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Log-Linear Model Analysis of Aftershock Sequences: A Review on the 6 February Earthquakes in Turkey

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ABSTRACT

Researchers have conducted numerous studies on earthquakes and aftershocks, some of which have utilized statistical analysis methods. However, there is no direct research examining the interaction between variables thought to influence aftershocks following major earthquakes. In this study, 2194 aftershocks with a magnitude of 3 or higher that occurred after two major earthquakes in Turkey on February 6, 2023 were analyzed using log-linear models with respect to variables such as depth, magnitude, time, and city. At the end of the study, all four primary variables - city, magnitude, depth, and time - were found to be statistically significant. Based on the parameter estimation values, it was found that the probability of aftershocks occurring in Malatya was 1.17 times greater than in Adıyaman, 2.82 times greater than in Gaziantep, and 1.38 times greater than in Hatay, while the probability of aftershocks occurring in Kahramanmaraş was 3 times greater than in Malatya. Thus, it can be said that the aftershocks are influenced by the center of the major earthquake. Additionally, it was found that the probability of aftershocks with a magnitude between 3 and 3.5 was 1.4 times greater than those with a magnitude of 4 or higher, and the probability of aftershocks with a depth of less than 10 kilometers was 2 times greater. We believe that the results of this study will provide information on aftershocks that occur after major earthquakes and will be helpful for future studies.

Keywords: Aftershock, Earthquake, Categorical data analysis, Log-linear model.

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Introduction

Earthquakes are seismic events that occur due to the movements of fault lines in the earth's crust. These movements occur as a result of the accumulation of stress and tension in the earth's crust. The intensity of earthquakes can be measured using the Richter scale or similar measures. Earthquakes usually occur in the form of main and aftershocks. Studies on earthquakes and aftershocks can address topics such as earthquake prediction, earthquake early warning systems, emergency planning, structural design, earthquake-resistant building materials, and damage reduction techniques. These studies are important for reducing the damage caused by earthquakes and for preparing people for earthquakes.

Many studies have been done by researchers to analyze earthquakes with large and small magnitudes to understand the behavior of the earth crust. Different statistical models such as hidden Markov process, machine learning, extreme value theory, statistical distributions have been used to analyze such data sets. For instance, Pisarenko et al. (2014) proposed a new method by combining generalized extreme value and generalized Pareto distributions to describe the tail probabilities [1]. Ma et al. (2021) used the peaks-over-threshold method to assess the possible damage of large earthquakes in China [2].

Beyreuther and Wassermann (2008) used the hidden Markov model to classify small earthquakes [3]. Yip et al. (2018) proposed a latent Markov process for earthquake prediction. Machine learning techniques are also widely used in seismic analysis [4]. Li et al. (2018) developed an early warning system for earthquakes based on a machine learning technique, generative adversarial network [5]. Mangalathu et al. (2020) classified building damages caused by earthquakes using different machine learning algorithms such as k-nearest neighbors, random forests, and decision trees [6]. Tehseen et al. (2020) reviewed over 70 manuscripts on the earthquake prediction implemented using the expert systems, fuzzy logic and machine learning [7]. In their study, Li et al. recorded the aftershocks following the Kahramanmaraş earthquake in Turkey. The study demonstrated the reliability of earthquake detection, phase picking, and magnitude estimation using deep learning techniques [8].

In this study, we focus on two large earthquakes and their aftershocks occurred on February 6, 2023, Turkey. These two major earthquakes are the deadliest events in the history of Turkey [9]. The earthquakes damaged many historical buildings such as masonry, mosques, and minarets [10]. The aim of this study is to contribute to the literature from a different statistical perspective using such earthquake data. In the study, 2194 aftershock data that occurred after the February 6th earthquake were evaluated in terms of depth, magnitude, time, and city variables. The three-way cross-classified aftershock data were analyzed according to log-linear models. The most suitable model was found based on the estimated parameters, and the results were interpreted.

The remaining parts of the presented study are organized as follows. Section 2 deals with the used statistical model and its theoretical properties. Section 3 is devoted to the empirical results of the study. Section 4 contains the concluding remarks.

Methods

Log-Linear Models

The concept of log-linear analysis, applied to contingency tables, can be compared to the use of analysis of variance (ANOVA) for continuously distributed factor-response variables. In ANOVA, the response observations are assumed to be continuous and have underlying normal distributions. However, in log-linear analysis, the response observations are considered as counts with Poisson distributions [11].

