International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 6, 2025
https://theaspd.com/index.php

Comparison of Seismic Hazard Studies in Iraq in Predicting Future Earthquakes

Mustafa Shakir Farman[1], and Ali K. Jaber[2]
[1]Technical Engineering College of Petroleum and Energy in Al-Muthanna, Al-Furat Al-Awsat Technical University, Kufa, Iraq.
[2]Technical Engineering College of Petroleum and Energy in Al-Muthanna, Al-Furat Al-Awsat Technical University, Kufa, Iraq.
[a)] Corresponding author: mustafashfr2016@gmail.com
[b)] ali.jaber@atu.edu.iq

Abstract
Several seismic studies have been conducted on and around the Iraq region. These studies describe the intensity of the ground shaking that may occur in the future at a given location or region, which is very important for engineering purposes. This raises the need to compare them to determine which one is closest in terms of future earthquake predictions. The (7.3Mw) earthquake of Halabjah, was one of the recent and strongest earthquakes in the cities of Iraq, which occurred on 12 November 2017. Therefore, seismic studies were compared with this earthquake, especially since they were all conducted before the Halabjah earthquake occurred. The comparison was in terms of the Maximum Expected Future Earthquake Magnitude. The most important conclusion drawn from this comparison is that the 1989 Iraqi seismic code expectation is the closest in terms of earthquake magnitude, while AbdulMuttalib et al. (2018) expectation is the closest in time. Also, the 7.3Mw earthquake of Halabjah is less than all the values of the maximum expected future earthquake magnitudes from all studies, therefore; other stronger earthquakes are expected to occur in this region.
Keywords: *Halabjah, Earthquake, Maximum Expected Earthquake, Seismic, Hazard, Ground Shaking.*

1. INTRODUCTION

Engineers should know the potential hazards of future earthquake events. For this purpose, detailed investigations and studies for the definition of the seismic hazard level of a given site or region are necessary. Such studies can, in general, only be justified for large, important projects such as nuclear power plants, major dams, etc. However, even for the design of all other structures in seismic zones, data about seismic hazard levels are necessary, (Mihailov, V., 2003). Usually, these data are available from special seismic maps such as iso-acceleration maps. These seismic maps and graphs are practical tools in earthquake-resistant design because they provide useful guidance when it is not feasible to make thorough studies on the earthquake hazard at particular locations. In these maps and graphs, which are elaborated for engineering purposes, seismic hazard is usually presented in terms of the probability of exceedance for given ground motion parameters within a given period, (Mihailov, V., 2003).

With the uncertainties associated with the location, magnitude, duration, resulting shaking intensity for future earthquakes, and other characteristics of future earthquakes, it is not surprising that the principles of probabilistic forecasting or Probabilistic Seismic Hazard Analysis (PSHA) are used to identify these uncertainties and to provide an explicit and clear description of the distribution of ground shaking that may occur in the future at a given location or region, (Baker, J. W., 2008).

In Iraq, some research and PSHA studies have been conducted attempting to describe the distribution of ground shaking that may occur in the future at a given location in the region of Iraq and its surrounding borders.

However, the most rigorous, Comprehensive, and complete ones that reached the final results in terms of all seismic activity parameters and also in terms of contours are Limited in number and can be summarized in five studies. The first of them was conducted at the end of the eighties of the last century, another two of them were conducted at the beginning of the current century, and the other two are the most recent and the mostly completed ones, as they were conducted at the end of the second decade of the current century, (AbdulMuttalib et al. 2018).

1.1EXISTING LITERATURE

The first complete study was conducted at the end of the eighties of the last century, which was the investigation for the elaboration of the preliminary draft seismic design code of Iraq for the year 1989.

This preliminary draft preparation was completed and reported at the end of 1988. These investigations are based on the Iraqi earthquake data file for the geographic region bounded by latitudes (29- 38)N and longitudes (39- 49)E which cover more than 600 earthquakes for the period 1900 - 1986 and few of them are historical earthquakes that took place before 1900, (Mahmood, D. S., et al. 1988). The sizes, locations, and shapes of seismic sources were identified based on the geological, tectonics, and seismo-logical information. Two kinds of area sources were identified in the report. Eight area seismic sources were modeled in the form of rectangular while the other two were in the shape of circles. Figure 1 represents the spatial distribution of the seismic sources, and Table 1 represents the maximum expected magnitude of the future earthquakes for each seismic source zone, (Mahmood, D. S., et al. 1988).

