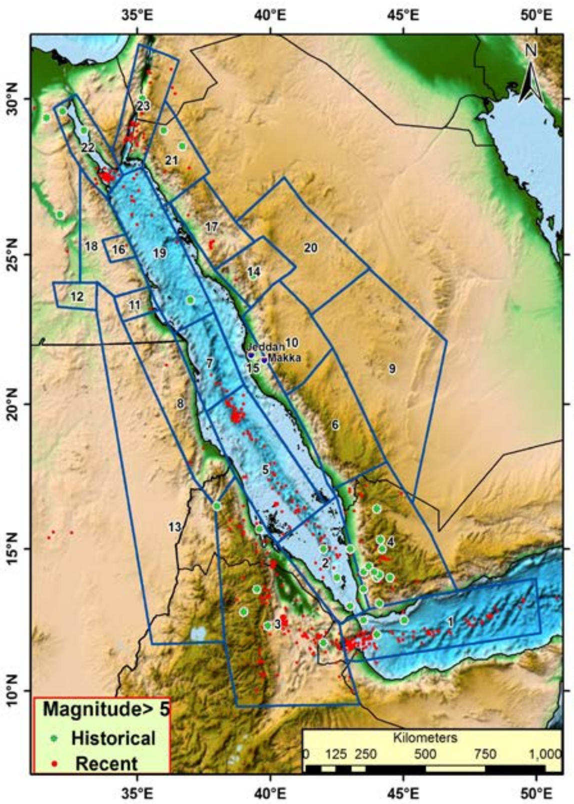

Fig. 8 Constructed seismogenic source mode (Rehman, 2016).

Based on these data seismogenic source model was constructed (Fig. 8). The names of each source zones are given in Table 1. Contrary to previously published seismogenic source models, this seismogenic source model treated separately the eastern coast seismicity of the Red sea from other relative seismically active central and southern Red sea areas (Fig. 9). This zone comprises of a part of the continental margin of Red sea which provides a hinge zone between Red sea and Arabian plate. This zone has very low seismic activity and no record for the historical earthquake was found.

Table 1. List of seismogenic zones generated.

Sr. No	Zone Name
1	Gulf of Aden
2	Southern Red sea
3	Afar region
4	Yemen Jezan zone
5	Central southern Red sea
6	Baha to Abha
7	Central Red sea
8	Western coast seismicity
9	Eastern background seismicity
10	Harrat Ad Damn zone
11	Egypt 1
12	Egypt 2
13	Western background seismicity
14	Hijaz zone
15	Eastern coast seismicity
16	Egypt 3
17	Yanbu suture zone
18	Egypt 4
19	Northern Red sea
20	Afif terrain
21	Tabuk zone
22	Gulf of suez
23	Gulf of Aqaba

Conclusion

The seismogenic sources are a vital part of seismic hazard studies. A careful and distinct opinion for selection of source model is the backbone of hazard assessment studies. This study presents a comprehensive seismogenic source model for western Saudi Arabia and Red sea coastal area. The seismic hazard studies in absence of accurate and comprehensive source model are doubtful. In this model, already published seismogenic source models, historical and recent seismicity, geological and tectonics studies, focal mechanism solutions, and finally gravity and magnetic studies incorporated.

The data from various sources including geophysical studies helped to modify preexisting models on solid grounds and generate a unique model. All source zones listed (Table 1) are based upon available resources that have been utilized exhaustively to generate and authenticate the seismogenic source model. An assortment of data has been carried out after an evaluation of the resources available. The anomalies and the parallels are studied meticulously so that the chances of error should be eliminated to the utmost.

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