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Comparison of Empirical Vs30 Modeling and Field Measurements in Kosova Using GIS-Based Spatial Analysis

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Abstract
Shear-wave velocity in the upper 30m (Vs30) is a key parameter for seismic site classification and hazard assessment. In regions with limited geophysical data, global empirical models, such as the slope-based approach developed by Allen and Wald (2007), are often used to estimate Vs30. This method relies on the correlation between terrain slope and shear-wave velocity: steep areas generally expose bedrock with higher Vs values, while flat areas typically contain softer materials with lower values. However, this approach does not always fully account for local geological characteristics. This study evaluates the accuracy of the Allen and Wald global model in Kosova by comparing predicted values with locally measured values obtained from field investigations using the MASW method. Model values were extracted at measurement locations using QGIS to analyze spatial deviations. The comparison assesses how well the global model represents local site conditions to identify potential differences. Ultimately, the analysis aims to evaluate the applicability of the slope-based method in Kosova and examine its limitations for detailed seismic site classification. Field measurements play a crucial role in ensuring more accurate seismic site characterization because they provide direct, location-specific data on subsurface conditions, reducing uncertainties associated with global or proxy-based estimation methods.

Keywords
Shear-wave velocity, Seismic site classification, Allen and Wald model, MASW, GIS.

1 Introduction

Seismic site conditions play a critical role in determining the level of ground shaking during earthquakes. Local soil properties can significantly amplify seismic waves, making accurate site characterization essential for earthquake-resistant design and seismic hazard mitigation. One of the most widely used parameters for describing site conditions is Vs30, defined as the average shear-wave velocity in the upper 30 meters of the ground.

Due to the high cost and time required for direct geophysical measurements, many regions lack detailed Vs30 information. To address this limitation, empirical models have been developed to estimate Vs30 from secondary parameters. One of the most influential approaches is the slope-based proxy method proposed by Allen and Wald, which estimates Vs30 using terrain slope derived from digital elevation models. This model is implemented in the global Vs30 map provided by the United States Geological Survey (USGS) and is commonly used in seismic risk models worldwide. Although the slope-based methodology provides consistent global coverage, it does not explicitly account for geological variation, sediment thickness, or subsurface stratigraphy. As a result, its accuracy and reliability vary between regions. Areas with complex geology, significant sedimentary basins, or strong lateral heterogeneity are particularly challenging for slope-based approaches.

Kosova is located in a tectonically active region of Southeast Europe and displays diverse geological and geomorphological conditions. However, publicly available Vs30 data in Kosova remains limited. The objective of this study is to evaluate the accuracy and applicability of the Allen and Wald Vs30 model for Kosova by comparing model predictions with field-measured Vs30 values. This work aims to assess the reliability of the global model under local geological conditions and to identify potential limitations when applying slope-based methods in seismic microzonation studies.

2 Study area

Kosovais located in Southeast Europe on the Balkan Peninsula and covers approximately 10,900 km². The country is characterized by diverse topography, with elevations ranging from 297 m in the DriniiBardhë valley to 2,565 m at Gjeravica, its highest peak. Several mountain ranges surround the territory, including the Kopaonik Mountains in the north, the Mali iSharrit Mountains in the south, and parts of the Alpet Shqiptare in the west. This varied relief reflects the complex geological setting of the region(The Independent Commission for Mines and Minerals, n.d.)

Kosova comprises a complex assemblage of sedimentary, igneous, and metamorphic rocks, resulting in significant lateral variability in subsurface conditions. The country is located within a tectonically active region influenced by the convergence of the Adriatic microplate and the Eurasian plate, where moderate seismicity poses a risk to the built environment. Due to the limited availability of systematic geophysical surveys, no national-scale Vs30 map based entirely on direct measurements currently exists. Consequently, global proxy-based models such as the Allen and Wald Vs30 model are commonly used in preliminary seismic assessments, making Kosova a suitable case study for evaluating their applicability under varied geological and topographic conditions.

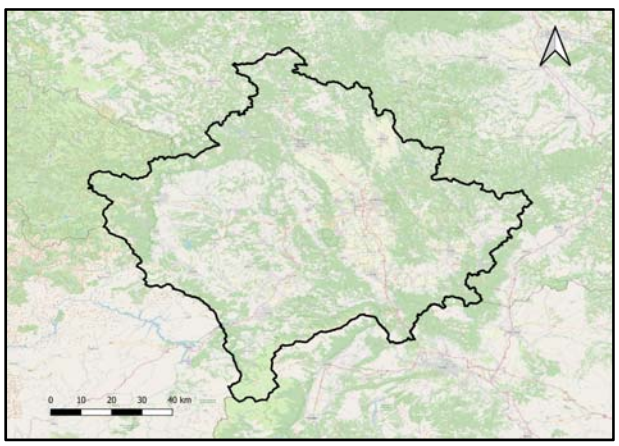


Fig. 1 Study area - Territory of Republic of Kosova.

3 Data and sources

This study uses two primary datasets: (1) the global Vs30 raster developed by Allen and Wald and distributed by the USGS, and (2) field-measured Vs30 values obtained from investigations conducted in Kosova. The USGS raster provides continuous global coverage and serves as the reference dataset for comparison.

