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Spatial Landslide consequence assessment and mapping using multiple correspondence analysis (MCA). Application in North Algeria.

Evaluarea și maparea consecințelor alunecărilor de teren folosind analiza corespondenței multiple (MCA). Aplicație în nordul Algeriei.

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Abstract. *North Algeria is very subject landslide Geo-phenomena, which causes each year very serious infrastructure damages and human lives. In order to estimate these damages and assess the effects of landslides on current development plans or future development programs, the analysis of the consequences seems like a very important criterion. Numerous approaches developed over the last decade, which have encountered difficulties in application, due to the lack of data on historical damage. This article presents a quantitative study of the potential consequences, based on GIS mapping in the Tizi ouzou area. The proposed methodology comports two principal stages ; the first identifies in a statistical way (Multiple correspondence analysis MCA) the correlations between the categories of exposed elements (land use, infrastructure, human) and the second phase consists in evaluating and mapping the damage potential of these elements using the technology of geographical information*

Key words: landslide; multiple correspondence analysis MCA; consequence analysis; GIS; mapping damage; inventory

1. Introduction

Global statistics as well as local statistics show that the damage caused by the landslide phenomenon has increased in recent years (Alexander, 2000). Evaluating the degree of this damage of a given type and volume gives notion about the study of the consequences. The Landslide consequence assessment is very important for on-going and future planning (emergency or land use) exercises and its application is useful further less developed component of quantitative landslide risk assessment. It is a way of measuring which people, facilities and resources are potentially vulnerable, where they are located and what might be the strategy to reduce this vulnerability (Puisant et al., 2006). It is defined as the result or potential result of a risk element resulting from a landslide expressed qualitatively or quantitatively, in terms of loss, disadvantage or gain, injury or loss of life (Glade and Crozier 2005, Puissant et al 2013). It is described as the process of describing and quantifying the relationship between exposures to a risk agent and the adverse health and/or environmental consequences that result from such exposures.

The advice that precious consequence assessment, that consider best available information accurately and transparently, will improve the decision-making, and will inform risk assessors of the breadth of methodologies used. Additionally, improved consequence assessments using better-defined approaches, will allow public to understand the landslide making process and gives for more consistent, repeatable results (Dale and Sam, 2005).

Consequence assessment can make use of (1) equations taken from professional literature, (2) numerical charts calculated from equations or from experimental data and (3) software models. Three categories of methods to evaluate landslide consequences have been developed in recent years by several researchers (Malet et al 2015). Léone et al. (1996), Maquaire et al. (2004), Bonnard et al. (2004), Glade (2003) and Malet et al. (2005) provide detailed summaries of such methods. The choice of the analysis method, more or less complex, depends above all on the scale of study. In most cases, a pure quantitative assessment (based on a detailed calculation of the value and vulnerability of the exposed elements) is difficult because the damage databases are scarce or not detailed enough. for this purpose, several other authors have preferred the empirical analytical approach based on a relative evaluation of the value of the elements exposed (Malet et al 2015, Puissant et al., 2013) or others that use expert approaches based on identification (map, photography, aerial) of homogeneous sensitive areas and key issues. It is only recently that there has been some progress concerning the Quantitative Consequences and Risks Assessments by Leroi 1996, Amatruda et al., 2004, Bell and Glade, 2004, Puissant et al., 2013. While qualitative methods rely mostly on subjective judgment, quantitative methods aim to evaluate losses due to landslides quantitatively for the probability of occurrence of a catastrophic event. Being reproducible and objective, quantitative methods for landslide risk assessment have received increased focus (Erener and Düzgün, 2012).

Because of the lack of complete landslide inventory maps and oversimplifications related to landslide influencing factors and triggers (Van Westen et al. 2006; Guzzetti et al., 2005; Erener and Düzgün, 2012), it is difficult to make temporal predictions of landslide occurrence (Erener and Düzgün, 2012). In addition, satellite imagery or aerial photography can give only a limited number of parameters, the use of the statistical approach that collects data for a reference (predefined rendering unit) and which must take into account the functional aspects and describe the socio-economic dimension of the areas covered is required. Landslide statistics in particular on the damage caused, including effects on population, local and regional infrastructure, activity, ...etc are influenced by the accuracy of the techniques used to compile, map and digitize these events, or the tendency to use statistical processing methods to manage these damages and extract the correlations between the various elements at risk. The considerable amount of quantitative and qualitative statistical data is the scope of the multi-criteria analysis (S. Chakhar, 2003). This leads us to implement a quantitative method that relies on the relative statistical evaluation of each element exposed to assess the consequence and using the GIS tools.

