Type area

Analysis of human vulnerability exposure to landslides using AHP- GIS method

A.Kab
University of Sciences and Technology Houari Boumediene, LEEGO, Faculty of Civil Engineering, BP. 32 El-Alia, 16111 Algiers, Algeria. E-mail: amelkab1984@gmail.com
L. Djerbal
University of Sciences and Technology Houari Boumediene, LEEGO, Faculty of Civil Engineering, BP. 32 El-Alia, 16111 Algiers, Algeria. E-mail: ldjerbal@usthb.dz
R. Bahar
University of Sciences and Technology Houari Boumediene, LEEGO, Faculty of Civil Engineering, BP. 32 El-Alia, 16111 Algiers, Algeria. E-mail: rbahar@usthb.dz

ABSTRACT: Landslides increasingly affect human health, killing thousands of people annually all over the world. However, human vulnerability is a crucial element in reducing landslide risks. This paper deals with the establishment of an efficient method for human consequences assessment (vulnerability). The adopted methodology is based on a statistical data-driven tool to estimate an individual's probability of death according to the landslide intensity, which can be used directly in landslide risk assessment and mitigation. The evaluation is based on the AHP (Analytical Hierarchical Processes) model to calculate each factor's weight. The work is made via GIS by using an ArcGIS-AHP extension.

In the current research, the five vulnerability factors were identified and mapped from existing documents, works, and new data which came from either remote sensing or fieldwork (Population density, land use, annual average growth rate, urbanization ratio and housing occupation ratio). Then, afterward, each parameter is classified into a number of significant classes based on their relative influence. The obtained human vulnerability map constitutes a powerful decision-making tool in land-use planning, within the national development program in the Northern provinces.

KEY WORDS: people vulnerability; landslide; data driven; risk; human consequence; vulnerability.

1 INTRODUCTION

Among natural disasters, Landslides are one of the most destructive hazards causing severe economic damage and human mortality. In recent years, in nothing Algeria (specifically Tizi Ouzou region) has been severely affected by landslides (Kab et al. 2018). For instance, until 2022, at least 39 cities of Tizi Ouzou region were affected by landslides for two weeks, causing infrastructure destruction and human mortality. Due to the highly destructive impacts of landslides, there is a great need for improved landslides risk mapping.

The necessity and significance of evaluating vulnerability to landslides and other natural hazards is predicated on the premise that the risks posed by such events, as well as the actual losses incurred, are contingent upon the prevailing societal and economic conditions that influence how individuals and communities are prepared for or respond to these occurrences (Birkmann, 2013; Cardona et al., 2012; Cutter et al., 2003).

vulnerability can also be viewed as the degree of loss to a given element at risk or a set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude and expressed on a scale from 0 (no damage) to 1 (total damage) (Roxana et al., 2013).

An additional factor that must be considered in vulnerability assessment is the target of analysis i.e. the elements at risk. In general terms, these are the objects or systems that pose the potential to be adversely affected (Hufschmidt et al., 2005) by a hazardous event. In (V.westen et al., 2006) the elements at risk are defined as the objects, population, activities and processes that may be differently affected by hazardous phenomena, in a particular area, either directly or indirectly.

The extent of damages or losses resulting from the occurrence of hazards can be significant. In the immediate aftermath of a disaster, the primary concern is the potential for loss of life and injury, as well as the impact on the functionality of essential services, infrastructure, and the economy. In the longer term, indirect economic consequences, social disruption and environmental degradation may become of greater importance. It is often difficult to quantify the consequences of disasters, as many of them cannot be easily measured (Schuster and Highland 2001)

Generally, vulnerability can be measured either on a metric scale, e.g. in terms of a given currency, or a non-numerical scale, based on social values or perceptions and evaluations (Glade 2013, Roxana et al., 2013). Direct human (social) and physical losses can be described and quantified using different methods.

From 2004–2016, landslides have caused an annual average of over 4,000 deaths worldwide, and in the United States alone, they are estimated to kill 25–50 people each year (Froude & Petley, 2018; Schuster & Highland, 2001, pollock and Wartman, 2020). Understanding human vulnerability to landslides is essential for predicting and preventing human loss of life.

