Open Journal of Earthquake Research, 2025, 14(2), 35-48
https://www.scirp.org/journal/ojer
ISSN Online: 2169-9631
ISSN Print: 2169-9623

Novel Approach to Earthquake Hazard Assessment Territory Republic of Moldova

Evgheni Isicico, Victoria Ghinsari, Vasile Alcaz

Institute of Geology and Geophysics, State University, Chisinau, Republic of Moldova
Email: alcazv@gmail.com

How to cite this paper: Isicico, E., Ghinsari, V. and Alcaz, V. (2025) Novel Approach to Earthquake Hazard Assessment Territory Republic of Moldova. *Open Journal of Earthquake Research*, **14**, 35-48.
https://doi.org/10.4236/ojer.2025.142004

Received: January 10, 2025
Accepted: March 24, 2025
Published: March 27, 2025

Abstract

The paper deals with the assessment of the seismic hazard of Moldova Republic based on the Eurocode 8 requirements for setting the probabilistic level of seismic effects. Unlike traditional methodologies, this study integrates deterministic elements into the probabilistic framework to enhance the accuracy of hazard estimation. A detailed geometric analysis of the Vrancea focal zone—the primary source of seismic hazard for Moldova—was conducted, and two mathematical models for earthquake intensity were developed. Finally, new seismic hazard maps for the territory of Moldova were created in terms of both of MSK—intensity and acceleration. Compared to previous maps, the new version offers higher reliability and can serve as a foundation for updating the Seismic Regulatory Codes of the Republic of Moldova.

Keywords

Seismic Hazard, Catalog, Recurrence, Vrancea Focal Zone

1. Introduction

The primary seismic hazard for the Republic of Moldova originates from the subcrustal seismicity of the Vrancea zone, which is compactly situated at the bend of the Eastern Carpathian arc. A seismic zoning map typically represents the seismic hazard of a specific region. Before 1991, when Moldova was part of the former Soviet Union, its seismic zoning was conducted using the USSR's all-union probabilistic methodology and OSR-78 zoning maps [1]. The current seismic zoning map of the Republic of Moldova is shown in **Figure 1**.

The seismic hazard assessment of the OSR-78 map was significantly underestimated. This was confirmed by a series of earthquakes in the former USSR—Spitak (07.12.1988), Racha (29.04.1991), and Sakhalin (07.12.1988)—where observed impacts exceeded expected levels by 2 - 3 MSK intensity points [2]. Similar discrepancies

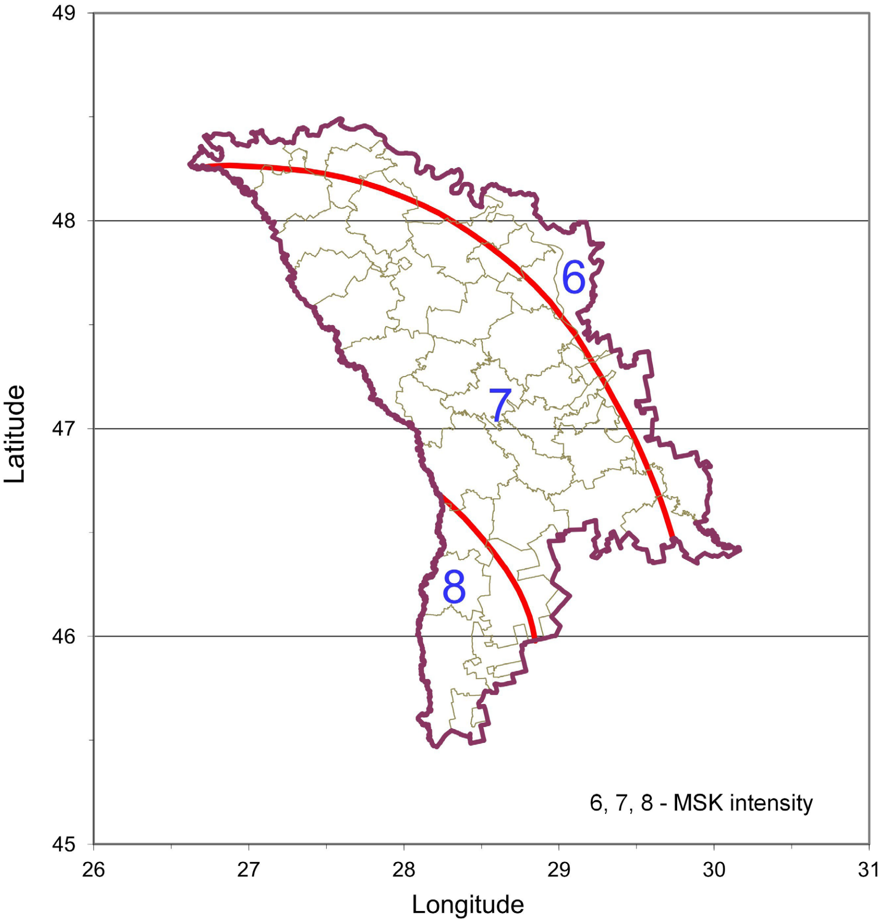

Figure 1. Normative seismic zoning map Republic of Moldova.

observed and predicted intensity values were also noted in earthquakes from other regions, including Kobe (17.01.1995), Bhuj (26.01.2001), Boumerdes (21.05.2003), and Bam (26.12.2003) [3]. In all these cases, seismic hazard assessments were based on the traditional Probabilistic Seismic Hazard Analysis (PSHA). Klügel [4] analyzed the major uncertainties and sources of errors in PSHA, highlighting that, since the method relies on statistical approaches, one of the primary sources of error is the limited historical seismicity data.

