NORMALIZATION OF LOCAL MAGNITUDE SCALE FOR ROUTINE EARTHQUAKE PROCESSING: INSIGHTS FROM ALBANIAN NATIONAL EARTHQUAKE MONITORING CENTRE

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Abstract

This study investigates the normalization of the local magnitude (ML) scale utilized in routine local and regional earthquake processing by the Albanian National Earthquake Monitoring Centre. A dataset comprising 406 events from the national database of earthquakes in the Institute of Geosciences (IGEO) spanning 2 years (2021-2022) is analyzed. Events with magnitudes in the range 2.0 ≤ ML ≤ 4.3 are considered, primarily focusing on moderate earthquakes prevalent in the region. Event depths range from 0.5 km to 64.3 km, reflecting the shallow activity associated with the seismically active crust and continental subduction. Regression analysis is conducted to compare ML values reported by TIR with those from the Euro-Mediterranean Seismological Centre (EMSC) and the National Observatory of Athens (NOA), representative seismological agencies for the region. This analysis builds upon previous work covering events from 2021 to 2022, yielding parametric relations. The study utilizes the local model implemented in SEISAN for ML computation. The analysis extends over a longer period, focusing specifically on moderate earthquakes and incorporating a more concentrated spatial extension. Orthogonal regression methodology is employed, accounting for variations in the analyzed variables. The findings contribute to the normalization of the ML scale for local and regional earthquake processing, enhancing the accuracy of seismic magnitude determination and reporting. This work provides valuable insights for seismic monitoring and hazard assessment efforts, particularly related with an representative and homogenize regional earthquake catalogue.

Key words**:** *local magnitude scale, earthquake processing, seismic monitoring, regression analysis, Albanian National Earthquake Monitoring Centre.*

Përmbledhje

Ky studim trajton normalizimin e shkallës së magnitudës lokale (ML) të përdorur në përpunimin rutinë të tërmeteve lokale dhe rajonale nga Qendra Kombëtare Shqiptare e Monitorimit të Tërmeteve. Është analizuar një grup të dhënash që përfshin 406 ngjarje nga baza e të dhënave kombëtare të tërmeteve në Institutin e Gjeoshkencave (IGEO) që përfshin 2 vite (2021-2022). Ngjarjet me magnitudë në intervalin 2.0 ≤ ML ≤ 4.3 janë marrë në konsideratë, duke u fokusuar kryesisht në tërmetet mesatare të përhapura në rajon. Thellësia e ngjarjeve varion nga 0.5 km në 64.3 km, duke reflektuar aktivitetin e cekët të lidhur me koren sizmikisht aktive dhe subduksionin kontinental. Analiza e regresionit kryhet për të krahasuar vlerat e ML të raportuara nga TIR me ato nga Qendra Sizmologjike Euro-Mesdhetare (EMSC) dhe Observatori Kombëtar i Athinës (NOA), agjenci sizmike përfaqësuese për rajonin. Kjo analizë bazohet në punën e mëparshme që mbulon ngjarjet nga 2021 deri në 2022, duke nxjerrë relacione parametrike. Studimi përdor modelin lokal të zbatuar në SEISAN për llogaritjen ML. Analiza shtrihet në një periudhë më të gjatë, duke u fokusuar veçanërisht në tërmetet e moderuara dhe duke përfshirë një shtrirje hapësinore më të përqendruar. Përdoret metodologjia e regresionit ortogonal, duke llogaritur variacionet në variablat e analizuar. Gjetjet kontribuojnë në normalizimin e shkallës ML për përpunimin lokal dhe rajonal të tërmeteve, duke rritur saktësinë e përcaktimit dhe raportimit të magnitudës sizmike. Kjo punë ofron njohuri të vlefshme për monitorimin sizmik dhe përpjekjet për vlerësimin e rrezikut, veçanërisht lidhur me një katalog rajonal të tërmeteve përfaqësues dhe homogjenizuar.

Fjalë kyçe: *shkalla e magnitudes locale, procesimi i tërmeteve, monitorimi sizmik, analiza regresionit, Qëndra Kombëtare e Monitorimit Sizmik.*

Introduction

One of the most important parameters that is evaluated when an earthquake occurs is the magnitude. With the development of science and technology, various types of magnitudes have been used to measure the energy released by the earthquake. They use different types of seismic waves and are appropriate to the event depending on the distance from the epicenter and the depth of the focus. The idea of a logarithmic scale was first developed by

Richter (1935). The formula for the ML magnitude involves taking the logarithm of the maximum amplitude of seismic waves and correcting it based on the distance between the epicenter and the seismograph. The standard formulation for ML according to Richter is written:

$$ML = \log A - \log A_0$$

Where A is the maximum amplitude of the trace in nanometers nm measured at the output of a horizontal component instrument that is filtered so that the response of the seismograph filter replicates that of a standard Wood-Anderson seismograph but with a magnification static of 1 and R is the hypocentral distance in km, usually less than 1000 km, -logA0 is the normalizing distance term.

