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PROPOSED SEISMOTECTONIC PROVINCES FOR KURDISTAN REGION–NORTH-EASTERN IRAQ

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A B S T R A C T

The seismotectonic provinces are the basis of many seismology studies in a given area. The seismotectonic provinces, in which the seismic activity is distributed homogenously and lay in same tectonically and geologically region, are used as the basic maps in seismology studies and preparation of seismic hazard maps. In the last decays, the seismological studies of the Kurdistan Region (north and northeastern of Iraq) didn't proceeded well and there are not comprehensive seismicity map and perfect Fault map in this region. Also, there is not efficient Seismotectonic division in Iraq, as well as in Kurdistan Region. The study area encompassed by the 40.50–47.50°E longitudes and 33.50–39.50°N latitudes. This research reviews the structural zones, tectonics and neotectonics, fault map and finally the seismicity of area to delineate the seismotectonic provinces of Kurdistan region. In addition, the seismicity parameters (λ,β and M_{max}) related to each province have determined by common procedure of Kijko-Sellevoll. The earthquake database constructed using local networks (Iran and Turkey), international broadband (USGS and EMEC) networks and also data from published researches. Totally five seismotectonic provinces were delineated and their seismicity parameter were determined in this research which could be used as a basis of future seismology studies in Kurdistan Region.

INTRODUCTION

Seismotectonics deals with tectonic plate boundary interactions and the resulting crustal deformation, seismicity and their spatial and temporal evolution. The progressive buildup of tectonically induced elastic strain in the crust is released suddenly by earthquakes, primarily along faults. There is, therefore, a direct link between plate tectonic processes, crustal deformation and seismicity. Based on this relationship, earthquakes can provide direct insights into active tectonic processes; while, on the other hand, investigations of tectonic deformation can be used to understand the earthquake generating process and can be utilized in seismic hazard evaluations. Seismotectonic studies permit the identification and quantification of seismic hazards within the framework of regional tectonics (Rahiman and Pettinga 2009).

The development of a seismotectonic model for an area or region allows for the separation of the Earth's crust into seismic source zones that have distinctive geologic, tectonic and seismogenic properties, and exhibiting similar earthquake potential throughout (Reiter 1990). Present day seismicity within the Kurdistan region provides direct evidence of active tectonic processes operating in this area. However, the origin of this seismicity in the context of Kurdistan region's tectonic setting and structural evolution has remained poorly understood. No detailed previous work has been done on the seismotectonics of the Iraq and specially Kurdistan Region In particular, in terms of correlating the observed seismicity with identifiable structural geological features along which tectonic deformation is accommodated. Kurdistan Regional is one of Iraqi governorates which located in north and north-eastern parts of Iraq (Figure 1).

At present, this part of Iraq is developing rapidly in many aspects and the need for basic general maps for planning and decision-making is seriously important. One of the most useful and essential basic map is such countries is seismotectonic provinces map which should be used as essential information in seismic hazard evaluation studies.

To delineate the seismotectonic map of study region in this research we review the tectonics and neotectonics setting, structural subdivisions, fault map and the seismicity of region to delineate the seismotectonic provinces of Kurdistan region.

In addition, the seismicity parameters including the annual rate of occurrence (λ) and also the seismicity(β)parameters of each province are determined by common procedure proposed by Guttenberg-Richter (Richter, 1958) and Kijko-Sellevoll (1992).The study area encompassed by the 40.50–47.50°E longitudes and 33.50–39.50°N latitudes.The results are presented as seismotectonic

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provinces map and the list of seismicity parameters of each seismotectonic province.

Tectonics And Neotectonics Setting

The tectonic framework of the Middle East is divided into 1) Zagros fold-and-thrust belt, 2) Unstable Arabian shelf, and 3) Stable Arabian shelf as illustrated by in Figure 2. In other hand, according to Buday (1980) and Buday and Jassim (1987), the Iraqi lands divide into five main zones including Unfolded zone (south and south west of Iraq), Low Folded zone, High Folded zone, Imbricated zone and Thrust zone which divided to more subdivisions individually (Figure 3). The study area, in north Iraq, is mainly located in Zagros fold-thrust belt zone and some parts located in Zagros foreland sediments or Arabian Unstable Shelf. Zagros fold-thrust mountain belt as a part of the Alpine-Himalayan orogenic belt is one of the youngest and the most active continental collision zones on the earth (Snyder and Barazangi 1986); it extends from the Taurus Mountains in southeastern Turkey to the Minab Fault east of the Strait of Hormoz in southern Iran (Mirzaei and Gheitanchi 2002). According to Jackson (1980); Berberian (1981), (1995); Molnar and Chen (1982) the belt is a broad zone of continuing compressional deformation that experiences horizontal shortening of the basement on reactivated normal faults that stretched and thinned the basement of a continental margin on which the Mesozoic sedimentary cover was deposited. Two major faults dominate the tectonics of the northeastern boundary of the Zagros (Figure 4) including the Main Zagros Reverse Fault with a northwest-southeast strike from north Iraq to south of Iran and a series of right-lateral strike-slip faults called the Zagros Main Recent Fault.