In cases where more than two categorical variables are involved, determining the relationship between the variables in contingency tables using chi-square independence tests may become difficult or even impossible. In such cases, logarithmic linear models, which allow for testing a larger number of hypotheses compared to chi-square and do not impose restrictions on the number of rows and columns in both two-dimensional and three-dimensional tables, are preferred. In multidimensional contingency tables, a model is created to investigate the relationships between the variables, and the parameters in the model are estimated and tested for significance. The overall goodness-of-fit of a model is assessed by comparing the expected frequencies to the observed cell frequencies for each model. The Pearson chi-square statistics or the likelihood ratio statistic (G^2) can be used to test a model fit, with (G^2)being more commonly used due to its use in maximum likelihood estimation [12].

Table 1. Hierarchical model representation and equations

Model	Model equation
0→ X,Y,Z	$logE_{ijk} = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z$
1→ X,YZ	$logE_{ijk} = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z + \lambda_{jk}^{YZ}$
2→ Y,XZ	$logE_{ijk} = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z + \lambda_{ik}^{XZ}$
3→ Z,XY	$logE_{ijk} = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z + \lambda_{ij}^{XY}$
4→ XZ,YZ	$logE_{ijk} = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z + \lambda_{ik}^{XZ} + \lambda_{jk}^{YZ}$
5→ XY,YZ	$logE_{ijk} = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z + \lambda_{ij}^{XY} + \lambda_{jk}^{YZ}$
6→ XY,XZ	$logE_{ijk} = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z + \lambda_{ij}^{XY} + \lambda_{ik}^{XZ}$
7→ XY,XZ,YZ	$logE_{ijk} = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z + \lambda_{ij}^{XY} + \lambda_{ik}^{XZ} + \lambda_{jk}^{YZ}$
8→ XYZ	$logE_{ijk} = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z + \lambda_{ij}^{XY} + \lambda_{ik}^{XZ} + \lambda_{jk}^{YZ} + \lambda_{ijk}^{XYZ}$

For three-dimensional contingency tables, nine different logarithmic linear models can be created, which can be grouped into five categories: logarithmic linear models with complete independence, logarithmic linear models with partial independence, logarithmic linear models with conditional independence, logarithmic linear models containing all two-way interactions, and logarithmic linear models containing all interactions. These models are referred to as progressive (hierarchical) models.

X, Y and Z show the variables in a three-dimensional contingency table, R, C, and K represent the level numbers of these variables. The explanations of the terms in the models are given below.

E_{ij} is the expected frequency for cell, (i, j and k), which is calculated over the model. λ reflects the constant term. For the logarithmic linear models in Table 1, the following constraints must be met.

$$\sum_{i=1}^{R}\lambda_i^X = \sum_{j=1}^{C}\lambda_j^Y = \sum_{k=1}^{K}\lambda_k^Z = \sum_{i=1}^{R}\lambda_{ij}^{XY} = \sum_{j=1}^{C}\lambda_{ij}^{XY} = \cdots = \sum_{k=1}^{K}\lambda_{ijk}^{XYZ} = 0$$

$\lambda_{ij}^{XY}, \lambda_{ik}^{XZ}, \lambda_{jk}^{YZ}$ and λ_{ijk}^{XYZ} show two-way and three-way interactions, respectively.

Statistical Analysis

The study included 2191 aftershock data. The data source is https://deprem.afad.gov.tr/last-earthquakes.html . Three-dimensional cross-table was obtained according to the dept (<10=1, ≥ 10=2), citys (Adıyaman=1, Gaziantep=2, Hatay=3, Kahramanmaraş=4, Malatya=5), time(00:00-08:00=1, 08:01-16:00=2, 16:01-23:59=3) and magnitude (3-3,4=1, 3,5-4=2, >4,1). The best model was decided by backward stepwise methods. By making parameter estimates of the best model, the variables that are significant are interpreted (p>0.05).

Results

Comparison of Aftershocks According to City, Magnitude, and Depth

Table 2. Number of aftershocks according to city, magnitude, and depth.