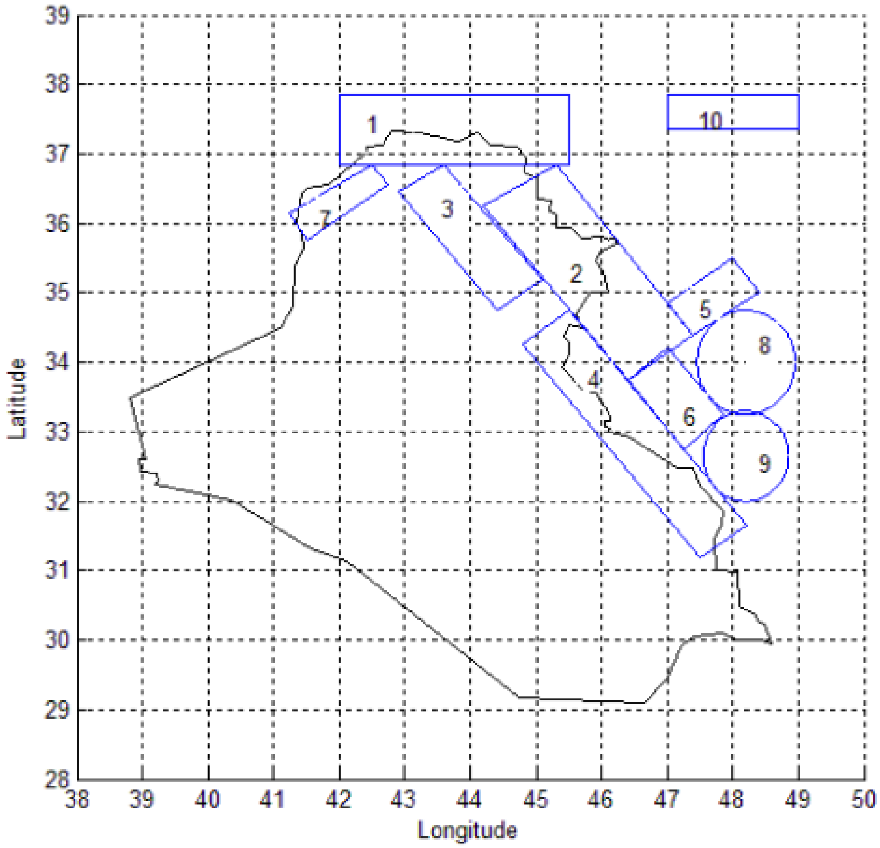

Figure 1: Seismic Sources Model of Iraq according to Iraqi Seismic Code of 1989, (Mahmood, D. S., et al. 1988)

Table 1: The Maximum Expected Magnitude of Future Earthquakes for each Seismic Source Zone according to the Iraqi Seismic Code of 1989, (Mahmood, D. S., et al. 1988)

Seismic Source Zone Number	[a]**Maximum Expected Earthquake Magnitude, M_{max}**
1	8.0
2	7.6
3	7.6
4	7.6
5	5.9
6	5.5
7	6.0
8	8.0
9	6.2
10	6.5

[a] Magnitude Scale is the surface wave magnitude Scale (Ms)

Research by Al-Sinawi et al. (2003) considers the seismic activity of the Iraqi geographic region outlined by latitudes (28.5- 38.5)N and longitudes (38- 49.5)E which cover the Iraqi Earthquakes data for the period from 1900 to 1988. Historical data for the period 1260 B.C. –1900 A.D. were included. Figure 2

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 6, 2025
https://theaspd.com/index.php

represents the spatial distribution of the seismic sources. Their study did not show the expected maximum magnitudes but rather presented the observed maximum magnitudes. Table 2 represents the maximum observed magnitude of each seismic source zone, (Al-Sinawi, S. A., et al. 2003).