Field measurements were collected during several seismic investigations in Kosova. Additional Vs30 data were obtained from the study "Seismic Microzonation: Case Study Ulpiana Settlement in Prishtina – Kosova" (Dojcinovski et al., 2014).

Spatial analysis was performed in QGIS. The USGS Vs30 raster was clipped to the territory of Kosova using a national boundary dataset, producing a localized Vs30 map. A DEM obtained from OpenTopography was also clipped to the study area and used to examine relationships between topography and Vs30 distribution.

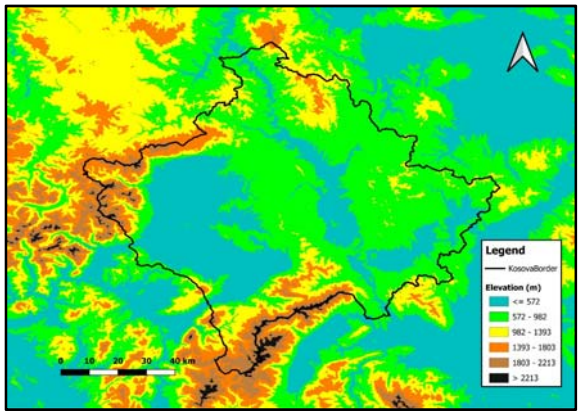


Fig. 2 Elevation map of Kosova extracted from Open topography.

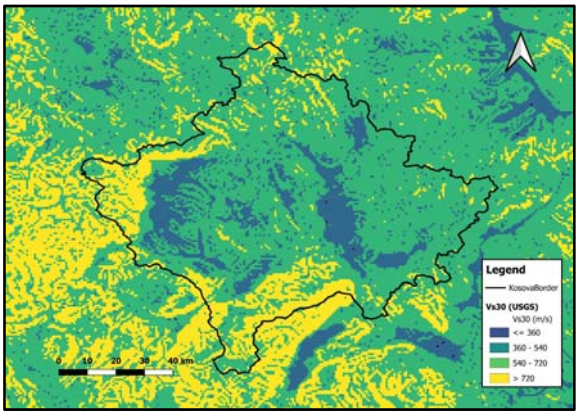


Fig. 3 Vs30 extracted from USGS global dataset.

Figures 2 and 3 show a general relationship between topography and predicted Vs30 values, reflecting the slope-based approach used in the Allen and Wald model. While topographic slope is the primary predictor, the final USGS Vs30 raster also incorporates additional adjustments to account for regional variations in surface conditions. Fig. 4 presents the slope-based Vs30 estimates prior to these adjustments.

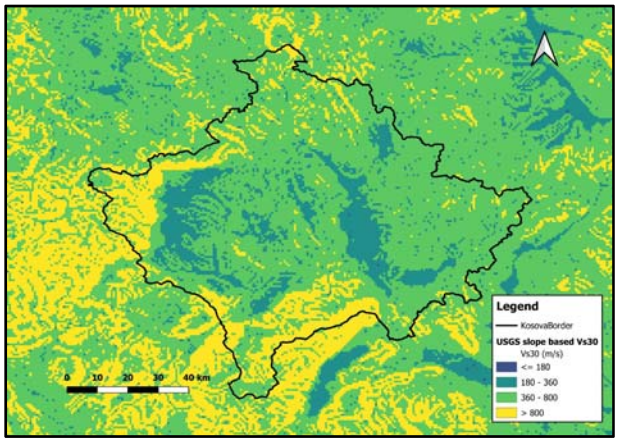


Fig. 4 Predicted values of Vs30 based only on slope.

By comparing Fig 4 and Fig 3, it can clearly be seen that they predict the same overall trend in the whole territory of Kosova indicating that topographic slope plays a dominant role in controlling the large-scale spatial distribution of predicted Vs30 values.

4 Methodology

After acquiring the datasets, spatial analysis was performed in QGIS. The global Allen and Wald Vs30 raster was clipped to the boundary of Kosova to produce a localized Vs30 map (Fig. 3). Field

measurement locations were then overlaid on the raster to compare predicted and measured Vs30 values (Fig. 6).

The Allen and Wald method estimates Vs30 from topographic slope derived from Digital Elevation Models (DEMs), assuming that steeper terrain generally corresponds to higher Vs30 values and flatter areas to lower values. The DEM (Fig. 2) was processed in QGIS to generate a slope map of Kosova (Fig. 5).

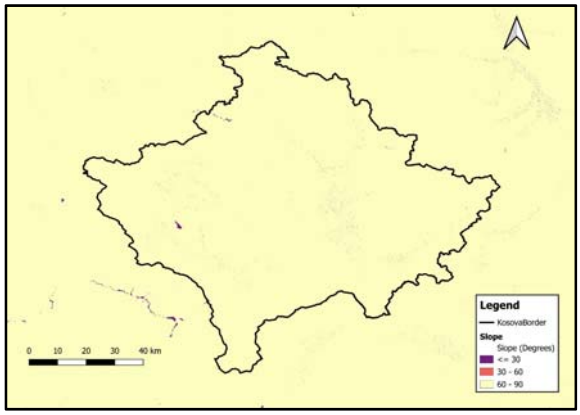


Fig. 5 Slope map of Kosova derived from the Digital Elevation Model (DEM) using the GDAL slope algorithm in QGIS. Slope values are expressed in degrees, illustrating the spatial distribution of terrain steepness.