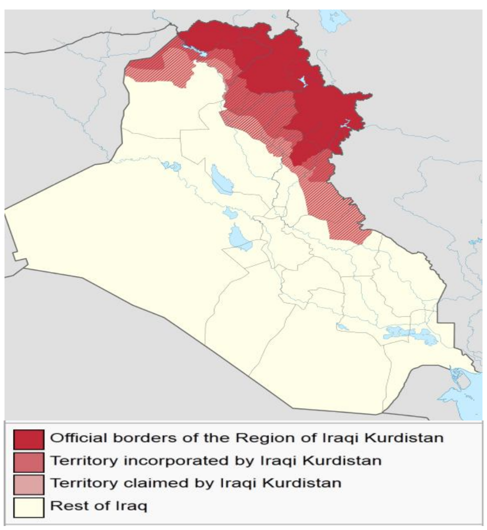

Figure 1 Kurdistan region in Iraq (Wikipedia, 2014)

The Zagros Main Recent Fault is a prominent right-lateral strike-slip fault system with a northwest-southeast trend in the northeast Zagros border zone that is broadly parallel to, and younger than, the Main Zagros Reverse Fault. It is a major seismogenic structure that comprises several segments with different levels of seismicity. As mentioned by Tchalenko and Braud (1974), Berberian (1995) and Shabani and Mirzaei (2007) more intense seismic activity in the Zagros is concentrated along the Zagros Main Recent Fault, between 33°N and 35°N on the Dorud and Nahavand segments in Lurestan, and Sahneh segment in Kermanshah in western Iran, while the Morvarid (north of Kamyaran in Iran) and Piranshahr segments, near the border on Iran-Iraq and extended to north east of Kurdistan Region (Iraq), show relative seismic quiescence. Many authors (e.g. Jackson and McKenzie 1984, Jackson *et al*. 1995, Berberian 1995) believe that the Zagros Main Recent Fault dies out southward at about 31°N, but there are some indications that it may extend southeastward (e.g., Baker *et al*. 1993). The Zagros Reverse Fault Segments strike between N065W and N060W trends (Tchalenko and Braud 1974, Mirzaei and Gheitanchi 2002, Shabani and Mirzaei 2007).

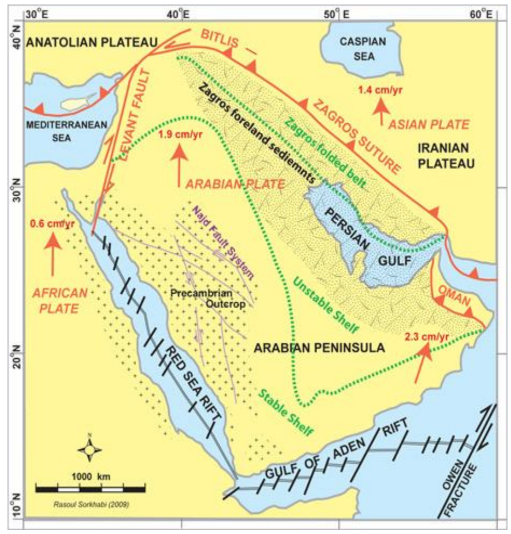

Figure 2 The tectonic framework of the Middle East (Sorkhabi 2010)

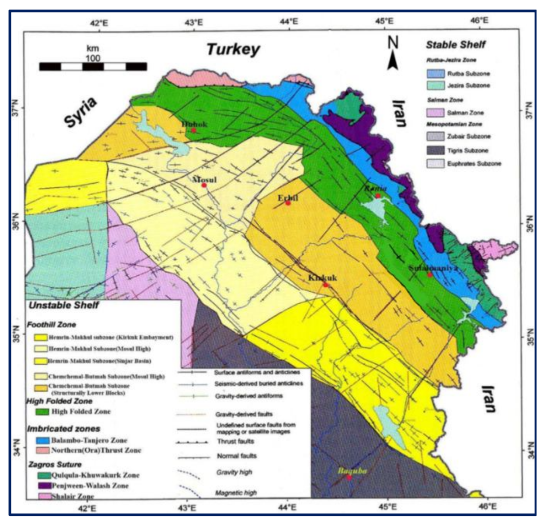

Figure 3 Tectonic subdivisions of Kurdistan Region in north of Iraq (Buday and Jassim 1987)

Because of existences of active tectonic deformations in crust in the study region, many neotectonic evidences were assessed and published by researchers. From Proterozoic to now whole steps of Plate Tectonic Wilson Evolution were occurred in Middle East and this evolution is running now. Present rifting in Red Sea cause the movement of Arabian Plate to north and north-east and its compression against Eurasian Plate. In other side the movement of Arabian Plate causes the rotation of northern parts of plate