As the limitations of the probabilistic PSHA method in providing reliable seismic hazard assessments became evident, alternative approaches began to emerge, particularly deterministic seismic hazard assessment (DSHA). The basic methodology was laid by Klügel *et al.*, [5] and later significantly developed [6] [7]. An improved version of DSHA is neo-deterministic procedure, in which empirical attenuation laws were replaced by numerical modeling (theoretical seismograms) [8]. Last decades several deterministic and probabilistic seismic hazard assessments have been performed in the region [9]-[13].

Unlike PSHA, which primarily relies on the probabilistic analysis of earthquake catalogs and ground motion, DSHA—a scenario-based methodology—is strictly grounded in observable facts and data. At the same time, scenario-based seismic hazard analysis provides essential input data for the probabilistic assessment of seismic hazard (PSHA). This approach can serve as a foundation for developing an integrated procedure that combines the strengths of both probabilistic and deterministic methods while minimizing their limitations [14]. In this study, the authors aimed to implement such approach.

2. Data and Research Methodology

The ROMPLUS Earthquake Catalogue [15], which is continuously updated, is the most comprehensive resource for representing seismicity in the Carpathian region. The catalogue provides earthquake magnitude values derived from both historical (pre-instrumental) records and instrumental measurements, standardized as moment magnitude (M_w), which is defined as a function of seismic moment [16].

For seismic hazard assessment of the Vrancea source, magnitude recurrence is a key factor. The earthquake recurrence law, established by Gutenberg and Richter [17], assumes that earthquakes occur randomly, with their frequency decreasing exponentially as magnitude increases. This relationship is expressed as:

$$\log n(M) = a - bM$$

were $n(M)$ is the number of earthquakes per year with a magnitude equal to or greater than M, and a and b are constants.

To analyze the recurrence of subcrustal earthquakes in the Vrancea region—the primary source of seismic hazard for Moldova—a dataset of 85 strong earthquakes ($M_w \geq 6.0$) occurring between 1501 and 2018 was selected from [15]. These events represent the main shocks, with foreshocks and aftershocks excluded. Using the linear regression method, the following expression was derived to estimate the average annual occurrence of Vrancea earthquakes with a magnitude equal to or greater than M_w:

$$\log n\left(M_w \geq 6.0\right) = 3.64 - 0.72 \cdot M_w \tag{1}$$

If the source magnitude is limited by an upper bound magnitude $M_{\max}$, the recurrence relationship can be modified in order to satisfy the property of a probability distribution [18]:

$$\mathrm{n}\left(\geq m\right) = e^{\alpha - \beta m} \frac{1 - e^{-\beta\left(M_{\max} - m\right)}}{1 - e^{-\beta\left(M_{\max} - M_{\min}\right)}} \tag{2}$$

This equation includes the threshold magnitude $M_{\min}$ in a data set and the maximum credible magnitude $M_{\max}$ for the corresponding seismic zone. The values of α and β are determined according to the formulas:

$$\alpha = a \times ln10\,, \quad \beta = b \times ln10$$

In our study $\alpha = 8.37$, $\beta = -1.66$, the threshold lower magnitude $M_{min} = 6.0$. For a long time, researchers believed that the maximum possible magnitude of the Vrancea focal zone did not exceed 7.5 [19]. However, starting in the 1990s, this value began to be revised. According to the ROMPLUS catalog [15], the strongest earthquake in the Vrancea zone occurred in 1802, with a magnitude of $M_{\max} = 7.9$. Various authors [20]-[22] estimate this value to be no greater than 8.1. This value was used in the recurrence relationship (2). **Figure 2** compares the recurrence magnitude relationships for the Gutenberg-Richter (1) and Hwang (2) formulas for subcrustal earthquakes in the Vrancea zone.