Frequent use of GIS refers to spatial decision making. Indeed, GIS, through its capacity in the storage, management, analysis, modeling and display of spatially referenced data, presents itself as the most appropriate tool for understanding spatial decision problems. Nevertheless, the current GIS technology still suffers from several shortcomings, due in large part to a lack of analytical capabilities capable of supporting the multi-criteria nature of spatial problems. Since the CMA clearly offers several decision-making advantages when conflicting interests must be taken into account, it provides the necessary support to fill these gaps. The most widely used solution to evolve GIS into a real decision-making tool is to couple it with operational research tools and in particular with multi-criteria analysis (GIS-AMC integration strategy). This strategy makes it possible to better engage in the analysis of the phenomena of landslide.

2. Methodology

In the adopted methodology, combining the identification of the exposure elements at risk (EAR) and their damage value led to evaluate landslide potential consequences damages (Maquaire *et al.,* 2004, Puissant et al.,2006). A mathematical model developed with the use of the resulting contribution of each element by a statistical Multiple Corresponding Analysis (AMC). Landslide potential consequences is expressed in classes form instead of a numerical size (Maquaire et al., 2004). The process takes place in three main phases shown in figure 1: (i) identification of the element at risk exposure (ii) potential consequence assessment and (iii) consequence zoning.

The first step is to define Element at risk exposure (the probable affected elements by the landslide phenomena, such as properties, inhabitants, or environment). The landslides consequences of and risk depend on the elements nature presents in a region (Alexander 2005, Corominas et al., 2014).

The list of elements at risk exposure is necessary to assess the potential consequence and elaborating consequence map, a typology of the main element at risk observed in a region is evaluated. Buildings, roads, land use, population and infrastructure were considered for the analysis (Malet et al., 2015, Puissant et al., 2006; Erener and Düzgün, 2012).

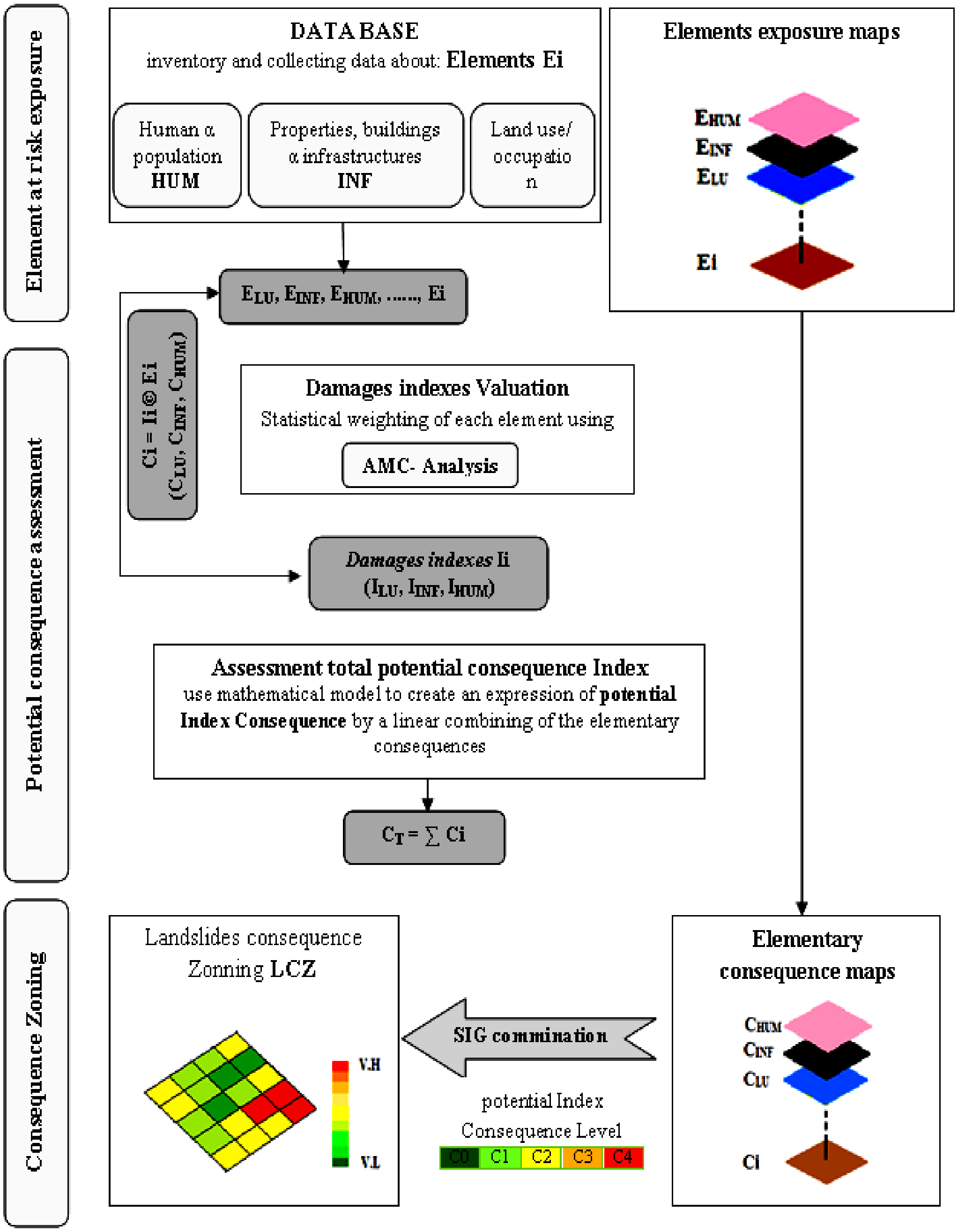

Fig.1. Process used to evaluate landslide consequences.