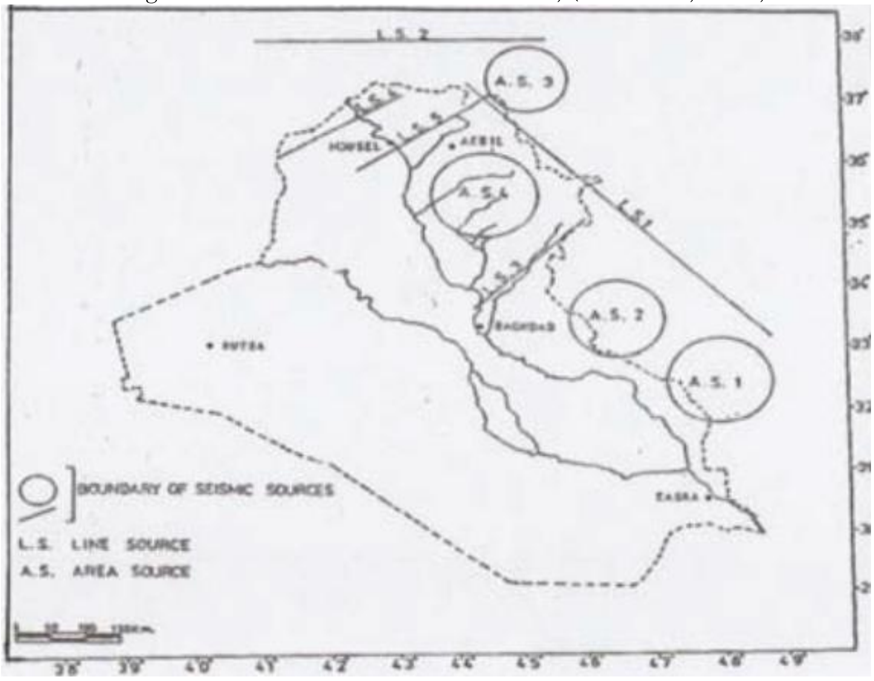

Figure 2: Seismic Sources Model of Iraq adopted by Al-Sinawi et al. (2003).

Table 2: The Maximum Observed Magnitude of each Seismic Source Zone according to Al-Sinawi et al. (2003).

Seismic Source Zone Number and Type	^{a}Maximum Observed Earthquake Magnitude, M_{max}
Line source#1	6.7
Line Source #2	7.2
Line Source #3	5.2
Line source #4	5.3
Line Source#5	6.1
Area Source#1	5.6
Area Source#2	5.6
Area Source#3	6.0
Area Source#4	5.5

[a] Magnitude Scale is the body wave magnitude Scale (Mb)

In these two studies, Poisson distribution was used to represent the probability of future earthquake occurrence. The de-clustering process was not applied to the earthquake data, which means, this data includes dependent events while Poisson distribution is used for independent events, (AbdulMuttalib et al. 2018).

Probabilistic seismic hazard analysis (PSHA) has been carried out by Ameer et al. (2005) and applied to the Iraqi geographic region defined between latitudes (29- 38.5)N and longitudes (39- 50)E. The study includes the Iraqi earthquake data for the time period from 1905 to 2000 and is based on thirteen area sources as presented in Figure 3. Table 3 represents the maximum expected magnitude of the future earthquakes for each seismic source zone, (Ameer, A. S., et al. 2005).

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 6, 2025
https://theaspd.com/index.php