Different researches have been devoted to quantifying the physical vulnerability of buildings to landslides, but there are no comparable studies that quantifies human vulnerability for use in risk assessment. The few methods that exist rely extensively on expert judgment and are not easily transferable (AGS, 2007; Corominas et al., 2014; Lee & Jones, 2014, pollock and Wartman, 2020). Furthermore, these methods only inform the potential for human losses and do not explore the underlying causes of human mortality

The objective of this study is twofold: firstly, to identify the vulnerability of human populations to landslides and secondly, to explore the underlying causes of mortality. In order to address this issue, an indirect approach utilising multi-criteria decision-making has been put forth as a potential solution. The analytic hierarchy process (AHP) has recently been employed in landslide studies, integrating subjective and objective assessments into a unified framework. This approach entails measuring the consistency of decision-makers' judgments, generating pairwise comparisons for selecting a single solution, and considering criteria and sub-criteria for evaluating options.

2 MATERIALS AND METHODS

Study area

Tizi Ouzou is one of the most vulnerable to landslides in Northern Algeria. It has an area of about 2 992,96 km2 and is located between 36° 28’ latitude North, 36° 55’ latitude North East, 03° 45’ longitude East, 04° 31’ longitude East (Figure 1). At the origin of the existence of a fragmented relief. The altitude reaching 2000m (Ras-Timedouine, at an altitude of 2305m, in the mountain range of Djurdjura). It has a long coast to the Mediterranean Sea, with a population of about 1,198,561 inhabitants, i.e. a density of 405 inhabitants per km². The region has a Mediterranean climate with average annual precipitation between 600-1000mm/year. The hydrographic network of the region is made up of a dense, well hierarchical and mostly enclosed.

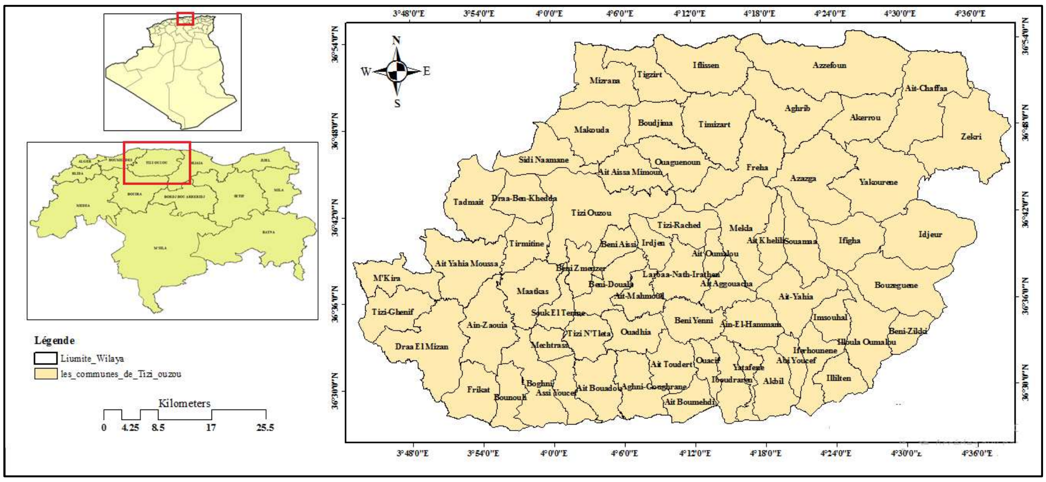

Figure 1: Location of study region.

1.1. Landslide inventory

The landslide inventory was constructed collecting data from different sources. The first source is an inventory going back to 2012 which was made from aerial photographs interpretation and validated by intensive field work in two test areas within the region. This census concerned 39 dairas which represent an area estimated at approximately 53% of the total area of this region (Figure 2) and only concerns landslides with an area greater than 1ha affecting urban sites (where populations are subject to danger).
The study led to the identification of 84 instabilities affecting urban sites and/or road infrastructure (Kab et al. 2018).
The second source is the interpretation of aerial images covering center of the study region. The images were taken from Google earth satellite, in November 2022. They allowed us to identify 40 new landslides stereoscopically in low-urbanization area (Kab at al. 2023).