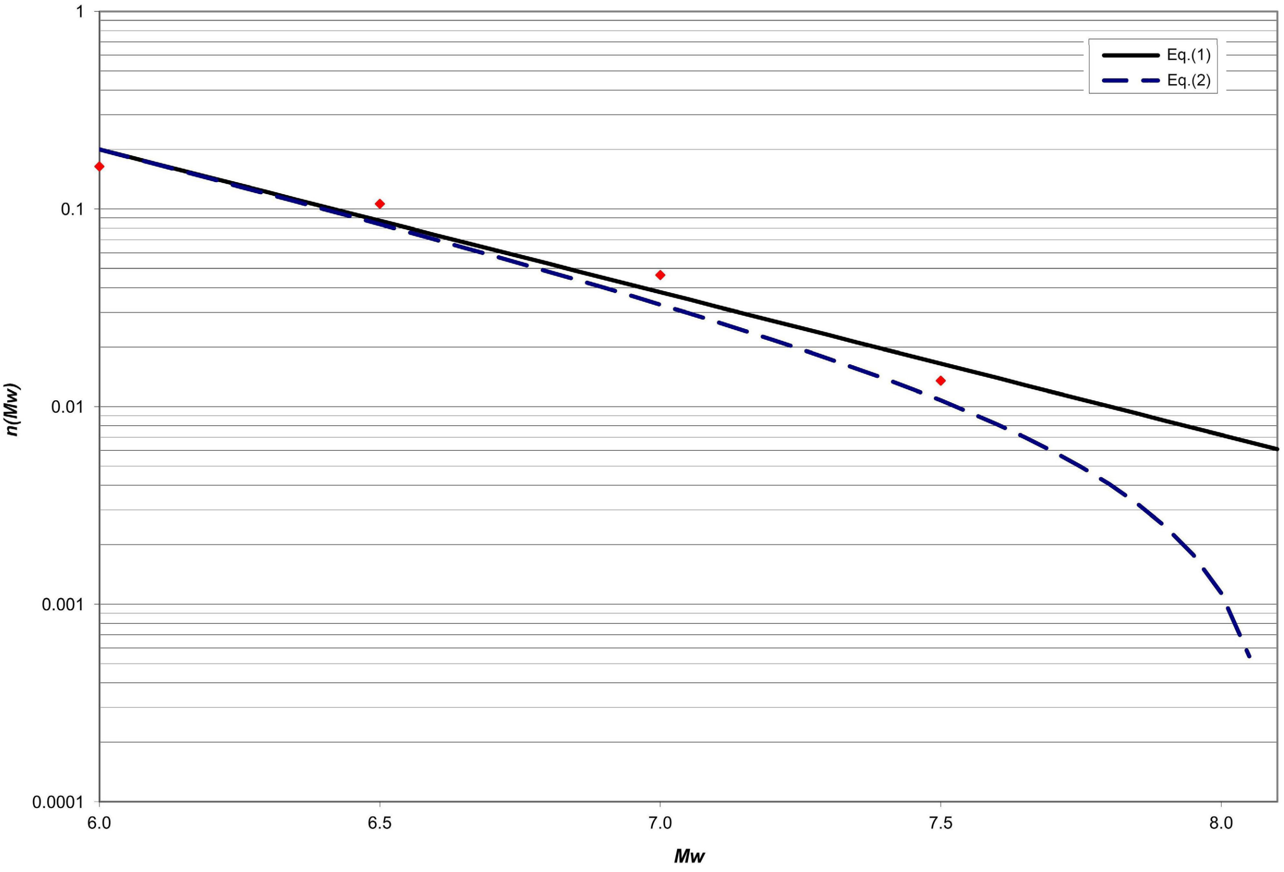

Figure 2. Comparison of magnitudes recurrence relations for the Vrancea earthquakes over the period 1501-2018 according to Gutenberg-Richter and Huang and Huo equations.

The reciprocal of the average annual number of earthquakes represents the average recurrence period T (in years) for an earthquake with a magnitude equal to or greater than M_w. **Table 1** shows the frequency of events with specific magnitudes and their corresponding recurrence periods.

The first step in seismic hazard studies for any territory is selecting the format for predicted values. The seismic hazard assessment in this study is based on the requirements of Eurocode 8 [23]. This choice is primarily driven by the high reliability of the predicted assessments, ensuring no more than a 10% probability of exceedance over 50 years. Additionally, the Republic of Moldova is currently a candidate for European Union membership, making the focus on the Eurocode 8 standard particularly relevant and justified.

According with EUROCOD-8, the average return period $T = 475$ years ensures that the probability of exceeding the design impacts does not exceed 10% over 50 years. **Table 1** shows that a magnitude of $M_w = 7.9$ corresponds to a return period of 404 years, which is closest to 475 years, and ensures no more than a 12% probability of exceeding the design impacts. This level of probabilistic reliability can be considered quite acceptable for the purposes of mass construction in the Republic of Moldova and the earthquake with magnitude $M_w = 7.9$ as design earthquake in the present study. Note that this value corresponds to the largest observed magnitude of the Vrancea source [15].

Table 1. Frequency and recurrence periods of Vrancea earthquakes.

M_w	Frequency n		Recurence period T (yr)	
	Equation (1)	Equation(2)	Equation (1)	Equation (2)
6.0	0.2002	0.2002	4.996	4.996
6.5	0.0871	0.0836	11.48	11.96
7.0	0.0379	0.0328	26.38	30.46
7.5	0.0165	0.0107	60.61	93.06
7.6	0.014	0.0081	71.58	122.9
7.7	0.0118	0.0059	84.54	168.7
7.8	0.01	0.0041	99.84	246.4
7.9	**0.0085**	**0.0025**	**117.9**	**403.9**
8.0	0.0072	0.0011	139.3	880.9
8.1	0.0061	7E−17	164.5	1E+16

Over its centuries of activity, the Vrancea seismic zone has displayed several patterns, the most notable of which are the elliptical shape of the intensity isolines (with the major axis oriented southwest-northeast) and the alternating direction of primary seismic energy radiation along the major axis of the ellipse [22] [24]. This characteristic is likely influenced by the direction of rupture propagation within the focal zone. The least favorable scenario for the Republic of Moldova occurs when the seismic energy is directed northeastward.

Below, the geometry of the Vrancea seismic zone is examined in more detail.

The locations of the epicenters of Vrancea earthquakes during the instrumental period are shown in **Figure 3** (372 events with $M_w \geq 4$ from 1968 to 2018). These epicenters align closely with a linear function having an azimuth of 53 degrees. The root-mean-square deviation of the hypocenters from a vertical plane along this azimuth is only 7 km. Vertically, the earthquake foci are distributed within a depth range of 75 to 170 km, with an uneven distribution—most events are concentrated at depths greater than 120 km.

It is well known that the energy released by an earthquake is closely related to the rupture magnitude at its source, and the rupture length can extend up to several hundred kilometers for earthquakes with magnitudes greater than 7 [25]. Given the spatial geometry of the subcrustal focal region, it can be conventionally divided into two zones where ruptures predominantly occur in specific directions: one in which ruptures propagate upward toward the northeast, and another in which they propagate downward toward the southwest.