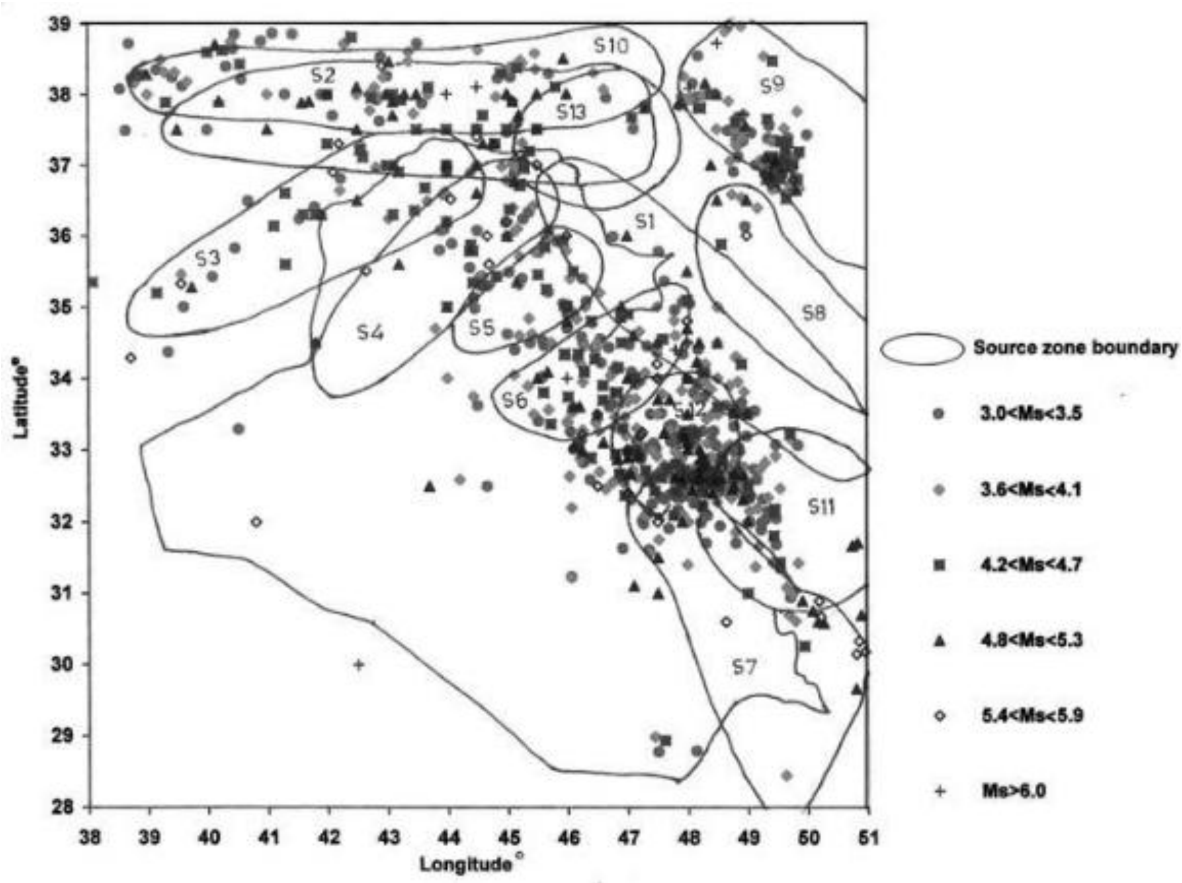

Figure 3: The Seismic Sources Model of Iraq was proposed by Ameer et al. (2005).

Table 3: The Maximum Expected Magnitude of Future Earthquakes for each Seismic Source Zone according to Ameer et al. (2005).

Seismic Source Zone Number	**[a]Maximum Expected Earthquake Magnitude, M_{max}**
1	7.68
2	7.53
3	6.53
4	5.85
5	6.45
6	6.62
7	6.52
8	7.92
9	6.80
10	7.51
11	5.66
12	6.99
13	6.53

[a] Magnitude Scale is the surface wave magnitude Scale (Ms)

The first of the two most recent probabilistic seismic hazard analyses (PSHA) has been carried out by W. Abdulnaby et al. (2020), [6]. They published a seismicity study on the Iraq region that was conducted and published as a report 3 years before their final publication in 2020, (Onur, T., et al. 2016). Their study applied to a larger Iraqi geographic region defined between latitudes (26- 40)N and longitudes (36- 51)E. Their study includes the Iraqi Earthquake data for about 4,000 seismic events of moment magnitude (Mw) 4.0 and larger for the time period from 1900 to 2009 and based on twelve area sources presented in Figure 4. They used the Poisson distribution to represent the probability of future earthquake occurrence. However, in their study, the de-clustering process is not applied to the earthquake data, which means, this data includes dependent events while Poisson distribution is used for independent events to a probability of earthquake occurrence. Table 4 represents the maximum expected magnitude of the future earthquakes for each seismic source zone, (Abdulnaby, W., et al. 2020).

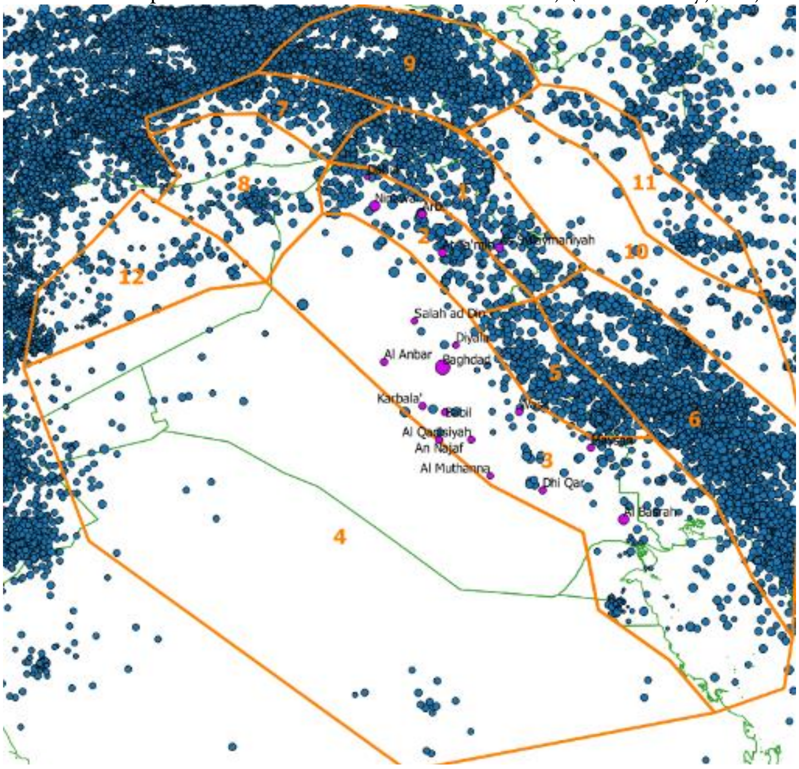

Figure 4: Seismic Sources Model of Iraq proposed by Abdulnaby et al. (2020).