(Vernant *et al* 2004a). Researches published by Nilforooshan *et al* (2003) and Vernant *et al* (2004a,b) using GPS fixed stations in Arabian and Eurasian plates showthe present collision of these plates. Figure 4 shows the plate tectonic movement rates relative to Eurasian fixed station in Middle East and surrounding regions. According to geodynamic measurements in Iranian crust in 28 GPSsites from 1999 to 2001 and in Turkish crust from 2000 to 2002 by Vernant *et al* (2004a) the collision rate between Arabian-Iranian crust is 22±2mm per year which is lower than global tectonic movements presented by DeMets *et al* (1990 and 1994) and in the case of Arabian-Turkish crust is 15±2mm per year.According to Sorkhabi (2010) the Arabian continental plate, which collided with the Asian plate along the Bitlis-Zagros suture during the Eocene, is still converging with Asia at a rate of 1.9 to 2.3 cm per year based on GPS measurements (see Figure 2). Global measurements of relative plate motions of Arabia with respect to Eurasia show higher velocities of 2.4-3.5 cm per year (Sorkhabi 2010). This continental collision gave rise to the Zagros orogeny and its Cenozoic foreland basin, which was superimposed on the Paleozoic-Mesozoic Tethys shelf basin (Mohajel and Fergusson 2014).

Figure 4 Present state of movement vectors of plates relative to Eurasian Plate as a fixed station (Vernant et al 2004a).

The existence of subcrustal (>50 km) earthquakes in the ISC and USGS catalogues has led some to postulate active subduction of the continental crust of the Arabian shield beneath the Zagros (Nowroozi 1971; Bird *et. al.* 1975; Moores and Twiss 1995). The cumulative thickness of sediments in the Middle East region reaches up to 12 km. The Zagros deformation and salt domes have folded the sedimentary beds into large, gentle anticlines. The western and southern boundaries of the Arabian plate are bounded respectively by the Red Sea and Gulf of Aden rifts. These Neogene continental rifts have separated Arabia from Africa, and are further pushing Arabia against Asia. The rift-shoulder uplifts have outcropped the Precambrian rocks (part of the Nubian-Arabian shield) along the Red Sea and are capped at places by rift-related volcanic rocks. Generally and in tectonic points of view, the Iraqi lands divide into two grate regions of Unstable (Inner Platform) and Stable (Outer Platform) Shelf (Sorkhabi 2010).

Fault Maps

Fault map are of basic information in delineation of seismic zones because many seismic events occur around the trace of faults. There is little information about active fault in Iraq and only small-scale fault map of Iraq was published by Buday (1987). To fulfill this problem we tried to collect data from any published literatures and finally checking with satellite images to control the more accurate location of fault traces. Consequently the fault map of Kurdistan Region and surrounding area was prepared according to published maps like tectonic map of Iraq (Sissakian 2000), Zagros Fault map (Bernerian 1979, 1981), Tectonic Map of Iran (Nogolsadat, 1994), the geological maps of northern Iraq in 1:250.000 scale, Active Faults of Turkey (General Directorate of Mineral Research and Exploration), Major Active Faults of Iran (Hessami *et al*, 2003) and Tectonic Map of Syria (Brew *et al*. 2001). In other hand, to control and increasing the accuracy of fault location we use the satellite Images of region and the results of some local studies including Azad *et al* (2009), Baban *et al* (2014a,b), Ameer *et al* (2005). The final fault map of Kurdistan Region is shown in Figure 6. It is worth to mention that this map is the first detailed fault map of Kurdistan Region and used in this study for the first time. This map can be used as a basis for future more detailed fault map of Kurdistan Region.

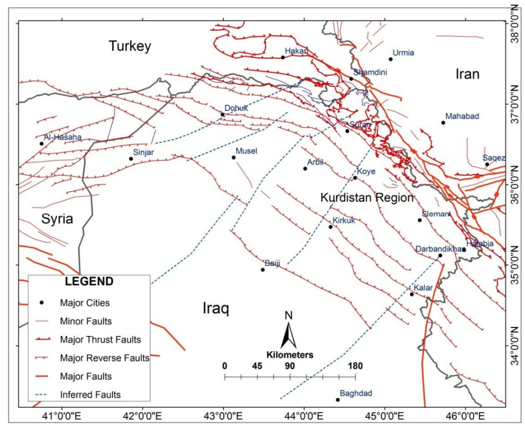

Figure 4 Fault maps of Kurdistan region and surrounding area

Maggi and Priestley (2005) believe that the Middle East is a tectonically complex region consisting of terrains as diverse as Precambrian shields and young orogens. The dominant tectonic feature is the Turkish–Iranian plateau, a recently elevated, seismically active region along the Zagros–Bitlis suture, which results from the collision of the Arabian Plate with Eurasia. One of the most seismic zones in study area locates in southern parts of Turkey which suffered by thrust faulting of Zagros-Bitlis zone. Based on Saroglu *et al* (1992) and Hull *et al* (2004) the major faults of this region are south-east Anatolian Thrust Fault (SEAT) and Simdinli-Yokeskova Fault zone.