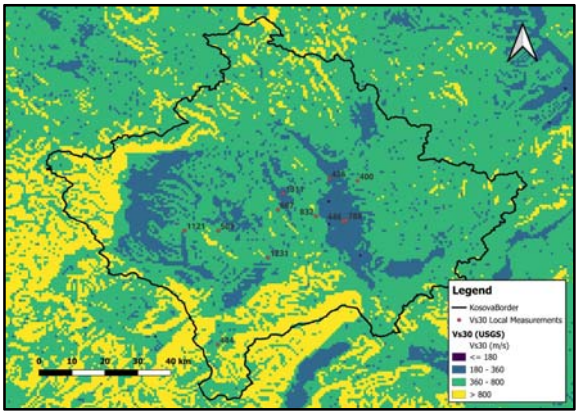


Fig. 6 Field measurement locations were overlaid on the clipped raster.

In Fig 6, the measured values of the shear-wave velocities from the field measurements were overlaid on the USGS raster. Because of the limited number of available measurements, the results should be interpreted cautiously. The differences between the measured values and the predicted values can be further explained using geological maps.

5 Results

Table 1 presents the field-measured and model-predicted Vs30 values for the 11 investigation locations in Kosova. The average absolute difference between measured and predicted values is approximately 345 m/s. While some locations show good agreement, with differences as low as 15 m/s, other sites exhibit substantial discrepancies exceeding 1000 m/s. These results indicate that the Allen and Wald model performs inconsistently across different geological settings within the study area.

Table 1. Comparison of measured and predicted Vs30 values at field investigation locations in Kosova.

ID	Longitude	Latitude	Measured Vs30 (m/s)	Predicted Vs30 (m/s)	Difference (Predicted - Measured) (m/s)
P01	21.1125	42.51833	446	254	-192
P02	20.83333	42.38333	1231	574	-657
P03	20.6478	42.0621	484	469	-15
P04	20.8904	42.621	1311	271	-1041
P05	21.1643	42.6673	400	429	29
P06	20.525	42.4839	1121	499	-622
P07	20.65	42.483	503	597	94
P08	21.061	42.676	436	298	-138
P09	21.1226	42.52134	788	252	-536
P10	21.0106	42.5367	832	436	-396
P11	20.87	42.56	687	615	-73

6 Discussions

The comparison between field-measured and predicted Vs30 values reveals significant discrepancies across the study area. While some locations show good agreement, the Allen and Wald model generally underestimates measured Vs30 values, with an average deviation of approximately 345 m/s. This indicates that the global slope-based model does not fully capture local site conditions in Kosova.

The discrepancies are likely related to geological factors not explicitly considered by the model, including lithology, sediment thickness, weathering, and subsurface stratigraphy. Consequently, reliance solely on slope-based Vs30 estimates may lead to inaccurate site classification and ground-motion assessments, particularly in sedimentary basins. Although the model provides a useful first-order approximation in data-scarce regions, it should not replace site-specific geophysical investigations.

This study is limited by the small number and uneven distribution of available measurements. Future work should expand the dataset and develop hybrid Vs30 models that integrate topographic, geological, and geophysical information.

7 Conclusions

This study assessed the performance of the Allen and Wald global slope-based Vs30 proxy model in the Republic of Kosova by comparing predicted Vs30 values with locally measured Vs30 obtained from MASW investigations. The analysis was conducted using GIS-based spatial methods to evaluate deviations, correlations and spatial patterns across the study area. The comparison revealed that although some locations show good agreement between predicted and measured Vs30 values, significant discrepancies are present at many sites. Predicted Vs30 values generally underestimate measured values, particularly in areas characterized by high Vs30 associated with shallow bedrock or stiff geological formations. The average deviation of approximately 345 m/s indicates that the global slope-based model does not sufficiently capture local site conditions in Kosova when applied without regional calibration.

In the context of seismic hazard assessment and microzonation in Kosova, reliance solely on the global slope-based model may result in inaccurate site classification and ground-motion estimates, particularly in urban areas located within sedimentary basins. A study of seismic hazard assessment and microzonation would benefit from using geological and tectonic maps for the territory of Kosova, as well as more field investigation surveys.

While the Allen and Wald model may serve as a useful first-order approximation in data-scarce regions, it should not replace site-specific geophysical investigations or detailed geological analysis for local seismic applications. Future work should focus on increasing the number and spatial distribution of Vs30 measurements and developing hybrid approaches that integrate terrain, geological and geophysical data. Despite its limitations, this study provides valuable insight into the applicability and limitations of global Vs30 proxies in Kosova and highlights the importance of region-specific calibration for reliable seismic hazard assessment.

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