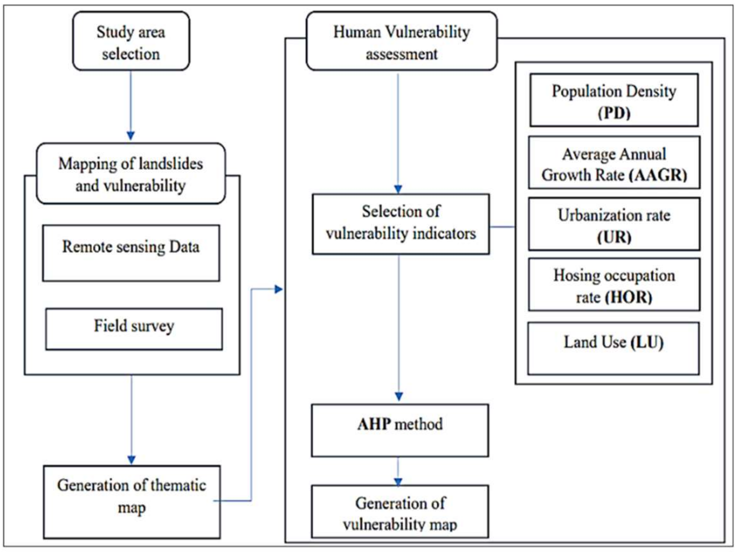

Figure 2: landslides inventory map (detected between 2012-2018 and in November 2022).

Landslide Human vulnerability
In landslide risk analysis, human vulnerability may be expressed as the probability that an individual will be killed in a landslide (Corominas et al., 2014).

The human losses are of critical importance compared to infrastructure, research investigating the vulnerability of people to landslides is rare (Glade, 2003; Lin et al., 2017; Massey et al., 2019). this is explained as human losses in landslides are often linked to the collapse of occupied buildings and are therefore indirect, a function of structural vulnerability (Jakob et al., 2012).
Human vulnerability also depends on human behavior, including hard-to-measure factors such as prior knowledge of hazards, situational awareness and decision-making capacity. (Eidsvig et al., 2014). Human data is difficult to collect; people have often moved, been dispersed in hospitals or died. Finally, ethical approval is required for human research subjects, presenting an additional challenge for studies of human vulnerability.
A robust methodology is essential for effective calculation, which can be an excellent tool for emergency response and land use planning and decisions. The flowchart presented in Figure 3 shows the procedure adopted for this work. The approach adopted in this study includes three main stages: (i) acquisition of information, (ii) the development of a digital database using GIS and (iii) the zonation of vulnerability on a regional scale.

Figure 3: Methodology for landslides human vulnerability assessment.

Precise qualitative and quantitative census of the different criteria (vulnerable targets and vulnerability factors) was carried out, based on database (Land use plan-Local urban planning plan, census databases etc.).

Population density (PD), Average Annual Growth Rate (AAGR), Land Use (LU), Housing Occupancy Rate (HOR), and Urbanization rate (UR) were selected as indicators or factors for vulnerability assessments (Table 1 and Figure 4 (a) to (e)).
The PD, AAGR, UR, HOR data were collected with a pixel size of 30 × 30 m and grouped into five classes: very high, high, moderate, low, and very low. The LU map was divided into six zones categories (water, forest, agriculture, built and urban, bare ground, rangeland).

Table 1. Investigated vulnerability factors.

Factors	Relationship with Vulnerability
Population density (PD)	Datasets in Geotiff. (resolution of 30m) derived from the corresponding population count datasets by dividing the number of people in each pixel by the pixel surface area.
Average Annual Growth Rate (AAGR)	Registration data (births, deaths and migrants). compares the average annual percent change in populations, resulting from a surplus (or deficit) of births over deaths and the balance of migrants entering and leaving a country. The rate may be positive or negative
Land Use (LU)	Landsat 8 satellite image and the supervised digital classification technique of images (remote sensing) was used using the Google Earth engine and the integration of a classification algorithm (Machine Learning SVM method)
Housing Occupancy Rate (HOR)	edited by the authors based on the data of the relevant censuses. (Number of occupied accommodations / Total number of available accommodations) x 100
Urbanization rate (UR)	Based on country census data and UN urbanization data. World map relating to the rate of urbanization by state and territory, i.e. the percentage of the population living in an environment defined as urban.