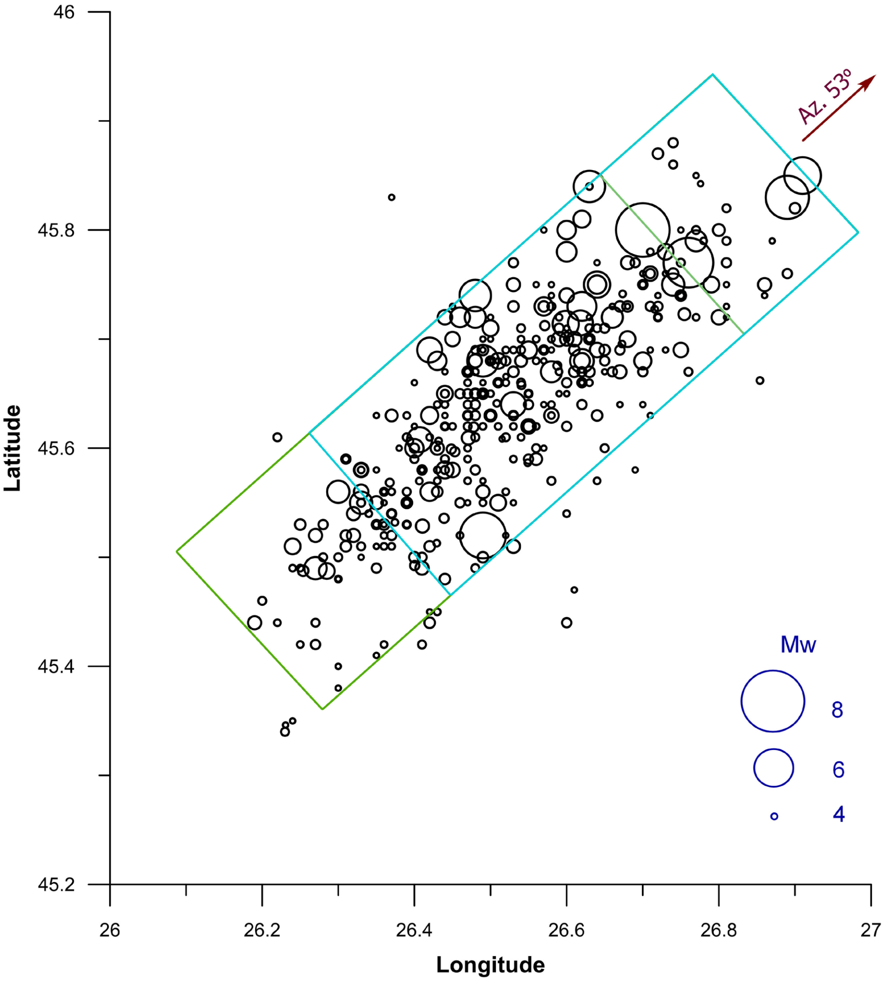

Figure 3. Epicenters of Vrancea earthquakes with $M_w \geq 4$ for the period 1968-2018 (plain view).

Figure 3 and **Figure 4** show these delineated zones, along with the plan and vertical projections of the earthquake foci. The strongest seismic event of the 20th century—the November 10, 1940 earthquake—is also included. Major earthquakes with $M_w \geq 6$, for which macroseismic data are available, are marked on the vertical projection. A list of these events is provided in **Table 2**.

The accuracy of historical data of the Vrancea earthquake was studied in [24]. It is shown that the error in determining the coordinates of the epicenters reaches ±0.5˚, in determining the depth is ±20 km.

An analysis of **Figure 4** suggests that the location of the 1940 earthquake, determined during the pre-instrumental period, likely contains some errors. Recent studies [26] indicate that the hypocenter of this event should be located at least 15 - 20 km to the southwest.

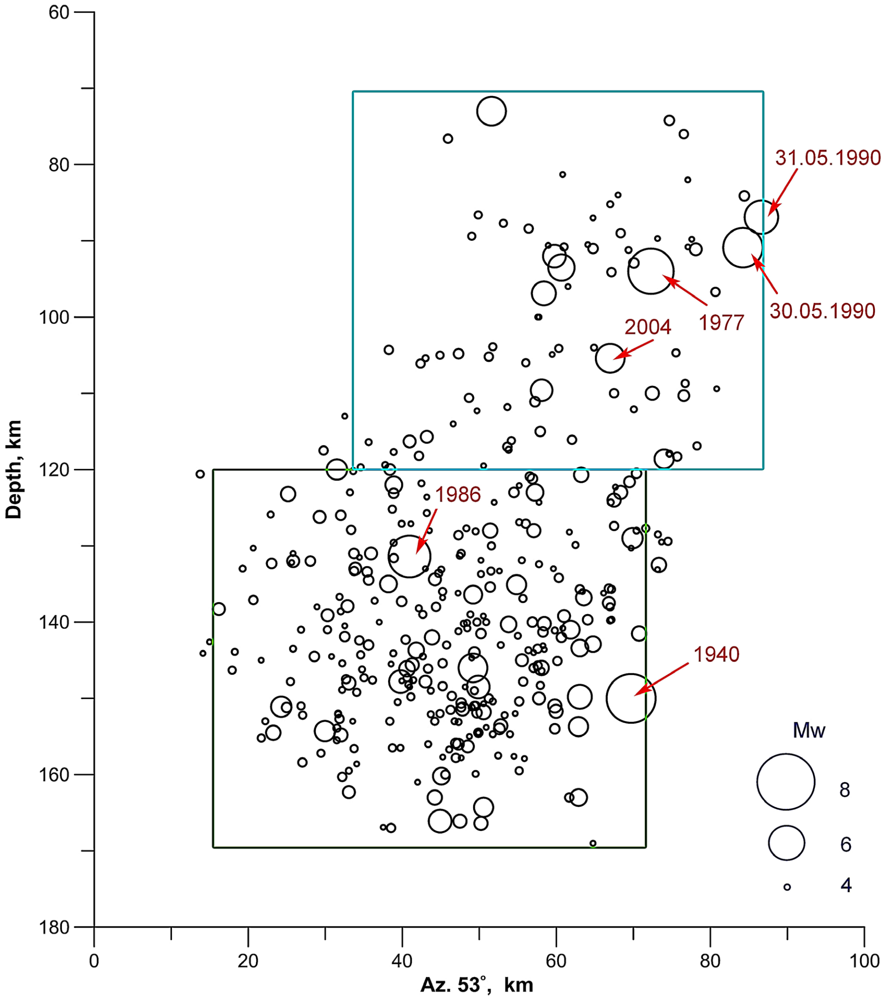

Figure 4. Epicenters of Vrancea earthquakes with $M_w \geq 4$ for the period 1968-2018 (vertical projection).