Table 4: The Maximum Expected Magnitude of the Future Earthquakes for each Seismic Source Zone according to Abdulnaby et al. (2020).

Seismic Source Zone Number	**[a]Maximum Expected Earthquake Magnitude, M_{max}**
1	7.8
2	7.6
3	7.6
4	7.4
5	7.8
6	8.0
7	7.8
8	7.6
9	7.9
10	7.6
11	7.8
12	7.8

[a] Magnitude Scale is the moment magnitude Scale (Mw)

The most recent and complete study was made by AbdulMuttalib et al. (2018). They applied probabilistic seismic hazard analysis on the same Iraqi geographic region adopted by Abdulnaby et al. (2020). Before applying PSHA, they collected seismic data records from four sources and applied data processing steps to get the net Iraqi earthquake data of 6472 independent seismic events of Mw ≥ 4 for the time period from 1900 to 2016 including historical earthquakes that took place before 1900, [8]. Their study is based on the same twelve area sources adopted by Abdulnaby et al. (2020) which are presented in Figure 4. Table 5 represents the maximum expected magnitude of the future earthquakes for each seismic source zone, (AbdulMuttalib et al. 2018).

Table 5: The Maximum Expected Magnitude of the Future Earthquakes for each Seismic Source Zone according to AbdulMuttalib et al. (2018).

Seismic Source Zone Number	**[a]Maximum Expected Earthquake Magnitude, M_{max}**
1	7.15

2	7.72
3	7.35
4	7.35
5	7.05
6	7.42
7	7.17
8	5.97
9	7.79
10	7.42
11	7.20
12	5.75

[a] Magnitude Scale is the moment magnitude Scale (Mw)

1.2 Objective and Scope of this Work

The previously reviewed Seismic Hazard Studies in Iraq will be compared with the earthquakes that occurred after these studies to know which of them are near in Predicting Future Earthquakes. This comparison will be focused on the prediction of the magnitude and time of occurrence of future earthquakes.

1.3 Earthquake Chosen to Compared with Previous PSHA Studies

Comparison of the previously reviewed Seismic Hazard Studies in Iraq in Predicting Future Earthquakes will be with the earthquakes that occurred after these studies. The 12 November 2017 (7.3Mw) earthquake was one of the strongest and most influential earthquakes in the cities of Iraq. It occurred near Halabjah city on the Iranian side of the border, at the southern part of source No.2 of the sources model of Abdulnaby et al. (2020) which is presented in Figure 4, and as shown in detail in Figure 5. This earthquake with Magnitude 7.3Mw occurred after the previously reviewed studies and will be adopted in comparison. In this comparison, the Maximum Expected Future Earthquake Magnitude from each of the previously reviewed studies will be compared with the magnitude of the 7.3Mw earthquake of Halabjah.

2 COMPARISON OF PREVIOUS PSHA STUDIES IN IRAQ

The 12 November 2017 (7.3Mw) earthquake in Halabjah occurred at the location of coordinates 45.88°E and 34.79°N, which is near Halabjah city on the Iranian side of the border, at the southern part of source No.2 of the sources model of Abdulnaby et al. (2020) as shown in detail in Figure 5. The magnitude of the 7.3Mw earthquake of Halabjah will be compared with The Maximum Expected Future Earthquake Magnitude of the seismic source zone where the earthquake of Halabjah occurred from each of the previously reviewed studies. As shown in Figure 1, the earthquake of Halabjah is located inside source No.2 in the Seismic sources model of Iraq according to the Iraqi seismic code of 1989, (Mahmood, D. S., et al. 1988). Also as shown in Figure 2, its location is nearest to line source #3 in the Seismic sources model of Iraq adopted by Al-Sinawi et al. (2003). As shown in Figure 3, it is located within seismic source zone 1 or 6 of the thirteen area sources adopted by Ameer et al. (2005), [5]. Maximum Expected Future Earthquake Magnitude in these seismic sources from each of the previously reviewed studies are summarized in Table 6.

Table 6: The Maximum Expected Future Earthquake Magnitude of the Seismic Source Zone where the Earthquake of Halabjah is occurred from each of the previously reviewed studies.