The presentday stress pattern of the Arabian-Eurasian collision zone in northern Iraq and surrounding regions from the formal stress inversion of the earthquake focal mechanism solutions was deduced by Abdolnaby *et al* (2014a,b) in which the focal mechanism solutions were done for 65 earthquakes in northern Iraq (Figure 5) and finally the stress pattern of region resolved. According to Abdolnaby *et al* (2014b) the pattern of present-day tectonic stress fields in northern Iraq and surrounding regions is controlled by the dynamics of the collision between the Arabian and Eurasian plates and the dominant mechanisms are including normal faulting (NF), normal faulting with strike-slip component (NS), strike-slip faulting (SS), thrust faulting with strike-slip component

(TS), thrust faulting (TF), and unknown or oblique faulting (UF) among which the most common tectonic regimes in the study area are the SS (43.94 %), UF (27.27 %), and TF (13.64 %); the less common tectonic regimes are the NF (9.09 %), NS (3.03 %), and TS (3.03 %) and the nature of strike-slip displacement on fault surfaces is left-lateral (sinistral).

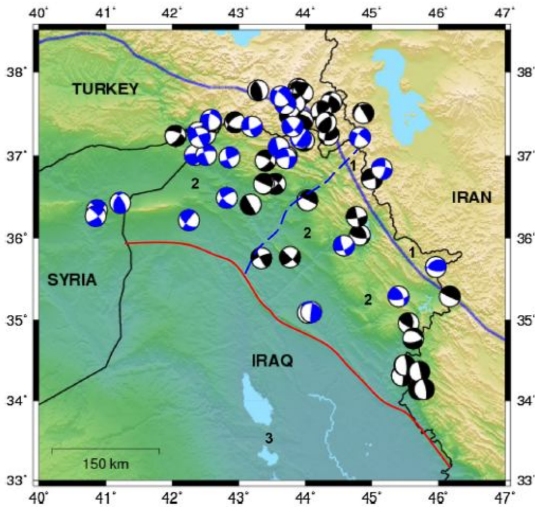

Figure 5 Focal mechanism solutions for 65 earthquakes in northern Iraq (after Abdulnaby et al 2014b)

Crustal Structure Of Study Region

Generally, the crustal studies are used to improve the resolution of existing regional models to derive a detailed structure of the tectonics in a given region (Gritto *et al* 2010). In the case of Kurdistan Region the crustal structure was studied by in seismic velocity point of view using seismic events recorded in North Iraq Seismographic Network (NISN). The Moho depths in Kurdistan Region were studies byGhalib *et al* (2007) and Gritto *et al* (2008) and the summary of results is shown in Figure 6. According to results the Moho depths beneath the Iran-Iraq and Turkey-Iraq borders are deeper about 2-10km than other parts. These differences were caused by thrusting along Zagros-Bitlis suture that makes the crust of this partto be thicker than other parts of region.

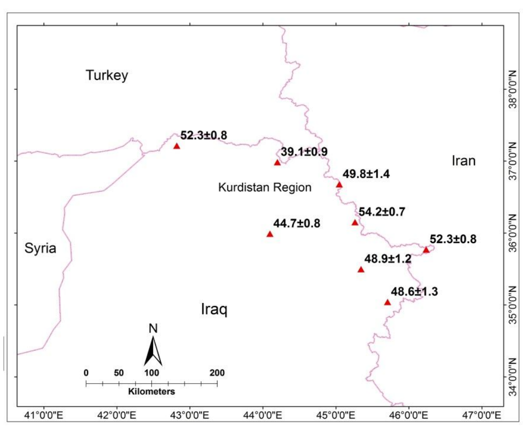

Figure 6 Moho depths [km] in Kurdistan region based on Gritto et al (2008)

Seismicity In Study Region

Seismicity of study region may help to delineate the seismotectonic provinces. The recorded earthquakes including historical and instrumental records were collected in this research to assess the seismicity of region. The earthquake catalogue is compiled from different data sources including ISC, USGS/ NEIC, IIEES earthquake catalogue (International Institute of Earthquake Engineering and Seismology of Iran), EMEC (European Mediterranean Seismological Centre), earthquake catalogue of National Earthquake Monitoring Center of Turkey for earthquakes greater than M=4.0 Richter for all types of magnitude. The historical earthquakes were extracted from past studies mainly by Ambraseys (1988, 1989) and Tchalenko (1977) and earthquake catalogue of Turkey (Onur *et al*., 2008), the historical earthquake of Syria (Sbeinati *et al* 2005), Significant earthquakes of the world (Gans and Nelson, 1981), previous studies by Alsinawi and Al Moosawi (1980), Alsinawi and Al-Qasrani (2003) for Iraq. To have a unique earthquake database all collected data were mixed and similar records omitted from database. Figure 7 shows seismicity map of Kurdistan including major faults and location of past earthquakes which recorded in the Kurdistan region and adjacent areas from 1900 to 2014.According to seismicity map of study region the past earthquake locations are mainly observed along Zagros-Bitlis Suture Zone and also in northern parts of region around the Van Lake in Turkey which are the highly seismic zones.