Table 2. Earthquakes with $M_w \geq 6$, from 1940 to 2018, for which macroseismic intensity data are available

Data	Time	Latitude	Longitude	*H, km*	M_w
10.11.1940	01:39:07.00	45.8	26.7	150	7.7
4.03.1977	19:21:54.10	45.77	26.76	94	7.4
30.08.1986	21:28:37.00	45.52	26.49	131	7.1
30.05.1990	10:40:06.40	45.83	26.89	90.9	6.9
31.05.1990	00:17:47.90	45.85	26.91	86.9	6.4
27.10.2004	20:34:36.00	45.84	26.63	105	6.0

Thus, among the strongest Vrancea earthquakes with available macroseismic data, the lower zone of the epicentral area—characterized by a northeastern rupture direction—is represented by two events (1940 and 1986), while the upper zone—with a southwestern rupture direction—is represented by four events

(1977, two events in 1990, and 2004).

For both seismogenic zones, mathematical models of the macroseismic field were developed. The initial data for these models were derived from archival records of observed earthquake intensities in several settlements across Moldova, Romania, and Ukraine, located within an azimuthal range of 0˚-110˚ relative to the earthquake epicenter. The analysis included macroseismic data with an intensity of at least five MSK points, comprising 278 observation points for earthquakes in the lower zone and 1073 for those in the upper zone.

The macroseismic field equations—functions of earthquake magnitude, hypocentral distance, and the shape of the isoseismal ellipsoid—were derived using the "Multiple Regression" program [27]. The first two parameters are traditionally used to describe any macroseismic field, while the third parameter accounts for the specific characteristics of Vrancea earthquakes, which display a pronounced isoseismal ellipsoid shape. This parameter defines the location of the observation point relative to the average position of the ellipse's axes.

The azimuth of the ellipse's major axis was determined from V. Shumila's data [28], which analyzed the intensity fields of 17 Vrancea earthquakes and yielded a value of $\Theta_o = 54^\circ \pm 2^\circ$. The equations for the intensity field are as follows:

$$I = 1.084M_w - 6.85\lg R + 1.54\cos\gamma + 13.7 \pm 0.35 \text{ —for the lower zone,} \quad (3)$$

$$I = 0.922M_w - 3.44\lg R + 0.24\cos\gamma + 7.27 \pm 0.34 \text{ —for the upper zone,} \quad (4)$$

where:

- M_w—magnitude based on seismic moment;
- R—hypocentral distance;
- γ—the angle between the azimuth of the observation point and the azimuth of the major axis of the ellipse.

The correlation coefficients for both cases are similar, with values of 0.9, and the variances are comparable, both equal to 0.12. By positioning the hypocenter at the closest possible distance from the territory of Moldova within each zone, the intensity field can be modeled.

3. Research Results

Based on Equations (3) and (4), the intensity distribution for a selected probability level of design impacts can be calculated. **Figure 5** displays the isoseismal intensity fields for each of the two zones considered. The hypocenter coordinates used are as follows:

- Lower zone: $\varphi = 45.8$, $\lambda = 26.7$, $h = 120$ km
- Upper zone: $\varphi = 45.85$, $\lambda = 26.9$, $h = 75$ km

To avoid possible severe underestimation of hazard, due to the influence of uncertainties in input parameters, the seismic hazard calculation was carried out for the least favorable case when the distance from the focus of the design earthquake to the border of Moldova is minimal.

A comparative analysis of the intensity distributions in the two zones, along with the coefficients from Equations (3) and (4), leads to the following conclusions:

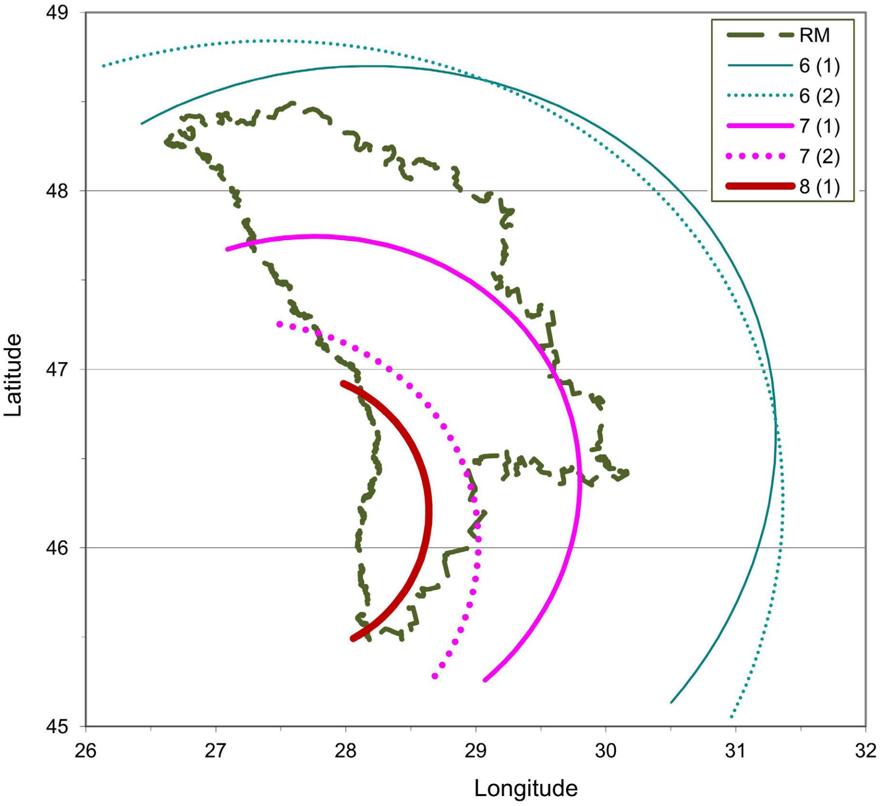

Figure 5. Isoseismal intensity distribution for the design earthquake (M_w = 7.9) for the lower (1) and upper (2) zones of the Vrancea seismic source.