Ref. No.	**Investigator**	**Seismic Source Zone Number**	**Maximum Expected Earthquake Magnitude, M_{max}**	**Magnitude Scale**
3	Iraqi Seismic Code of 1989	2	7.60	Ms
4	Al-Sinawi et al. (2003)	line source #3	7.60[a]	Mb
5	Ameer et al. (2005)	1 or, 6	7.68 or, 6.62	Ms
6	Abdulnaby et al. (2020)	2	7.6	Mw
8	AbdulMuttalib et al. (2018)	2	7.72	Mw

[a] the observed maximum magnitude

It can be noticed in Table 6 that the Maximum Expected Future Earthquake Magnitudes from previous studies are in different magnitude scales therefore it is need to Homogenize them in one scale before making their comparison. Several researchers have defined the converting relations between Mw and other magnitude types, this to homogenize the data magnitudes. Scordilis (2006) derived global relations depending on a data collected from around the world, (Scordilis, E. M., 2006). Yazdi and Zare (2012) derived the converting relations between Mw and other magnitude types during building an earthquake catalog for the middle east including Iraqi data. The Yazdi and Zare (2012) converting relations will be used to homogenize the Maximum Expected Future Earthquake Magnitudes with the Mw scale. Which are, (Yazdi, P., and Zare, M., 2012):

$$Mw = 0.663Ms + 2.118 \qquad \text{for} \quad 2.8 \quad Ms \quad 6.1 \qquad (1)$$

$$Mw = 0.931Ms + 0.449 \qquad \text{for} \quad 6.1 \quad Ms \quad 8.2 \qquad (2)$$

$$Mw = 0.874Mb + 0.828 \qquad \text{for} \quad 3.5 \quad Mb \quad 6.0 \qquad (3)$$

Therefore, Table 6 will be reformulated with the Mw scale only in Table 7. The value from Al-Sinawi et al. (2003) will be removed because it represents the observed maximum magnitude rather than the expected maximum magnitude.

Table 7: The Maximum Expected Future Earthquake Magnitude of the Seismic Source Zone where the Earthquake of Halabjah is occurred from the previous studies, homogenized with Mw.

Ref. No.	Investigator	Seismic Source Zone Number	Maximum Expected Earthquake Magnitude, M_{max}
3	Iraqi Seismic Code of 1989	2	7.52
5	Ameer et al. (2005)	1 or, 6	7.60 or, 6.61
6	Abdulnaby et al. (2020)	2	7.6
8	AbdulMuttalib et al. (2018)	2	7.72

There are many methods used for estimating the maximum expected future earthquake magnitude M_{max} in a region or source, most of them depending on the maximum observed magnitude value, or on the geometry of active faults if available. But, recent exact methods usually depend on the number of earthquakes, as well as on the largest observed earthquakes, such as the Kijko and Singh (2011) method, (Kijko, A., and Singh, M., 2011). The largest observed earthquakes occurred in the distant past, and thus it remains only the number of earthquakes affects the maximum expected future earthquake magnitude M_{max} value which is increased with the increased number of processed earthquake data. Therefore, Table 7 will be reformulated in Table 8 to include the number of earthquakes and the time period of the seismic data for the previous studies. Accordingly, it can be noticed from Table 8 that in general the maximum expected future earthquake magnitude M_{max} value increased from 7.52Mw to 7.72Mw as the number of earthquakes increased from 600 to 6472.

From Figure 3 of the study by Ameer et al. (2005), the seismic source boundaries are overlapping, thus the data of the overlapping regions is used for both overlapping sources, and this will give overestimated results for one of the overlapping sources. Accordingly, the results of the study of Ameer et al. (2005) shown in Table 7 may have an overestimation and therefore will not be taken into account. Therefore, Table 8 is reformulated without the study of Ameer et al. (2005).

Table 8: The Maximum Expected Future Earthquake Magnitude of the Seismic Source Zone where the Eearthquake of Halabjah is occurred from the previous studies, homogenized with Mw.

Investigator	Seismic Source Zone Number	Maximum Expected Earthquake Magnitude, M_{max}	Number of earthquakes	Time period of recorded data
Iraqi Seismic Code of 1989	2	7.52	600	1900 to 1986
Abdulnaby et al. (2020)	2	7.6	4000	1900 to 2009
AbdulMuttalib et al. (2018)	2	7.72	6472	1900 to 2016

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 6, 2025
https://theaspd.com/index.php