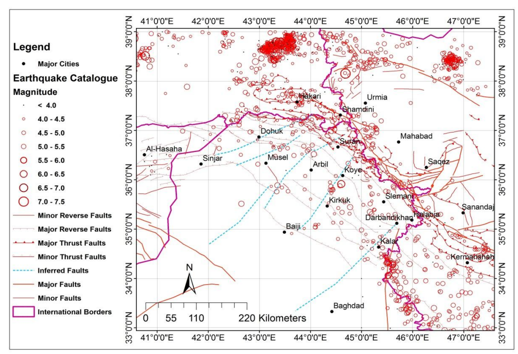

Figure 7 Map of tectonic elements and seismicity of the Kurdistan region and surrounding area

In the starts of 1980 decay this sight was common that, in the majority parts of continent the earthquakes were occurred in upper crust and mantel and the lower crust is aseismic (Chen & Molnar, 1983). This can be concluded from these that the behavior of rocks in the upper crust is brittle and most of faults are strike-slip and in the lower crust is ductile and show the creep, so the behavior of rock in higher depths is depends on the temperature (Scholz 1988). The study area is western part of Iranian Plateau which Jackson(2001) believe that most of earthquakes occur in Upper Crust. Also,based on researches presented by Maggi*et al* (2000) show that the depth of Moho is about 45km and the depth of seismogenic zoneis about 20km.

Proposed Seismotectonic Provinces

Seismotectonics is a field of geological studies in which the relationship between the earthquakes, active tectonics and individual faults of a region are evaluated. It try to understand which seismic sources are responsible for seismic activity in a given area by analyzing a combination of regional tectonics, recent instrumentally recorded events, accounts of historical earthquakes, focal mechanism, crustal structures and other evidences.

Some parts of study region can be characterized by active and passive faults, height and seismic activity (historical and instrumental earthquakes). Tectonic studies indicate that the study area has a different density of active and recent faults in different parts. Earthquake data show that most activity is concentrated in Iran-Iraq and Turkey-Iraq borders and less activity is observed in south and south western parts of area. In this research by using the collected data, which presented in more details in previous sections of this paper, including the geological maps, fault map, spatial distribution of earthquakes (seismicity map), focal mechanism of recorded events, tectonic subdivisions and crustal structural studies (Moho depth) and finally checking with satellite images, the seismotectonic map of area prepared as it is illustrated in Figure 8. The study area is divided into five Seismotectonic provinces that have different characteristics in tectonic and seismicity viewpoints.

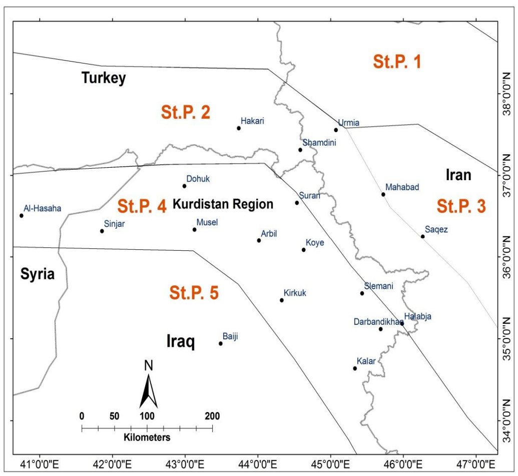

Figure 8 Major seismotectonic provinces of Kurdistan region

Seismicity Parameters

Seismicity refers to the geographic and historical distribution of earthquakes. This data are used to quantify the seismic hazard of an area. The most common method for evaluation of seismicity in an area is statistical studies of frequency of occurrence of magnitude and distribution of earthquake occurrence in time span, in which the general view of seismicity of area revealed.

This simple evaluation in study area shows that the small to intermediate earthquakes have great role in seismicity of area and very large earthquakes (M>6.5) didn't occurred in area, as just one event larger than M=6.0 occurred that has a magnitude of 6.2 (occurred near Dookan city). To determine the seismicity of area two usual methods of Guttenberg-Richter (Richter 1958) and Kijko-Sellevoll (1992-2001) have used. The spatial distribution of instrumental seismic events in catalogue span (1900-now) is shown in Figure 7.

Guttenberg-Richter Procedure

This method is the most common method to estimate the seismicity of an area. By using the Guttenberg-Richter relationship, the seismicity of area will be meaningful mathematically and the correlation of magnitude-frequency of occurrence is defined. The coefficients of seismicity are revealed by fitting of data. The simple Guttenberg-Richter (GR) relationship is a linear equation that defined as Equation 1:

$$Log_{10}N_c = a - b.M \qquad (1)$$

In which M is magnitude of earthquake; 'N_c' is cumulative frequency of earthquake with magnitude larger than M. the coefficient 'a' and 'b' are the constants which reveal the seismicity of study area. '10^a' shows the number of earthquakes larger than M=0 and 'b' indicate the relative frequency of large to small magnitude earthquakes which be determined by regression method. This equation is written in exponential distribution form as Equation 2:

$$N_c = N_o.\exp(-\beta.M) \qquad (2)$$

Comparing these two equations, the following symmetry is concluded:

$$a = Log\ N_o$$
$$\beta = b.Ln\ (10) \qquad (3,4)$$

in which the 'No' and 'a' are indicator of the rate of seismic event occurrence and 'Beta' and 'b' indicate the frequency of large and small earthquakes in area.