According to Hutton and Boore (1987) the -logA0 term is written:

$$-\log A_0 = n*\log(r/100) + K*(r-100) + 3.0$$

Where r is the distance of the hypocenter in kilometers, and n, K are constants that are estimated from the regression analysis, and thus the local magnitude is calculated according to:

$$ML = \log A + n*\log(r/100) + K*(r-100) + 3.0$$

This equation was estimated for the Albanian territory by Muco e Minga (1991), and was later improved by Dushi (2009), after the modernization of the Albanian seismic monitoring network.

Methodology

The methodology used in this work is based on orthogonal regression, Fuller (1987) which examines the linear relationship between two variables: one response (Y) and one predictor (X) where both contain measurement error and is used to determine whether two instruments or methods provide comparable measurements. The analysis is based on the regression comparison between the ML values reported by TIR (identification code of Albanian Seismic Network ASN in the Internatinal Seismological Center ISC), EMSC and NOA, as representative seismological agencies for the region.

The data used in this analysis are 406 events, which are part of the TIR database (REA), for the period 01.01.2021-06.08.2022 (duration 1.5 years). The magnitude taken into consideration varies in the segment $2.0 \leq ML \leq 4.3$, i.e. mainly in the class of moderate earthquakes that mostly populate the database. The depth of the events varies in the interval $0.5 \text{ km} \leq h \leq 64.3 \text{ km}$, typical for the shallow activity associated with the seismically active crust and of course also with the continental subduction, which is apparently also expressed by the presence of special earthquakes with a depth below the observed Moho boundary.

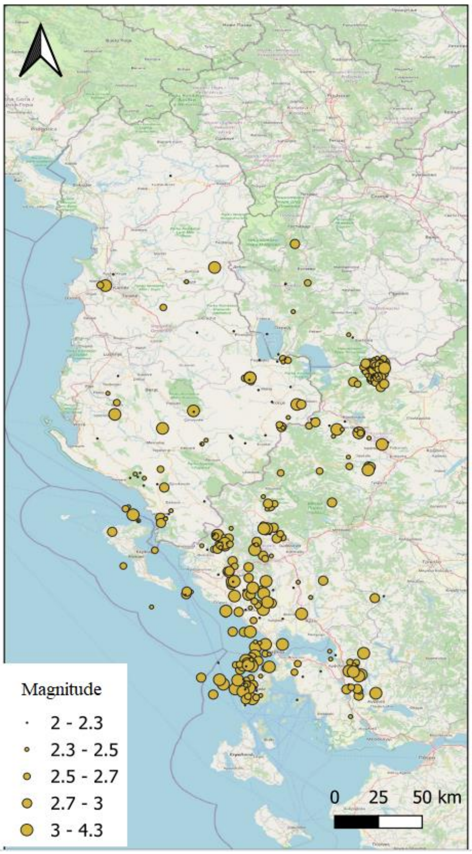
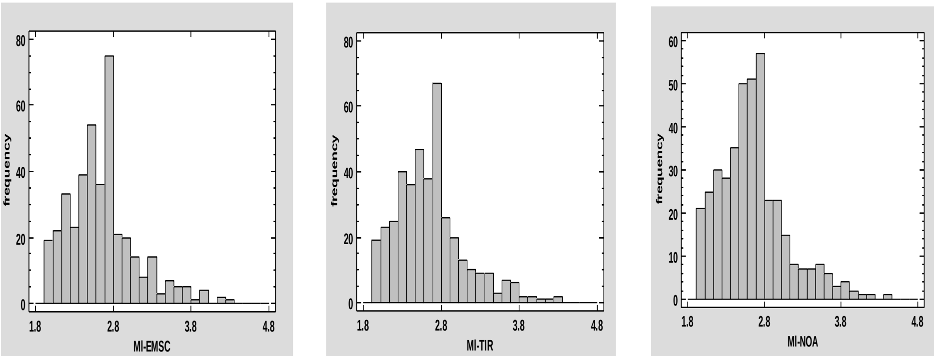


Figure 1. Earthquake epicenters and magnitude scale

The distribution of magnitude (Figure 2) is quite similar for the three different agencies (2a, 2b, 2c). They are skewed to the right with a long tail extending towards the higher values. There is a clear peak in the histograms, indicating the most common value of magnitude is around 2.8.



a) b) c)

Figure 2 The magnitude distribution histograms for the catalogue a) EMSC b) TIR c) NOA

The selected events exhibit a satisfactory degree of spatial coverage across the country, as evidenced by the ray paths depicted in figure 3. The star-like pattern of lines radiating outward from various points on the map represents the propagation of seismic waves from earthquake epicenters.