- The seismic impacts from the lower zone are more intense within the territory of Moldova, as expected, since the rupture's strike is directed toward the northeast.
- The intensity field of earthquakes from the lower zone attenuates more rapidly.
- The alignment of the azimuth of the linear function approximating the earthquake epicenters with the average azimuth of the major axis of the ellipse in the observed intensity fields indicates the dominant influence of the Vrancea focal zone's configuration on the orientation of the ellipse's major axis.
- The isoseismals of earthquakes of the lower zone show a significantly more pronounced ellipsoidal shape.
- The seismic impacts of the lower zone completely overlap all other potential impacts within the territory of the Republic, establishing it as the primary seismic hazard for Moldova.

4. Discussion

When analyzing the results, it is important to note that various models for MSK-intensity attenuation of Vrancea earthquakes have been proposed [22] [29]-[31]. The key distinction of the models presented in this paper is that they are based on macroseismic data collected within a narrow azimuthal range—specifically in the direction from the source to the Republic of Moldova. In other words, Equations (3) and (4) are not as universally applicable as other models and may be less suitable for other territories, such as Romania and Bulgaria. However, for the territory of Moldova, these equations provide a more accurate intensity prediction, as they account for a crucial characteristic of the Vrancea source—namely, the directivity of seismic energy radiation.

It is important to emphasize the final conclusion from the previous section: the impacts from the lower zone completely overlap all other potential impacts within the territory of the Republic of Moldova. This is crucial, as it allows the seismic hazard assessment for Moldova to focus solely on earthquakes originating from the lower seismogenic zone. In other words, using Equation (3), seismic hazard maps for the Republic of Moldova can be generated at the required probability level. **Figure 6** presents such a map, depicting the intensity of potential impacts for an earthquake with a magnitude of $M_w = 7.9$.

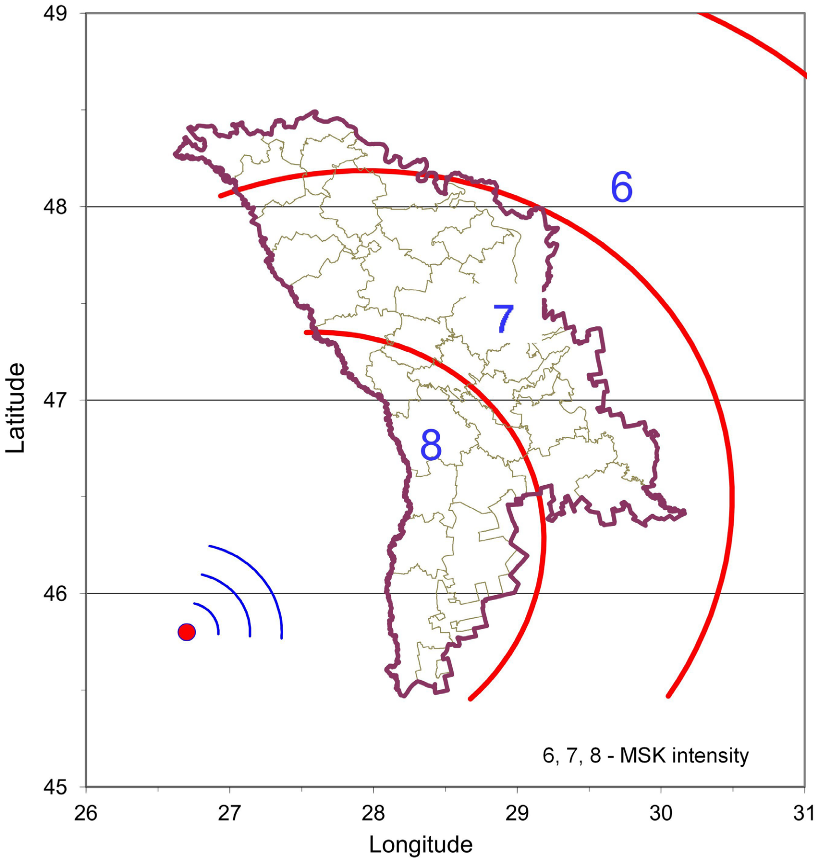

Figure 6. Intensity map (MSK points) for the design earthquake ($M_w = 7.9$).

To analyze the results, we compared two seismic hazard maps of the Republic of Moldova: the previous map (**Figure 1**) and the new one generated in this study (**Figure 6**). The comparison reveals a significant difference: the hazard level on the new map is higher. This can be explained by the higher calculated magnitude ($M_w = 7.9$ versus $M_w = 7.7$) in this study. Additionally, the use of a two-level focal zone model with differing isoseismal ellipticities—used here for the first time in Moldova—further differentiates our results. Lastly, the first study didn't account for the directivity of the rupture strike.

Unlike the current seismic zoning map, the new map for the Republic of Moldova aligns well with the European standard, Eurocode 8 [23]. As explained, Eurocode 8 ensures that the probability of exceeding design impacts within a 50-year period is no more than 10%. As noted in Section 2, our methodology provides a 12% probability of non-exceedance, which is quite close to the Eurocode requirement. This level of reliability (12%) can be deemed acceptable for mass construction in Moldova.

In summary, we can conclude that the current seismic hazard map is outdated, both in terms of its methodological framework and its inability to incorporate modern understanding of the specific characteristics of the Vrancea seismic source (such as the directivity of rupture propagation, etc.).