Depth	City	Magnitude		
		3-3.4	3.5-4	>4
<10	Adıyaman	109 (106.382)	65 (72.072)	36 (31.546)
	Gaziantep	70 (66.362)	42 (44.959)	19 (19.679)
	Hatay	94 (93.211)	63 (63.149)	27 (27.640)
	Kahramanmaraş	450 (453.388)	313 (307.166)	132 (134.446)
	Malatya	201 (204.658)	143 (138.654)	60 (60.689)
≥10	Adıyaman	24 (21.851)	20 (19.324)	11 (13.824)
	Gaziantep	4 (5.562)	5 (4.919)	5 (3.519)
	Hatay	22 (18.673)	16 (16.514)	9 (11.814)
	Kahramanmaraş	64 (65.951)	63 (58.324)	39 (41.724)
	Malatya	33 (34.962)	26 (30.919)	29 (22.119)

* The values in the parenthesis are the percentages.

When Table 2 is examined in terms of depth, it can be concluded that aftershocks with less depth are more common. This indicates that aftershocks are more likely to be closer to the surface. In terms of city, aftershocks are observed in Kahramanmaraş and Adıyaman. When the aftershocks following major earthquakes are examined in terms of intensity, it is seen that the number of earthquakes decreases as the magnitude increases. That is, it is possible to say that the magnitude of aftershocks is less compared to the major earthquake that occurred before. However, the occurrence of aftershocks, especially those above 4, is an indicator of how strong the previous earthquake was.

Determination of the Best Model with Backward Stepwise Method

The log-linear models are applied to data used and the main effects and interaction terms are hierarchically tested to decide which terms will be included in the model. Therefore, in the three-way table, the significance of the main effect terms, two-way interaction and three-way interactions are examined.

Table 3. Degrees of freedom (df), p-value and test statistic values for K-Way and higher-order effects.

	K	df	G^2	p-value	χ^2	p-value
K-way and Higher Order Effects	1	29	2559.086	<0.001	3746.930	<0.001
	2	22	45.991	0.002	47.777	0.001
	3	8	6.377	0.605	6.351	0.608
K-way Effects	1	7	2513.095	<0.001	3699.153	<0.001
	2	14	39.614	<0.001	41.426	<0.001
	3	8	6.377	0.605	6.351	0.608

Hypotheses for K-way and higher effects:

H_{01}: One-way and higher effects are not significant.

$p = 0.000 < 0.05$ H_0 is reject; one-way and higher interactions are important.

H_{02}: Two-way and three-way interactions are not significant.

$p = 0.000 < 0.05$ H_0 is reject; Two-way and three-way interactions are significant.

H_{03}: Three-way interaction is not significant.

$p = 0.605 > 0.05$ H_0 is accept; Three-way interaction is not significant.

H_{04}: One-way effect is not significant.

$p = 0.000 < 0.05$ H_0 is reject; one-effect is important.

H_{05}: Two-way interactions are not significant.

$p = 0.000 < 0.05$ H_0 is reject; Two-way interactions are significant.

H_{06}: Three-way interaction is not significant.

$p = 0.608 > 0.05$ H_0 is accept; Three-way interaction is not significant.

Table 4 was obtained to analyze whether two-way interactions and main effects were significant.

Table 4. The degree of freedom, p value and test statistic values of two-way interaction and main effects terms.

Effect	df	X²	p-value
city*magnitude	8	2.524	.961
city*depth	4	12.236	.016
magnitude *depth	2	24.763	.000
city	4	1101.330	.000
magnitude	2	361.185	.000
depth	1	1050.580	.000

It can be concluded from Table 4 that city and magnitude interaction is not statistically significant (p>0.05). City and depth interactions with magnitude and depth are statistically significant (p<0.05). In addition, three of the main effects were found significant (p<0.05). The parameter estimates of the main effects are as given in Table 5.

Table 5. Parameter estimates of the main effects.