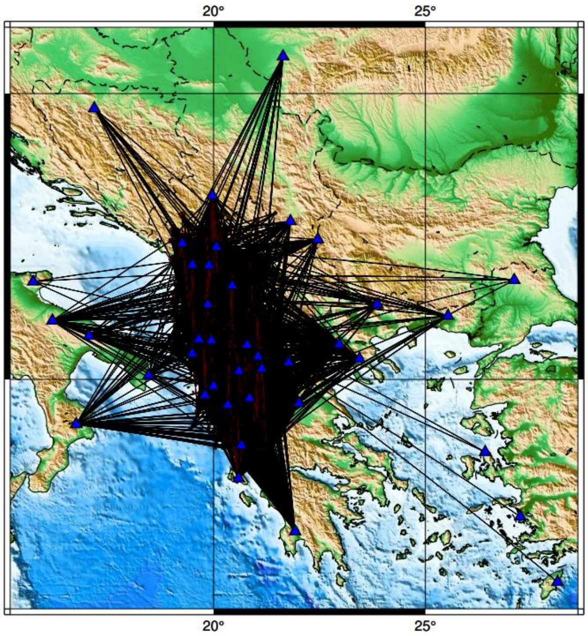


Figure 3 Ray-Path coverage of events. The black lines indicate the data communication links between seismic stations. Blue triangles represent seismic stations that are part of regional and national seismological networks including TIR, NOA and others.

The analysis was based on the evaluation obtained through the local model currently used by TIR, implemented in SEISAN:

$$ML = \log_{10}(A) + 1.11\log_{10}(R) + 0.00189*R - 1.69$$

This equation is an extension of the equation of Hutton and Boore (1987), determined on the analysis of the seismicity of Southern California, typical in depth and magnitude with that of Albania, corrected with a factor of 1.69 (free term). This correction was based on the preliminary analysis of events recorded during the month of January 2021.

This analysis follows the one carried out in the period 01.01.2021-01.11.2021, where a total of 1451 events were analyzed for the TIR-EMSC model and 743 events for the TIR-NOA model done by Gjuzi et al (2021). The methodology used was linear regression maximum likelihood estimation. Parametric relationships were obtained from this analysis:

$$ML_{TIR} = 0.990 * ML_{EMC} - 0.035$$

$$ML_{TIR} = 0.995 * ML_{NOA} - 0.014$$

including the earthquakes of the Thessaly series, in March 2021. Mainly the events taken into consideration populate the Albanian territory and that of northern and northwestern Greece.

Currently, a longer period has been taken into consideration, but with ML limited to a more defining class such as that of moderate earthquakes. Also, a more focused extension in space.

Results and interpretations

Using ML reported by TIR and ML reported by EMSC we have done the analysis and the model obtained has the form :

$ML_{-TIR} = -0.07 + 1.02*ML_{-EMSC}$

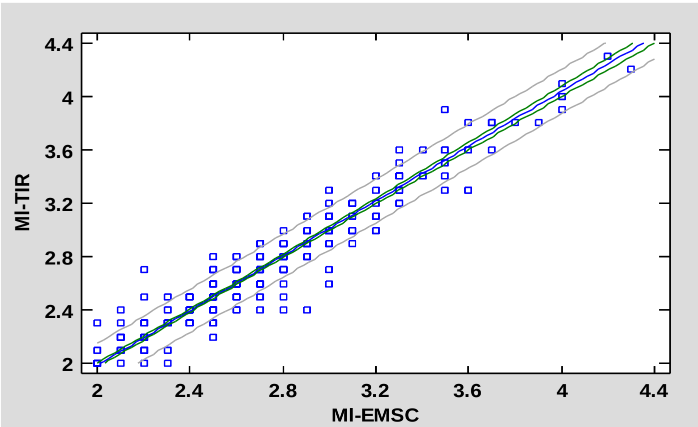


Figure 4 .Plot of fitted model TIR-EMSC with 95% confidence interval bounds in dashed lines

The results of the regression analysis are presented in the following tables :

Table 1. Coefficients of the regression model applied to MI-TIR and MI-EMSC values.

Parameter	Orthogonal Estimate	Standard Error	t Statistic	P-Value
Intercept	-0.0759314	0.0376866	-2.01481	0.0446
Slope	1.02936	0.0140284	73.377	0.0000

Table 2. Estimated error variances for the regression model, showing the variance and standard deviation (sigma) of measurement errors in MI-TIR and MI-EMSC, as well as the residual variance.