To create a landslide indexed vulnerability map of Tizi Ouzou, by using AHP (Analytical Hierarchical Processes) model to calculate each factor's weight. The work is made via GIS by using an ArcGIS AHP extension.
Questionnaires based on the analytical hierarchy process (AHP) were prepared to evaluate the landslides human vulnerability according to experts' knowledge. The principal of experts was peoples and included Ph.D. students, faculty members, and executive experts of the regional landslides company, Roads and Urban Development Office, Management and Planning Organization. The AHP method applies a hierarchical structure to indicate a problem with users' judgments to develop priorities for alternatives. It requires developing a binary comparison matrix for each

factor, specifying a scale ranging from 1 to 9 depending on the importance of the parameter, this rule is called “interdependence relationship”.
The weights assigned to the factors are judgments resulting from a good knowledge of the terrain and mastery of the importance of the factors in the landslides process (Saaty 1984).
It is necessary to calculate a consistency ratio (CR) to indicate the reliability of the judgments of the calculated matrix (SAATY, 1977). To show that the matrix is coherent, the value of (RC) must be less than 0.1 (10%).
The consistency ratio (CR) is calculated by the following equation

$$RC= IC/RI \qquad (1)$$

With (RC) coherence ratio, (RI) random index developed by SAATY 1977 and (IC) the coherence index calculated by the equation below

$$IC = \lambda \max -n/n-1 \qquad (2)$$

λ max: maximum eigenvalue of each factor in the matrix table and n the size of the matrix (SAATY, 1990).
After computing the weights of layers by using the AHP model, pixel values of every layer were normalized according to the equation (3). Then the landslides humain vulnerability map (LHV) was created based on the raster-calculator tools in ArcGIS 10.2, according to:

$$LHV = \frac{\sum W_i N_i}{\sum W_i} \qquad (3)$$

Wi is the weight of ith variable calculated by AHP, Ni is the normalized layer of variable i, and n is the number of variables.