Effects	Parameter	Estimate	Standard error	Z-value	p-value	95% Confidence Interval	
						Lower bound	Upper bound
depth	1	0.756	0.039	19.332	<0.001	0.679	0.832
city	1	-.160	.073	-2.196	.028	-.304	-.017
	2	-1.035	.113	-9.156	.000	-1.257	-.813
	3	-.319	.078	-4.098	.000	-.472	-.167
	4	1.107	.052	21.348	.000	1.005	1.208
magnit	1	.358	.053	6.715	.000	.253	.462
	2	.092	.054	1.714	.087	-.013	.198

When we refer to Table 5, it can be observed that the probability of aftershocks occurring in Malatya is 1.17 times higher than in Adıyaman, 2.82 times higher than in Gaziantep, and 1.38 times higher than in Hatay. However, the probability of aftershocks occurring in Kahramanmaraş after this major earthquake is three times higher than in Malatya. Hence, it can be clearly deduced that Kahramanmaraş, which is the epicenter of the earthquake, has the highest probability of aftershocks. Upon examining the table with respect to earthquake magnitude, it can be stated that the probability of aftershocks in the range of 3 to 3.5 is 1.4 times higher than those with a magnitude of 4 or greater. Additionally, it was found that the probability of aftershocks with a depth of less than 10 kilometers is two times greater. The best model selection with backward stepwise method shown in Table 6.

Table 6. Determination of the best model with backward stepwise method.

Step		Effects	χ^2	df	p-value
0	Generating class	city* magnitude *depth	.000	0	.
	Deleted effect	city* magnitude *depth	6.377	8	.605
1	Generating class	city* magnitude, city*depth, magnitude *depth	6.377	8	.605
	Deleted effect	city* magnitude	2.524	8	.961
		city*depth	12.236	4	.016
		Magnitude *depth	24.763	2	.000
2	Generating class	city* magnitude, magnitude *depth	8.901	16	.917
	Deleted effect	city*depth	12.282	4	.015
		magnitude *depth	24.808	2	.000
3	Generating class	city*depth, magnitude *depth	8.901	16	.917

When interpreting Table 6, the generating class expression tests the compatibility of the model, while the deleted effect expression tests the significance of interactions. The steps continue until all examined interactions are statistically significant. In this case, the city-depth and intensity-depth interactions are statistically significant and are included in the model. So, the best model for these three variables is the model represented by XY, XZ. In this case, the model equation is $logE_{ijk} = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z + \lambda_{ij}^{XY} + \lambda_{ik}^{XZ}$. Although it is expressed by the variables itself, it is in the form of $logE_{ijk} = constant + depth_i + city_j + magnitude_k + depth_i \times city_j + depth_i \times magnitude_k$. The test statistics value of the best model is given in Table 7 which shows that the model is statistically significant.

Table 7: Test statistics and p-value of XY,XZ model.

	Test statistics	df	p-value
G^2	8.901	16	0.917
χ^2	9.015	16	0.913

The parameter estimates of the best fitting model are given in Table 8.

Table 8. Parameter estimates for XY, YZ model

Parameter	Estimate	Standard error	z-value	p-value	95% Confidence Interval	
					Lower bound	Upper bound
Constant	3.096	.139	22.223	.000	2.823	3.370
[city = 1] * [depth= 1]	-.184	.192	-.961	.337	-.560	.192
[city = 2] * [depth = 1]	.712	.305	2.336	.019	.115	1.309
[city = 3] * [depth= 1]	-.159	.201	-.791	.429	-.554	.235
[city = 4] * [depth = 1]	.161	.145	1.110	.267	-.123	.445
[magnitude = 1] * [depth= 1]	.758	.149	5.076	.000	.465	1.050
[magnitude = 2] * [depth = 1]	.491	.154	3.192	.001	.190	.793

The contribution of interaction terms with $p > 0.05$ to the model is not statistically significant. Interpreting the interaction parameters according to the results in Table 8, it can be said that the risk of occurrence of aftershocks with a depth of less than 10 km increases by 2.1 times when the magnitude of the aftershock is between 3-3.4, and by 1.6 times when it is between 3.5-4.

Comparison of Aftershocks According to time, Magnitude and Depth

Table 9. Number of aftershocks according to time, magnitude and depth.

Depth	Time	Magnitude		
		3-3.4	3.5-4	>4
<10	00:00-08:00	172 (172.962)	152 (151.447)	69 (68.588)
	08:01-16:00	330 (329.573)	203 (207.023)	91 (87.410)
	16:01-23:59	422 (421.465)	271 (267.529)	115 (119.002)
≥10	00:00-08:00	25 (24.038)	27 (27.553)	20 (20.412)
	08:01-16:00	64 (64.426)	57 (52.977)	33 (36.591)
	16:01-23:59	59 (59.536)	46(49.470)	40(35.997)

* The values in the parenthesis are the percentages.