	Variance	**Sigma**
ML TIR	0.00696339	0.0834469
ML EMSC	0.00696339	0.0834469
Residual	0.0143417	0.119757

In the context of an orthogonal regression analysis, the information in the both tables provides insights into the relative magnitudes of the variability associated with different aspects of the model.

The smaller variances and standard deviations for the "ML TIR" and "ML EMSC" components suggest that these modeled components are capturing a significant portion of the variability in the data. The same analysis was done for ML reported by TIR and ML reported by NOA. The model obtained in this case has the form:

$ML\text{-}_{TIR} = -0.01 + 1.008 * ML\text{-}_{NOA}$

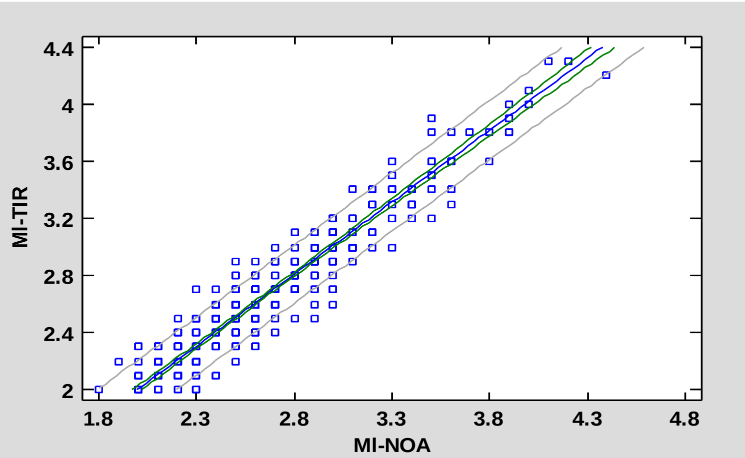
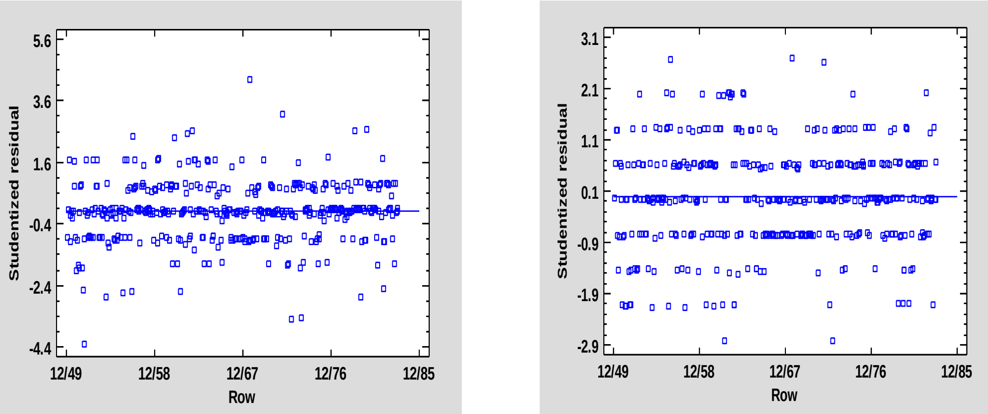


Figure 5. Plot of fitted model TIR-NOA with 95% confidence interval bounds in dashed lines

The residual plot presented provides a graphical assessment of the adequacy of the linear regression model utilized in the analysis. The random and scattered distribution of the residuals around the zero reference line suggests that the model is capturing the underlying relationships in the data in a satisfactory manner.



a) b)

Figure 6. Residuals for a) TIR-EMSC b) TIR-NOA

The residual plot illustrate a positive picture of the linear model's goodness-of-fit, with the random and evenly distributed residuals suggesting the model is doing a reasonable job of capturing the systematic relationships in the data. However, the presence of a few potential outliers and slightly uneven residual patterns in isolated areas indicates there may be room for fine-tuning the model to optimize its performance further.

Conclusions

Since $p < 0.05$ the statistical relationship between the variables is highly significant. We have a larger absolute value of the t-statistic indicates a stronger statistical relationship between the independent variable and the dependent variable.

The intercept is approximately 0 and the slope is close to 1, indicating that the magnitude reported by the Albanian National Earthquake Monitoring Centre is de facto equivalent to ML values reported by the EMSC and NOA. In terms of magnitude error estimation, the two agencies demonstrate a similar degree of accuracy.

On the other hand, the correlation coefficient of 0.96 is indicative of a strong dependence between the magnitudes reported by TIR and magnitudes reported by EMSC.

It is concluded that the difference between the orthogonal fit and maximum likelihood estimation, varies in the range 0.1-0.2. It is assumed that this reasonable difference is related to the regressive approach of both models. Based on our analysis, we can say that the orthogonal fit is the best way to compare the magnitudes reported by two different agencies.

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