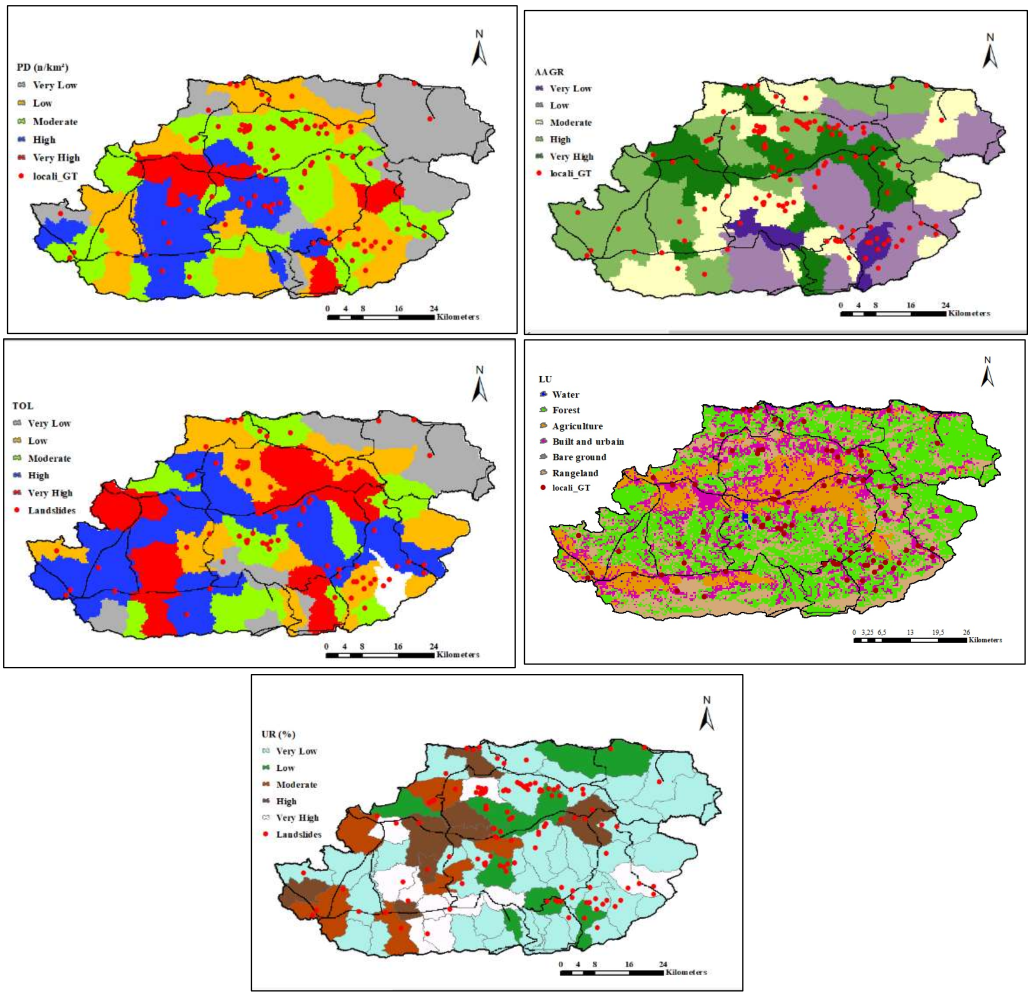

Figure 4. Vulnerability factors: (a) population density (PD), (b) Average Annual Growth Rate (AAGR), (c) Urbanization rate (UR), (d) Housing Occupancy Rate (HOR) and (e) land use (LU).

3 RESULTS AND DISCUSSION

The results obtained from the AHP indicate that among the landslide vulnerability parameters, Housing Occupancy Rate (0.363), Urbanization rate (0.279), and Average Annual Growth Rate (0.158) are the most important, followed by Population density (0.087), Land Use (0.064), and distance to medical centers and hospitals (0.049). Table 2 shows the weights assigned to each parameter (based on the AHP method and expert knowledge).

Table 2. The landslide's human vulnerability indicators based on the AHP method

Human Vulnerability Factor	weight
Population density (PD)	0.09
Average Annual Growth Rate (AAGR)	0.15
Land Use (LU)	0.08
Housing Occupancy Rate (HOR)	0.43
Urbanization rate (UR)	0.28

From the matrix created two by two for the factors PD, LU, AAGR, HOR, UR, and the normalized weight for each factor; the consistency ratio was also calculated according to the equation (1) of SAATY (1977), whose value obtained is 0.03 (Table .3).
The rule proposed by Saaty states that if the value of CR is less than 10%, the matrix can be considered sufficiently coherent to apply the calculation of the eigenvector to obtain the weighting. Herman and Koczkodaj (1996, p.26) describe such matrices as “Not-So-Inconsistent (NSI)”.
Table 3. AHP analysis results parameters

Parameter	Value
λ max	5,13
IC	0,03
IR	1,12
CR	0,03

The human vulnerability map was divided into five classes by using the equal interval method: very low, low, moderate, high, and very high (Figure 5), covering area percentage of 27.01%, 27.07%, 28%, 8.65, and 9.28 km2 of the region, respectively (Table 4).
The center of the area is more exposed to human lost, and several parts in the west and central areas have high human vulnerability (Figure 5).

Table 4. Areas with different flood vulnerability categories.

Human Vulnerability	Area in %
Very low	27.01
Low	27.07
Moderate	28
High	8.65
Very High	9.28

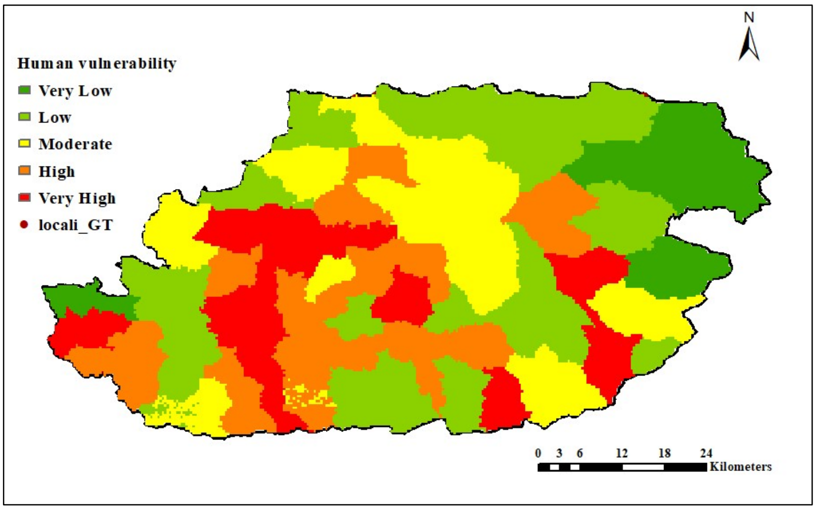

Figure 5: human vulnerability map for the region of Tizi Ouzou.