Kijko-Sellevoll(1992) Procedure

Although the Guttenberg-Richter primary function is quite simple and user-friendly to determine the seismicity parameters of an area, for best appropriating of earthquake nature and its characteristics with mathematical models, the double truncated Guttenberg-Richter's distribution function has presented as following:

$$G(m|T) = \Pr(M \le m) = \exp\left[-\lambda.T.\frac{\exp(-\beta.M_{max}) - \exp(-\beta.m)}{\exp(-\beta.M_{max}) - \exp(-\beta.M_{min})}\right] \qquad (5)$$

To determining seismicity of an area by this method, a simple technical FORTRAN code has presented by Kijko and Sellevoll (1992). In this research the latest version of mentioned code is used. This approach permits the combination of largest earthquake data and complete data having variable threshold magnitudes. It allows the use of the largest known historical earthquake ($M_{max,obs}$) which occurred before the catalogue began. It also accepts 'gaps' (Tg) when records were missing or the seismic networks were out of operation. Uncertainty in earthquake magnitude is also taken into account in that an assumption

Table 1 Estimation of Seismic parameters for major seismotectonic provinces of region

Seismotectonic Provinces	□(KS)	□(4.0)	*b-value(GR)*	*M*max	*M*obs
St.P. 1	1.67 ± 0.09	32.12 ± 3.67	0.79 ± 0.10	7.8 ± 0.53	7.7
St.P. 2	1.98 ± 0.11	25.42 ± 2.68	0.68 ± 0.03	7.6 ± 0.41	7.4
St.P. 3	1.84 ± 0.08	27.44 ± 3.02	0.65 ± 0.09	7.0 ± 0.33	6.0
St.P. 4	2.23 ± 0.12	22.73 ± 2.92	0.71 ± 0.05	6.8 ± 0.31	6.2
St.P. 5	2.36 ± 0.13	19.63 ± 3.71	0.86 ± 0.11	6.5 ± 0.32	6.0

is made that the observed magnitude is true magnitude subjected to a random error that follows a Gaussian distribution having zero mean and a known standard deviation (Kijko and Sellevoll, 1992).

Proposed seismicity parameters

In the five seismotectonic provinces delineated in study area the seismicity of each province calculated using two methods of Guttenberg-Richter (GR) and Kijko-Sellevoll (KS). The summary of results is presented in Table 1.These values are proposed for seismotectonic provinces of Kurdistan Region (NE Iraq) and surrounding area.

CONCLUSIONS

Seismotectonic maps are of basic information in seismology evaluations and especially in seismic hazard analysis of a given area. Kurdistan Region in north and northeast of Iraq is a developing area which needs to basic data. In this research by using the collected geological maps, fault map, spatial distribution of earthquakes, focal mechanism of recorded events, tectonic subdivisions and crustal structural studies (Moho depth) and finally checking with satellite images the seismotectonic map of area prepared. In addition, using the earthquake catalog and applying the most common approaches of Guttenberg-Richter (GR) and Kijko-Sellevoll (KS) the seismicity parameters of all delineated seismotectonic provinces were calculated.