When Table 9 is examined, it is possible to state that aftershocks occurring closer to the surface tend to occur more frequently between the afternoon and night hours (16:01-23:59). On the other hand, aftershocks at greater depths are more likely to occur between the morning and afternoon, as well as between the afternoon and night hours. Although memorable major earthquakes in Turkey are often recalled having happened after midnight, when analyzing earthquakes of magnitude 5.5 and above occurring since the year 2000, it is observed that 48.6% took place between 08:01 and 16:00, 25.7% between 00:00 and 08:00, and another 25.7% between 16:01 and 23:59 (AFAD). These findings support the provided information. The reason behind nocturnal earthquakes leaving a significant impact in people's memory can be attributed to individuals being at home and potentially asleep, thus being caught off guard by the earthquake without being prepared.

Determination of the Best Model with Backward Stepwise Method

The log-linear models are applied to data used and the main effects and interaction terms are hierarchically tested to decide which terms will be included in the model. Therefore, in the three-way table, the significance of the main effect terms, two-way interaction and three-way interactions are examined.

Table 10. Degrees of freedom (df), p-value and test statistic values for K-Way and higher-order effects.

	K	df	G^2	p-value	χ^2	p-value
K-way and Higher Order Effects	1	17	1629.508	<0.001	1885.754	<0.001
	2	12	43.793	<0.001	44.706	0.001
	3	4	1.823	0.768	1.828	0.767
K-way Effects	1	5	1585.715	<0.001	1841.048	<0.001
	2	8	41.970	<0.001	42.878	<0.001
	3	4	1.823	0.768	1.828	0.767

Hypotheses for K-way and higher effects:

H_{01}: One-way and higher effects are not significant.

$p = 0.000 < 0.05$ H_0 is reject; one-way and higher interactions are important.

H_{02}: Two-way and three-way interactions are not significant.

$p = 0.000 < 0.05$ H_0 is reject; Two-way and three-way interactions are significant.

H_{03}: Three-way interaction is not significant.

$p = 0.768 > 0.05$ H_0 is accept; Three-way interaction is not significant.

H_{04}: One-way effect is not significant.

$p = 0.000 < 0.05$ H_0 is reject; one-effect is important.

H_{05}: Two-way interactions are not significant.

$p = 0.000 < 0.05$ H_0 is reject; Two-way interactions are significant.

H_{06}: Three-way interaction is not significant.

$p = 0.767 > 0.05$ H_0 is accept; Three-way interaction is not significant.

Table 11 was obtained to analyze whether two-way interactions and main effects were significant.

Table 11. The degree of freedom, p value and test statistic values of two-way interaction and main effects terms.

Effect	df	χ^2	p-value
time*depth	2	7.854	.020
time* magnitude	4	10.677	.030
depth * magnitude	2	24.934	.000
time	3	175.719	.000
depth	1	1049.425	.000
magnitude	2	360.571	.000

The result indicates that all pairwise interactions are statistically significant starting from Table 11 (p<0.05). The parameter estimates of the main effects are as given in Table 12.

Table 12. Parameter estimates of the main effects.

Effects	Parameter	Estimate	Standard error	Z-value	p-value	95% Confidence Interval	
						Lower bound	Upper bound
depth	1	0.751	0.031	2.,267	<0.001	0.690	0.812
time	1	-.411	.049	-8.573	.000	-.507	-.316
	2	.150	.041	3.633	.000	.069	.232
magnitude	1	.338	.042	8.141	.000	.257	.419
	2	.115	.042	2.722	.006	.032	.198

When Table 12 is examined in terms of time, it can be observed that the probability of aftershocks occurring between the afternoon and midnight following a major earthquake is 1.5 times higher than the probability of occurrence during the hours from midnight until morning. Additionally, the probability of aftershocks occurring between the morning and afternoon is 1.2 times higher than the probability of occurrence between the afternoon and midnight. Upon examining the table with respect to earthquake magnitude, it can be stated that the probability of aftershocks in the range of 3 to 3.5 is 1.4 times higher than those with a magnitude of 4 or greater. Additionally, it was found that the probability of aftershocks with a depth of less than 10 kilometers is two times greater. The best model selection with backward stepwise method shown in Table 13.