The models showed that areas close to major rivers are much more exposed to flooding and were categorized as very high and high (about 38% of the area).
The vulnerability of population (Human) to the landslides risks depends mainly on the tolerance of the city's general framework and its ability to cope with landslide damage. In the Tizi Ouzou region, 17.92% of the area is of high and very high human vulnerability to landslides.
The land-use and PD maps (Figure 4 (a) and (e)) showed that residential areas with high and very high population densities are located in areas with very landslides hazards (Figure 5). Therefore, these areas require efforts to minimize future damages.
Generally, the human vulnerability map (Figure 5) indicated that the center of the area and several areas in west and central areas of the city are most exposed to landslide human vulnerability.
Un- planned developments of residential areas (housing occupancy rate, urbanization rate) along the built areas are the most influential causes of human fatalities. Appropriate urbanization systems (strategies) are necessary for better landslides management, and it is of great importance to identify the most vulnerable urban residents in all areas for decreasing landslide.
Due to human injuries (such as population density, average annual growth rate, housing occupancy rate, urbanization rate and land-use changes), the vulnerability map may change over time. Thus, it is important to perform similar future investigations and compare these results. It may be possible to predict human vulnerability maps for future periods by considering local human activities and population change's impacts.

4 CONCLUSION

This research demonstrates the potential of spatial analysis techniques in landslide risk assessment. The process of analytical prioritization was applied to create a human vulnerability map to landslides for the Tizi Ouzou region. To achieve this objective, five vulnerability induction elements were taken into consideration, namely population density, average annual growth rate, land use, housing occupancy rate, and urbanization rate. These elements act as a detector of weaknesses in the study area. By applying the AHP method, values of human vulnerability to landslides were calculated. The human vulnerability map was subsequently derived under AHP-GIS integration. The model outperformed an acceptable consistency ration (CR= 0,029 < 0,1 saaty 1980). Which indicates a good combination of the factors. Five levels of vulnerability were detected and had shown the significant degree of damage recorded in the majority of the territory of the study area. The housing occupancy rate and urbanization rate, are a significant parameter in landslide human vulnerability.
The integrated technique outlined in the present study shows credible results can be obtained without complex modeling and costly field surveys. The proposed method is especially helpful in areas with little data to describe and exhibit landslides. The human vulnerability map indicates

that the center and west central areas are very vulnerable to effect on human and must develop accurate management to prohibit landslides or provide a remedy

5 REFERENCES

AGS (2007). Commentary on practice note guidelines for landslide risk management 2007. Australian Geomechanics, 42, 115–158.

Batuwita, R.; Palade, V. Class Imbalance Learning Methods for Support Vector Machines. Imbalanced Learning;

Cardona, O.D., M.K. van Aalst, J. Birkmann, M. Fordham, G. McGregor, R. Perez, R.S. Pulwarty, E.L.F. Schipper, and B.T. Sinh, 2012: Determinants of risk: exposure and vulnerability. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 65-108.

Corominas, J., van Westen, C., Frattini, P., Cascini, L., Malet, J. P., Fotopoulou, S., et al. (2014). Recommendations for the quantitative analysis of landslide risk. Bulletin of Engineering Geology and the Environment, 73, 209–263. https://doi.org/10.1007/s10064-013-0538-8.

Eidsvig, U., Papathoma-Kohle, M., Du, J., Glade, T., & Vangelsten, B. (2014). Quantification of model uncertainty in debris flow vulnerability assessment. Engineering Geology, 181, 15–26. https://doi.org/10.1016/j.enggeo.2014.08.006

Froude, M., & Petley, D. (2018). Global fatal landslide occurrence from 2004 to 2016. Natural Hazards and Earth System Sciences, 18(8), 2161–2181. https://doi.org/10.5194/nhess-18-2161-2018

Herman, M. W., & Koczkodaj, W. W. (1996). A Monte Carlo Study of Parwise Comparison. Inf. Process. Lett., 57(1), 25-29.