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References

- Abdulnaby, W., Mahdi, N., Al-Shakory, H., and Numan, N., M., S., 2014b, Stress Patterns in Northern Iraq and Surrounding Regions from Formal Stress Inversion of Earthquake Focal Mechanism Solutions, Pure Appl. Geophys., 171, 2137–2153.
- Abdulnaby, W., Mahdi, N., Numan, N., M., S., and Al-Shakory, H., 2014a, Seismotectonics of the Bitlis–Zagros Fold and Thrust Belt in Northern Iraq and Surrounding Regions from Moment Tensor Analysis, Pure Appl. Geophys., 171, 1237–1250.
- Alsinawi, S., A., and Al Moosawi, H., I., 1980, Seismic zoning and other seismic parameter consideration for Iraq, Proceedings of the 7th World Conference on Earthquake Engineering, Istanbul, Turkey, Vol 1, pp 185-192.
- Alsinawi, S., A., and Al-Qasrani, Z., O., 2003, Earthquake hazard considerations for Iraq, Fourth International Conference of Earthquake Engineering and Seismology, Tehran, Islamic Republic of Iran.
- Ambraseys, N., N., 1988, Engineering seismology, Earthquake Eng. Struct. Dyn. 17, 1–105.
- Ambraseys, N., N., 1989, Temporary seismic quiescence, SE Turkey, Geophys. J. 96, 311–331.
- Ameer, A., S., Sharma, M., L., Wason, H., R., and Alsinawi S., A., 2005, Probabilistic Seismic Hazard Assessment for Iraq Using Complete Earthquake Catalogue Files, Pure appl. geophys., 162, 951–966.
- Azad O., I., 2009, Tectonic style and evolution of the NW segment of the Zagros Fold-Thrust Belt, Sulaimani governorate, Kurdistan Region, NE Iraq, Sulaimani University, Ph.D. Thesis.
- Baban E., N., Aram, N. T., andKakarash, I. M. G., 2014, Study of subsurface features using seismic reflection data in Erbil area, Kurdistan Region, Iraq, Arab J Geosci, 7, 3575–3588.
- Baban E., N., Bakhtiar, Q., A, and Nawzad, H., A., 2014, Study of subsurface structures using seismic reflection data for Kalar–Khanaqin area/Kurdistan region, Iraq, Arab J Geosci, 7, 2279–2291.
- Baker, C., Jackson, J., and Priestly, K., 1993, Earthquakes on the Kuzerun line in the Zagros Mountains of Iran: Strike-slip faulting within a fold and-thrust belt, Geophys. J. Int. 115, 41–61.
- Berberian, M., 1995, Master blind thrust faults hidden under the Zagros Folds: Active basement tectonics and surface morphotectonics, Tectonophysics, 241, pp. 193-224.
- Berberian, M., and King, G.C.P., 1981, Toward a Paleogeography and Tectonic Evolution of Iran. Canadian Journal of earth Science 18, 210.265.
- Berberian, M., Asudeh, I., Bilham, R., G., Scholz, C., H., and Soufleris C., 1979, Mechanism of the main shock and the aftershock study of the Tabas-e-Golshan (Iran) earthquake of September 16, 1978, a preliminary report, Bull. Seism. Soc. of America, 69, 6, 1851-1859
- Bird P., Toksoz, M., and Sleep, N., 1975, Thermal and mechanical models of continent-continent convergence zones, Journal of Geophysical Research, B, Solid Earth and Planets, 80, 4405–4416.
- Buday, T., 1980, The regional geology of Iraq, Stratigraphy and paleogeography, Dar AL-Kuttib Pub. House, University of Mosul, Iraq. 445p.
- Buday, T., and Jassim, S., Z., 1987, The Regional geology of Iraq: tectonic, magmatism and metamorphism. Vol. 2, S.E. Geol. Survey. Min. Invest., Baghdad, Iraq, 352p.
- Chen, W.P., Molnar, P.,1983, Focal Depths of Intracontinental and Intraplate Earthquakes and Their Implications for the Thermal and Mechanical Properties of the Lithosphere. J.Geophys.Res., 88, 4183-4214.
- De Mets, C., Gordon R., G., Argus D., F., and Stein, S., 1990, Current plate motion, Geophys. J. Int., 101, 425-478.
- De Mets, C., Gordon R., G., Argus D., F., and Stein, S., 1994, Effect of recent revisions to the geomagnetic reversal time scale on estimates of current plate motions, Geophys. Res. Lett., 21, 2191-2194.
- Gans, R., A., and Nelson, J., B., 1981, Catalog of significant earthquakes 2000 B.C. – 1979 Including Quantitative Casualties and Damage, Report SE-27, Published by World Data Center A for Solid Earth Geophysics, USA.
- Ghalib, H., A., A., *et al*, 2007, Seismic velocity modeling of north and northeast Iraq using receiver functions, 29th Monitoring Research Review: Ground-Based Nuclear Explosion Monitoring Technologies, Denver, Colorado, pp 54-61.
- Gritto, R., *et al*, 2008, Crustal structure of north Iraq

from receiver function analysis, 30th Monitoring Research Review of Ground-Based Nuclear Explosion Monitoring Technologies, Portsmouth, VA, pp 79-86.