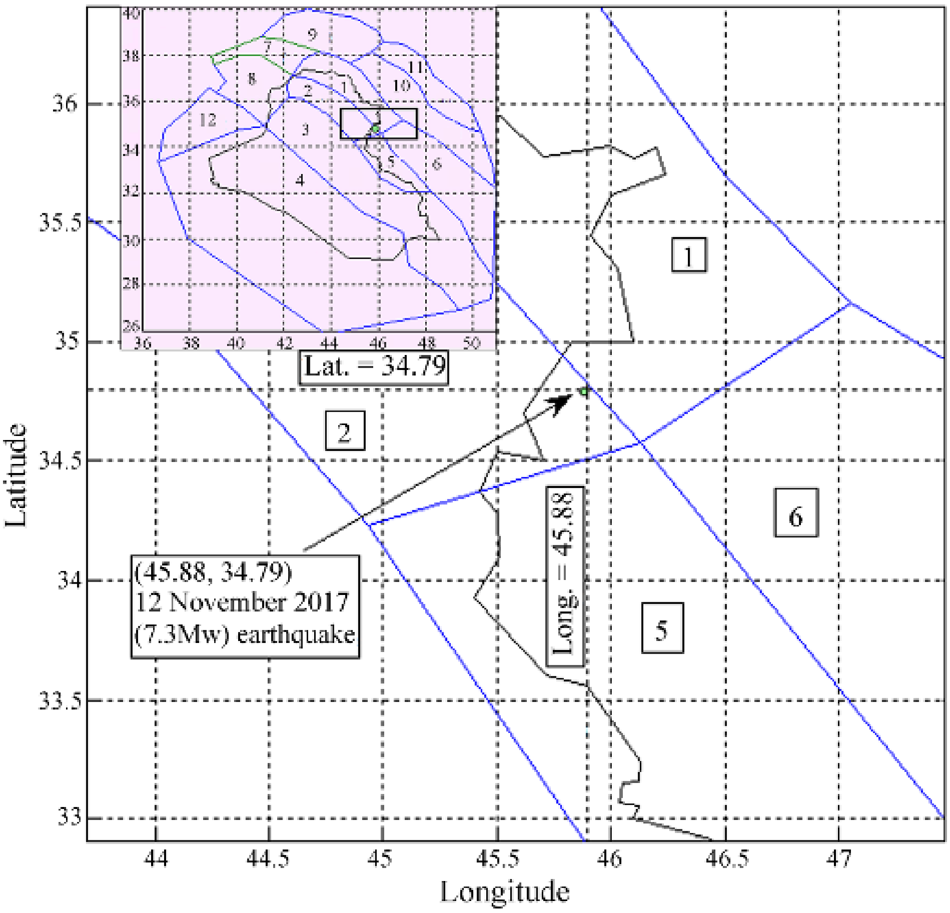

Figure 5: Coordinate the Location of the Earthquake of the 12 November 2017 (Halabjah).

It can be noticed that the 12 November 2017 (7.3Mw) earthquake of Halabjah is well within the maximum expected future earthquake magnitudes of seismic source zones of all the previously reviewed studies.

In the beginning, the comparison and determining the closest study in predicting future earthquakes depends not only on how close it is to the value of the earthquake that occurred after it but also on the time distance from the time of prediction until the occurrence of the future earthquake. The end of the time period of the recorded data can be considered as the predicting time.

It can be noticed from Table 8 that the Maximum Expected Future Earthquake Magnitude from the 1989 Iraqi seismic code is closer to the magnitude of the 7.3Mw earthquake of Halabjah. Despite this, AbdulMuttalib et al. (2018) had expected, a few months before the Halabja earthquake that a high-level earthquake would occur. The expectations of the 1989 Iraqi seismic code and that of Abdulnaby et al. (2020) were 31 years and 8 years before the Halabja earthquake occurred, respectively. Therefore, the expectation of the 1989 Iraqi seismic code is closer in terms of earthquake magnitude, while AbdulMuttalib et al. (2018) expectation is closer in time.

It also does not mean that the expected maximum future earthquake Mmax from the 1989 Iraqi seismic code, which is closer in value to the 7.3Mw earthquake of Halabjah, is the most accurate. Rather, Mmax is the value expected in the future as the maximum value in this region which is not only a measure of the severity of a future earthquake, but also a measure of its imminence. So the highest value beyond the 7.3Mw of the earthquake of Halabjah will raise expectations even more for a severe earthquake to occur soon in the region. That is why the earthquake of Halabjah occurred a few months later the expectation of AbdulMuttalib et al. (2018) and occurred 31 years after the expectation of the 1989 Iraqi seismic code.

In summary, The 1989 Iraqi seismic code expectation is closer in terms of earthquake magnitude, while AbdulMuttalib et al. (2018) expectation is closer in time. And because it is normally the maximum expected future earthquake magnitude M_{max} value increases with the increased number of processed earthquake data, it remains only the expectation of AbdulMuttalib et al. (2018) is the closest in time.