It is also valuable to compare our results with those of other seismic hazard studies in the region affected by the Vrancea zone. Since the new seismic hazard map for the Republic of Moldova is intended to serve as the foundation for the new building code, it is reasonable to compare it with the corresponding normative map of the nearest neighboring country, Romania. To facilitate this comparison, the developed map was converted to the same format as the Romanian map. A reliable equation for our region, which relates ground shaking acceleration (g) in points to the MSK intensity (I) [22], was used for this purpose:

$$A = 0.039e^{(0.5247 \cdot I)} / 9.81 \quad (5)$$

The seismic hazard map of design impacts (M_w = 7.9), expressed in terms of accelerations, is shown in **Figure 7**. To assess the compatibility of seismicity values

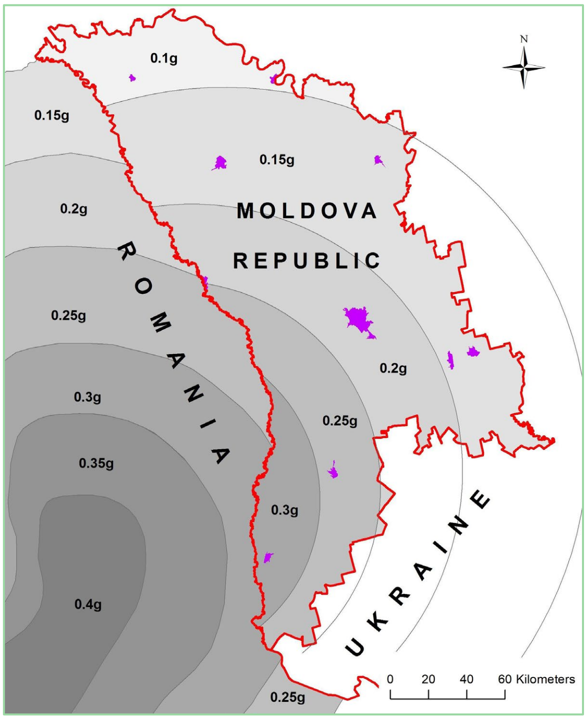

Figure 7. Intensity (g) map for the design earthquake (M_w = 7.9) and a fragment of the Romanian regulatory map P100-1-2013.

at the borders of Moldova and Romania, a fragment of the Romanian normative map P100-1-2013 [32] is also included. Overall, the alignment of the isolines along the shared border of the two countries appears to be quite accurate.

5. Conclusions

The seismic hazard methodology used in this study is based on a traditional probabilistic approach enhanced by deterministic elements, and it has proven effective. The new seismic hazard map for the territory of Moldova—developed in terms of both MSK intensity and acceleration—is more reliable than previous map and can serve as a foundation for updating Moldova's building Code for earthquake resistance.

Due to the lack of sufficient reliable statistical data on strong Vrancea earthquakes, simplified tectonic models were used.

Additionally, since this is the first application of this method, the effects of uncertainties in input parameters (such as magnitude, focal location, intensity, etc.) were not examined and will be the focus of future research.

Acknowledgements

We would like to express our deep gratitude to the anonymous reviewers who provided valuable feedback and contributed greatly to improving this article.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Buné, V.I. and Gorshkov, G.P. (1980) Seismic Zoning of the USSR Territory. Nauka. (In Russian)

[2] Ulomov, V.I. and Shumilina, L.S. (1999) Problems of Seismic Zoning in Russia. VNIINTPI of the State Construction Committee of Russia. (In Russian)

[3] Panza, G.F., Cioflan, C.O., Kouteva-Guentcheva, M., Paskaleva, I., Marmureanu, G. and Radulian, M. (2007) Preventive Actions to the Impact of Large Vrancea Events Carried on in the Framework of CEI. 3*rd CEI Conference Science and Technology for Safe Development of Life Line Systems*, Bucharest, 24-26 October 2007.

[4] Klügel, J. (2007) Error Inflation in Probabilistic Seismic Hazard Analysis. *Engineering Geology*, **90**, 186-192. https://doi.org/10.1016/j.enggeo.2007.01.003

[5] Klügel, J., Mualchin, L. and Panza, G.F. (2006) A Scenario-Based Procedure for Seismic Risk Analysis. *Engineering Geology*, **88**, 1-22. https://doi.org/10.1016/j.enggeo.2006.07.006

[6] Costa, G., Panza, G.F., Suhadolc, P., and Vaccari, F. (1992) Zoning of the Italian Region with Synthetic Seismograms Computed with Known Structural and Source Information. *Proceeding of* 10*th WCEE*, Madrid, July 1992, 435-438.

[7] Costa, G., Panza, G.F., Suhadolc, P. and Vaccari, F. (1993) Zoning of the Italian Territory in Terms of Expected Peak Ground Acceleration Derived from Complete Synthetic Seismograms. *Journal of Applied Geophysics*, **30**, 149-160. https://doi.org/10.1016/0926-9851(93)90023-r

[8] Panza, G.F., Romanelli, F. and Vaccari, F. (2001) Seismic Wave Propagation in Laterally Heterogeneous Anelastic Media: Theory and Applications to Seismic Zonation. *Advances in Geophysics*, **43**, 1-95. https://doi.org/10.1016/s0065-2687(01)80002-9

[9] Marmureanu, G., Cioflan, C.O. and Marmureanu, A. (2008). New Approach on Seismic Hazard Isoseismal Map for Romania. *Romanian Reports in Physics*, **60**, 1123-1135.

[10] Lungu, D., Demetriu, S., Aldea, A. and Arion, C. (2006) Probabilistic Seismic Hazard Assessment for Vrancea Earthquakes and Seismic Action in the New Seismic Code of Romania. *Proceedings of the First European Conference on Earthquake Engineering and Seismology*, Geneva, 3-8 September 2006, 1003.