- Gritto, R., Sibol, M., S., Caron, P., Ghalib, H., A., A., Herrmann R., B., Aleqabi, G., I., Ali, B., S., and Ali A., A., 2010, Crustal velocity models of Zagros-Bitlis zone from body and surface wave analysis, 32st Monitoring Research Review: Ground-Based Nuclear Explosion Monitoring Technologies, Orlando,FL., pp67-76.
- Hessami K., Jamali, F., and Tabassi, H., 2003, Major active faults of Iran, International Institute of Earthquake Engineering and Seismology, Tehran, Iran.
- Hull, A., Augello, A., and Erdik, M., 2004, Seismic Hazard Assessment for phase-I design, Hakkari Dam, Turkey, 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada, paper No. 1003.
- Jackson, J., A., 1980, Reactivation of basement faults and crustal shortening in orogenic belts, Nature 283, 343–346.
- Jackson, J., A., 2001, Living with earthquake: know your faults, J. Earthquake Eng., 5 (Special Issue 1), 5-123.
- Jackson, J., A., and McKenzi, D., P., 1984, Active tectonics of the Alpine-Himalayan belt between Western Turkey and Pakistan, Geophys. J. R. Astron. Soc. 77, 185–264.
- Jackson, J., Haines, J., and Holt, W., 1995, The accommodation of Arabia-Eurasia plate convergence in Iran, J. Geophys. Res. 100, 15205–15219.
- Kijko, A., and Funk, C. W., 1994, The assessment of seismic hazards in mines, J. South African Institute of Mining and Metallurgy, July, 179–185.
- Kijko, A., and Sellevoll, M. A., 1992, Estimation of earthquake hazard parameters from incomplete data files, Part II: Incorporation of magnitude heterogeneity, Bull. Seismol. Soc. Am. 82, 120–134.
- Maggi, A., and Priestley K., 2005, Surface waveform tomography of the Turkish–Iranian plateau, Geophys. J. Int.*160 (3), 1068-1080.*
- Maggi, J., A., Jackson, K., P., and Baker, C., 2000, A re-assessment of focal depth distributions in southern Iran, the Tien Shan and northern India: do earthquakes really occur in the continental mantle?,Geophys. J. Int., 143(3), 629-661.
- Mirzaei, N., and Gheitanchi, M. R., 2002. Seismotectonics of Sahneh Fault, middle segment of Main Recent fault, Zagros Mountains, western Iran, J. Earth & Space Physics 28 (2), 1–8.
- Mohajjel, M., & Fergusson, C., L., 2014, Jurassic to Cenozoic tectonics of the Zagros orogen in northwestern Iran. International Geology Review, 56 (3), 263-287.
- Molnar, P., and Chen, W. P., 1982. Seismicity and mountain building, in Hsued, K. J. (Ed.), Mountain Building Processes, Academic Press, London, pp. 41–57.
- Moores, E., M., and Twiss, R., J., 1995, *Tectonics*, New York: W. H. Freeman, ISBN 0 7167 2437 5.
- Nilforoushan, F., Masson, F., Vernant, P., Vigny, C.,Martinod, J., Abbassi, M.,Nankali, H.,Hatzfeld, D., Bayer, R.,Tavakoli, F.,Ashtiani, A., Doerflinger, E.,Daignières, M., Collard, P., andChéry, J., 2003, GPS network monitors the Arabia-Eurasia collision deformation in Iran, J. of Geodesy, 77 (7-8), 411–422.
- Nowroozi A., A., 1971, Seismotectonics of the Persian Plateau, Eastern Turkey, Caucasus, and Hindu-Kush Regions, Bulletin of the Seismological of America, 61, 317–341.
- Onur T., Tapridamaz, C., M. and Yoruk, A., 2008, The Earthquake Catalogues for Turkey, Turkish J. Earth Sci., 17, 405–418.
- Rahiman T., I., H., and Pettinga, J., R., 2009, Fracture lineaments, fault mesh formation and seismicity: toward a seismotectonic model for VitiLevu, Fiji, Bul. New Zealand Soc. forEarthquake Eng., 42, 1, 63-72.
- Reiter, L., 1990, Earthquake hazard analysis: New York, Columbia University Press, 254.
- Richter, C. F., 1958, Elementary Seismology, W. H. Freeman and Co., San Francisco, CA.
- Saroğlu F, Emre O, Kuscu I, 1992, Active Fault Map of Turkey. General Directorate of Mineral Research and Exploration Institute, Turkey.
- Sbeinati, M., R., Darawcheh, R. and Mouty, M., 2005, The historical earthquakes of Syria: an analysis of large and moderate earthquakes from 1365 B.C. to 1900 A.D., ANNALS OF GEOPHYSICS, VOL. 48, N. 3, pp 347-435.
- Scholz, C., H., 1988, The brittle–plastic transition and the depth of seismic faulting, Geol. Rundsch., 77 (1), 319–328.
- Shabani E., and Mirzaei, N., 2007, Probabilistic Seismic Hazard Assessment of the Kermanshah-Sanandaj Region of Western Iran, Earthquake Spectra, Volume 23, No. 1, pages 175–197.
- Sissakian, V., K., 2000. Geological map of Iraq. Sheets No.1, Scale 1:1000000, State establishment ofgeological survey and mining. GEOSURV, Baghdad, Iraq.
- Snyder, D., B., and Barazangi, M., 1986, Deep crustal structure and flexure of the Arabian plate beneath the Zagros collisional mountain belt as inferred from gravity observation, Tectonics 5, 361–373.
- Sorkhabi, R., 2010, Why So Much Oil in the Middle East?,Geoexpro Magazine, 7 Issue 1.
- Tchalenko, J. S., and Braud, J., 1974, Seismicity and structure of the Zagros _Iran_: The Main Recent Fault between 33° and 35° N., Philos. Trans. R. Soc. London, Ser. A 227, 1–25.
- Vernant, P., Nilforoushan, F., Chery, J., Bayer, R., Djamour, Y., Masson, F., Nankali, H., Ritz, J.-F., Sedighi, M., and Tavakoli, F., 2004b, Deciphering oblique shortening of central Alborz in Iran using geodetic data, Geophys. J. Int., 223 (1-2), 177-185.
- Vernant, P., Nilforoushan, F., Hatzfeld, D., Abbassi, M.R., Vigny, C., Masson, F., Nankali, H.,Martinod, J., Ashtiani, A., Bayser, R., Tavakoli, F.& Chery, J., 2004a, persent day curstal deformation and plate kinematics in the Middle East constrained by GPS measurements in Iran and nortern Oman, Geophys. J. Int., 157(1),381-398.

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