Table 13. Determination of the best model with backward stepwise method.

Step		Effects	χ^2	df	p-value
0	Generating class	time*depth * magnitude	.000	0	.
	Deleted effect	time*depth * magnitude	1.823	4	.768
1	Generating class	time* depth, time* magnitude, depth * magnitude	1.823	4	.768
	Deleted effect	time* depth	7.854	2	.020
		time* magnitude	10.677	4	.030
		depth * magnitude	24.934	2	.000
2	Generating class	time*depth, time * magnitude, depth* magnitude	1.823	4	.768

When interpreting Table 13, the generating class expression tests the compatibility of the model, while the deleted effect expression tests the significance of interactions. The steps continue until all examined interactions are statistically significant. In this case, the time-depth, time-magnitude, and depth-magnitude interactions are statistically significant and are included in the model. So, the best model for these three variables is the model represented by XY, XZ, YZ. In this case, the model equation is $logE_{ijk} = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z + \lambda_{ij}^{XY} + \lambda_{ik}^{XZ} + \lambda_{jk}^{YZ}$. Although it is expressed by the variables itself, it is in the form of $logE_{ijk} = constant + time_i + depth_j + magnitude_k + time_i \times depth_j + time_i \times magnitude_k + depth_j \times magnitude_k$. The test statistics value of the best model is given in Table 14 which shows that the model is statistically significant.

Table 14: Test statistics and p-value of XY, XZ, YZ model.

	Test statistics	df	p-value
G^2	1.823	4	0.768
χ^2	1.828	4	0.767

The parameter estimates of the best fitting model are given in Table 15.

Table 15. Parameter estimates for XY, XZ, YZ model.

Parameter	Estimate	Standard error	z-value	p-value	95% Confidence Interval	
					Lower bound	Upper bound
Constant	3.583	.134	26.781	.000	3.321	3.846
[time = 1] * [depth= 1]	.016	.158	.103	.918	-.293	.326
[time = 2] * [depth = 1]	-.325	.128	-2.535	.011	-.576	-.074
[time = 1] * [magnitude = 1]	-.340	.159	-2.142	.032	-.650	-.029
[time = 1] * [magnitude = 2]	-.018	.163	-.110	.912	-.337	.302
[time = 2] * [magnitude = 1]	.063	.139	.449	.653	-.211	.336
[time = 2] * [magnitude = 2]	.052	.147	.354	.723	-.237	.341
[depth= 1] * [magnitude = 1]	.761	.150	5.087	.000	.468	1.055
[depth= 1] * [magnitude = 2]	.492	.154	3.191	.001	.190	.794

The contribution of interaction terms with p > 0.05 to the model is not statistically significant. Interpreting the interaction parameters according to the results in Table 15, it can be said that the risk of occurrence of aftershocks with a depth of less than 10 km increases by 2.1 times when the magnitude of the aftershock is between 3-3.4, and by 1.6 times when it is between 3.5-4. Furthermore, the risk of aftershocks occurring between 08:01 and 16:00 increases by 1.38 times when the depth is greater than 10 km, and the risk of aftershocks occurring between 16:01 and 23:59 increases by 1.4 times when the magnitude is between 3-3.4.

Conclusion

In this study, aftershocks that occurred following two major earthquakes on February 6th in Turkey, along with their adverse consequences, were grouped based on the cities where the earthquakes occurred, the intensity of the earthquakes, their depth, and the hours of their occurrence. After this grouping, an analysis was conducted using log-linear models to examine the effects of these variables and the relationships between them. The analysis revealed a higher probability of aftershock occurrence in the epicentral and nearby provinces where the major earthquake occurred. It was observed that a significant portion of the aftershocks had a depth of less than 10 kilometers, indicating their proximity to the surface. Contrary to expectations, it was stated that aftershocks were more likely to occur during the early daylight hours until midnight. The perception that major earthquakes occur at night is likely due to the higher number of casualties in earthquakes that occur after midnight. The application of the analysis resulted in the determination that most of the aftershocks had an intensity greater than 3 but less than 4. This study demonstrates that the tabulation of qualitative or quantitative variables related to earthquakes and their aftershocks provides us with more detailed and interpretable information.

Conflicts of interest

There are no conflicts of interest in this work.

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