[11] Vacareanu, R., Lungu, D., Aldea, A., Demetriu, S., Pavel, F., Arion, C., Iancovici, M. and Neagu, C. (2014), Probabilistic Seismic Hazard Assessment for Romania. Part III: Seismic Hazard Maps. In: Vacareanu, R. and Ionescu, C., Eds., *Proceedings of the 5th National Conference on Earthquake Engineering & 1st National Conference on Earthquake Engineering and Seismology*, CONSPRESS, 229-236.

[12] Simeonova, S.D., Solakov, D.E., Leydecker, G., Busche, H., Schmitt, T. and Kaiser, D. (2006) Probabilistic Seismic Hazard Map for Bulgaria as a Basis for a New Building Code. *Natural Hazards and Earth System Sciences*, **6**, 881-887. https://doi.org/10.5194/nhess-6-881-2006

[13] Radulian, M., Vaccari, F., Mândrescu, N., Panza, G.F. and Moldoveanu, C.L. (2000) Seismic Hazard of Romania: Deterministic Approach. *Pure and Applied Geophysics*, **157**, 221-247. https://doi.org/10.1007/pl00001096

[14] Panza, G.F., Kouteva, M., Vaccari, F., Peresan, A., Cioflan, C.O., Romanelli, F., *et al.* (2008) Recent Achievements of the Neo-Deterministic Seismic Hazard Assessment in the CEI Region. *AIP Conference Proceedings*, **1020**, 402-409. https://doi.org/10.1063/1.2963863

[15] Oncescu, M.C., Marza, V.I., Rizescu, M. and Popa, M. (1999) The Romanian Earthquake Catalogue between 984-1997. In: Wenzel, F., Lungu, D. and Novak, O., Eds., *Vrancea Earthquakes: Tectonics, Hazard and Risk Mitigation*, Springer, 43-47. https://doi.org/10.1007/978-94-011-4748-4_4

[16] Kanamori, H. (1977) The Energy Release in Great Earthquakes. *Journal of Geophysical Research*, **82**, 2981-2987. https://doi.org/10.1029/jb082i020p02981

[17] Gutenberg, B. and Richter, C.F. (2012) Magnitude and Energy of Earthquakes. *Annals of Geophysics*, **9**, 1-15. https://doi.org/10.4401/ag-5590

[18] Hwang, H.M. and Huo, J.R. (1994). Technical Report NCEER-94-0015: Generation of Hazard-Consistent Fragility Curves for Seismic Loss Estimation Studies. National Centre for Earthquake Engineering Research. University of New York at Buffalo.

[19] Balan, Ş., Căpățînă, D. and Cornea, I. (1972) The Earthquake of March 4, 1977. 514. (In Romanian)

[20] Mäntyniemi, P., Mârza, V., Kijko, A. and Retief, P. (2003) A New Probabilistic Seismic Hazard 597 Analysis for the Vrancea (Romania) Seismogenic Zone. *Natural Hazards*, **29**, 371-385. https://doi.org/10.1023/a:1024787621646

[21] Zaicenco, A., Lungu, D., Alkaz, V. and Cornea, T. (1999) Classification and Evaluation of Vrancea Earthquake Records from Republic of Moldova. In: Wenzel, F., Lungu, D. and Novak, O., Eds., *Vrancea Earthquakes: Tectonics, Hazard and Risk Mitigation*, Springer, 67-76. https://doi.org/10.1007/978-94-011-4748-4_7

[22] Alcaz, V.G. (2007) Methodological Framework for Seismic Hazard and Seismic Risk Assessment in the Territory Republic of Moldova. Elena. (In Russian)

[23] Eurocode 8 (1994) Design Provisions for Earthquake Resistance of Structures. Part

1-1: General Rules—Seismic Actions and General Requirements for Structures. CEN, European Committee for Standardization.

[24] Drumea A.V., Stepanenko N.Y., Simonova N.A., Alexeev I.V. and Kardanet V.I. (2009) Atlas of Earthquake Intensity Maps of Moldova (18th-21st Centuries). Elena. (in Russian)

[25] Wells, D.L. and Coppersmith, K.J. (1994) New Empirical Relationships among Magnitude, Rupture Length, Rupture Width, Rupture Area, and Surface Displacement. *Bulletin of the Seismological Society of America*, **84**, 974-1002. https://doi.org/10.1785/bssa0840040974

[26] (2020) ISC-International Seismological Centre (ISC). http://www.isc.ac.uk/iscbulletin/search/catalogue/

[27] Davis, J. (1973) Statistics and Data Analysis in Geology. John Wiley and Sons Inc.

[28] Shumila, V.I. (1990) Models of Seismic Intensity Field for Transitional Carpathian Earthquakes in the Vrancea Area. In: Drumia, A.V., Shebalin, N.V., *et al.*, Eds., *Carpathian Earthquake of* 1986, Ştiinţa Press, 127-133. (in Russian).

[29] Demetrescu, G. (1941) The Earthquake of November 10, 1940. *Scientific Magazine V. Adamachi*, **27**, 1-17. (In Romanian)

[30] Drumya, A.V. and Shebalin, N.V. (1986) Earthquake: What, Where, Whan? Shtiintsa Press.

[31] Jianu, D. (1992) Attenuation of Intensity with Distance for Vrancea Intermediate Earthquakes. *Proceedings of XXIII General Assembly of European Seismological Commission*, **11**, 241-250.

[32] (2024) Seismic Zoning of Romania according to P100-1-2013. http://www.dlubal.com/en/load-zones-for-snow-wind-earthquake/seismic-uni-en-1998-1.html?¢er=45.97997430538993,25.032306121639838&zoom=6&marker=42.5674405419,13.815265106#¢er=45.97997430538993,25.032306121639838&zoom=6&marker=42.5350672313308,12.7825502622648