Also, it can be noticed from Table 8 that the 7.3Mw earthquake of Halabjah is less than all the values of the maximum expected future magnitudes. Accordingly, other stronger earthquakes are expected to occur in this region.

3 CONCLUSIONS

- The maximum expected future earthquake magnitude M_{max} value increased from 7.52Mw to 7.72Mw as the number of earthquakes increased from 600 in 1986 to 6472 in 2017.
- As the values of the maximum expected future earthquake magnitude increase, the severity of future earthquakes will be increased and the occurrence of a severe earthquake will be imminent.
- The 1989 Iraqi seismic code expectation is the closest in terms of earthquake magnitude, while AbdulMuttalib et al. (2018) expectation is the closest in time. And because it is normally the maximum expected future earthquake magnitude M_{max} value increases with the increased number of processed earthquake data, it remains only the expectation of AbdulMuttalib et al. (2018) is the closest in time.
- Also, it can be noticed from Table 8 that the 7.3Mw earthquake of Halabjah is less than all the values of the maximum expected future magnitudes. Accordingly, other stronger earthquakes are expected to occur in this region.

4 RECOMMENDATIONS

- There is an urgent need to collect and process seismic data for the period from 2016 until now and to add it to the previously processed data up to 2016. That is, for the previous nine years in which significant seismic activity occurred and it has not been taken into consideration until now.
- In addition, integrates statistical modeling and AI-based driven techniques, such as machine learning (ML) for pattern recognition and deep learning (DL) for seismic signal analysis, to improve the accuracy of earthquake prediction and hazard assessment.

REFERENCES

1. Mihailov, V., 2003, Engineering Seismology, Institute of Earthquake Engineering and Engineering Seismology, Ss. Cyril and Methodius University, Skopje, Macedonia.
2. Baker, J. W., 2008, An Introduction to Probabilistic Seismic Hazard Analysis (PSHA), Version 1.3, http://web.stanford.edu/~bakerjw/Publications/Baker_(2008)_Intro_to_PSHA_v1_3.pdf
3. AbdulMuttalib Isa Said and Mustafa Shakir Farman, 20018, "Re-evaluations of seismic hazard of Iraq, " Arabian Journal of Geosciences, 11(11), pp. 1-19, doi: 10.1007/s12517-018-3558-7
4. Mahmood, D. S., Khalifa, S., Jordanovski, L., and Dojcinovski, D., 1988, Seismic hazard evaluation and seismic zoning maps of Iraq, Investigations for elaboration of preliminary seismic design code of Iraq, Building Research Center, Baghdad, Iraq.
5. Al-Sinawi, S. A., and Al-Qasrani, Z. O., 2003, "Earthquake Hazards Considerations for Iraq, " Proc. 4rth Int. Conference of Earthquake Engineering and Seismology, Tehran, Iran,
http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.494.1736&rep=rep1&type=pdf
6. 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, " Journal of Pure and Applied Geophysics, Vol. 162, pp. 951-966, doi.org/10.1007/s00024-004-2650-y
7. Abdulnaby, W., Onur, T., Gök, R., Shakir, A. M., Mahdi, H., Al-Shukri, H., Numan, N. M. S., Abd, N. A., Chlaib, H. K., Ameen, T. H., and Ramthan, A., 2020, " Probabilistic seismic hazard assessment for Iraq, " J Seismol, Vol. 24, pp. 595-61, https://doi.org/10.1007/s10950-020-09919-2
8. Onur, T., Gök, R., Abdulnaby, W., Shakir, A. M., Mahdi, H., Numan, N. M. S., Al-Shukri, H., Chlaib, H. K., Ameen, T. H., and Abd, N. A., 2016, "Probabilistic Seismic Hazard Assessment for Iraq, " LLNL-691152, https://www.researchgate.net/publication/309312787 ,
doi.org/10.2172/1305883
9. Scordilis, E. M., 2006, "Empirical global relations converting Ms and Mb to moment magnitude, " Journal of Seismology, Vol. 10, pp. 225–236, doi.org/10.1007/s10950-006-9012-4
10. Yazdi, P., and Zare, M., 2012, "Building an Earthquake Catalog for The Middle East, " 15WCEE, LISB, http://www.iitk.ac.in/nicee/wcee/article/WCEE2012_5675.pdf
11. Kijko, A., and Singh, M., 2011, "Statistical Tools for Maximum Possible Earthquake Magnitude Estimation, " Acta Geophysica, Vol. 59, No. 4, pp. 674-700, doi.org/10.2478/s11600-011-0012-6