Hufschmidt, G, Crozier, M, & Glade, T(2005). Evolution of natural risk: research frame- work and perspectives. Natural Hazards and Earth System Sciences, 5(3), 375-387.

J. Birkmann (Ed.) (2013), Measuring Vulnerability to Natural Hazards: Towards Disaster Resilient Societies, United Nations University Press, Tokyo, Japan , pp. 9-79

J. Birkmann, O.D. Cardona, M.L. Carreño, A.H. Barbat, M. Pelling, S. Schneiderbauer, S. Kienberger, M. Keiler, D. Alexander, P. Zeil, T. Welle Framing vulnerability, risk and societal responses: the MOVE framework Nat. Hazards, 67 (2013), pp. 193-211, 10.1007/s11069-013-0558-5

Jakob, M., Stein, D., & Ulmi, M. (2012). Vulnerability of buildings to debris flow impact. Natural Hazards, 60(2), 241–261. https://doi.org/ 10.1007/s11069-011-0007-2.

Kab A., Djerbal L., & Bahar R. (2018). Landslide Susceptibility Mapping of Tizi-Ouzou Region, Algeria. Engineering Geology and Geological Engineering for Sustainable . Use of the Earth's Resources, Urbanization and Infrastructure Protection from Geohazards, Sustainable Civil Infrastructures.

Kab, A., Djerbal, L. & Bahar, R (2023). Implementation of PCA multicollinearity method to landslide susceptibility assessment: the study case of Kabylia region. Arab J Geosci 16, 291. https://doi.org/10.1007/s12517-023-11374-5

Lee, M., & Jones, D. (2014). Landslide risk assessment (2nd ed.). London: Institution of Civil Engineers

Lin, Q., Wang, Y., Liu, T., Zhu, Y., & Sui, Q. (2017). The vulnerability of people to landslides: A case study on the relationship between casualties and volume of landslides in China. International Journal of Environmental Research and Public Health, 14(2), 212. https://doi. org/10.3390/ijerph14020212

Massey, C., Thomas, K-L., King, A., Singeisen, C., Taig, T., & Horspool, N. (2019). SLIDE (Wellington): Vulnerability of dwellings to landslides (Project No. 16/SP740). GNS Science report; 2018/17.

Pollock, W., & Wartman, J. (2020). Human vulnerability to landslides. GeoHealth, 4, e2020GH000287. https:// doi.org/10.1029/2020GH000287

Robert L. Schuster and Lynn M. Highland 2001 Socioeconomic and Environmental Impacts of Landslides in the Western Hemisphere. U.S. Geological Survey. https://doi.org/10.3133/ofr01276

Roxana L. Ciurean, Dagmar Schröter and Thomas Glade (2013). Conceptual Frameworks of Vulnerability Assessments for Natural Disasters Reduction [Internet]. Approaches to Disaster Management - Examining the Implications of Hazards, Emergencies and Disasters. InTech;. Available from: http://dx.doi.org/10.5772/55538

Saaty, T. J. and Vargas, L. G., (1980), Decision Making with the analytic Network process: economics, political, social and technological application with benefits, opportunities, costs and risks, Spring Science + Business, USA

Saaty, T. J, (1996), Decision making in Complex Environments, The Analytical Hierarchy Process for decision Making with Dependence and Dependence and Feedback (USA: RWS Publications).

Schuster, R., Highland, L. (2001). Socioeconomic and environmental impacts of landslides in the western hemisphere. U.S. Geological Survey Open-File Report 01–276.

S.L. Cutter, B.J. Boruff, W.L. Shirley (2003). Social vulnerability to environmental hazards. Soc. Sci. Q., 84, pp. 242-261, 10.1111/1540-6237.8402002

Thomas Glade (Bonn) 2013. Vulnerability Assessment in Landslide Risk Analysis Vulnerabilitätsbewertung in der Naturrisikoanalyse gravitativer Massenbewegungen. Landslide hazard – Vulnerability assessment – Risk analysis. DIE ERDE 134 2003 (2)

Van Westen, CJ, Van Asch TWJ(2006). Landslide hazard and risk zonation-why is it still so difficult? Bulletin of Engineering Geology and the Environment, 65(2), 167-184.