The data useful for the analysis of the potential consequences were collected and treated in table 1 by distinguishing three consequence categories of exposed at risk elements with inspiration from Westen et al. 2008, which appear as the most revealing and probabilistic of the stakes (Léone et al., 1996):

- Land use / occupation (LU): This category includes land use, which is a physical description of the observed area of the land surface (which covers the land) and land use, which is the functional size that refers to the description of the areas according to their socio-economic purpose (Gregorio and Jansen 1997, Malet et al 2015). This information can be compiled by means of surveys or censuses and / or by the data already collected in the administrative and statistical registers, especially on urbanized areas (POS reports). The land use classes used for the consequence analysis show 5 classes due to lack of information on land property values.
- Infrastructures (INF): this category includes (a) buildings that are a permanent place of residence (building, detached house) or not permanent (place of commercial activity, industrial), particular monuments (mosques, cemeteries), etc ...; (b) network infrastructure (electricity, gas, water) as well as sanitation and drinking water networks; (c) principal road network (highway, national road); (d) secondary road network (wilaya or communal road) and (e) all that port / airport and these parking.
- Human or population (HUM): regroups peoples in their physical integrity which is subdivided into 4 classes; a human catastrophe in which a significant number of life lost to the liver, some deaths, only injuries that have been hospitalized and finally a population at risk that includes a group of people who have been evacuated or not yet and who are at risk as a ruin of their homes, workplace or traffic.

Table 1. **Element at risk parameters for each consequence category**

Consequence categories	**Design value**	**Element at risk parameter**
Land use / occupation (LU)	1	Urban area
	2	Agricultural area
	3	Forest area
	4	Water zone
	5	Industrial Zone
Infrastructure (INF)	1	Building and construction
	2	Main road
	3	Secondary road
	4	Networks
	5	Ports / Airport and parking
Human or population (HUM)	1	Human disasters or several deaths
	2	Some people deaths
	3	Injuries
	4	Exposed population

In the inventory phase, data regarding each element at risk is gathered for the studied area; national registration records for living and working; real property map, electricity grid map...etc (Falemo and Sköld, 2011). The inventory based on interviews, previous investigations and events (Falemo and Sköld et al., 2014), existing cadastral databases, which are expensive and sometimes unaffordable, to create data bases for the numerous run-outs of slopes. In addition, population data may be derived from existing census (Erener and Düzgün, 2012). Therefore, the elements at risk used in the analysis, mostly depends on the availability of digital databases and the accuracy depends on the existing database. In this study the elements at risk was defined as referencing to the existing database used by Kab et al. 2018 based on census and field exploration.
The elaboration of the elementary maps necessary for the analysis using GIS computer tool, was carried out by superposing and interpolating the BD to an inventory map of landslides, the latter interpolates an existing effect (damage) by considering it as a future event (Erener and Düzgün, 2012).

Next step is to assessing consequence. Statistical damages indexes valuation is necessary to define the contribution of each element at risk, we use here AMC, which used to show the correlation between a set of variable (Ei) of nominal qualitative nature. A relative value called '"damage index"' (Ii) is obtained for each of the elements to value the relative importance of each stake (Puissant et al., 2006). The exposed elements Ei for each issue associated with their respective indices (index damage Ii) makes it possible using equation 1 to evaluate the potential consequences of a landslide for each type of consequence (C_{LU}, C_{INF}, C_{HUM}):

$$\mathbf{Ci = Ii \copyright Ei} \quad (1)$$

The elementary consequences maps are then elaborated by allocation to each layer of element Ei its relative damage index Ii to can be used in consequence cartography by SIG. A mathematical model to create a quantitative expression between the consequences of the element Ei. A linear combination allowed finally to a total potential consequence (C_T) assessment.

The spatial characterization of landslides losses or damages is very relevant and difficult to be measured due to its temporal and spatial variability and discontinuity (Noori et al, 2014). Despite the fact that damages data can be obtained in landslides networks by aerial photographs and topographic maps, they are still considered as a point estimating of collected data for each single landslide occurred. Thus, estimating damages distribution within an area from collected data remains a problem of interpolation (Noori 2014). Therefore, we proceed to develop the various damages maps of the exposed elements at risk using the IDW method, which involves the process of evaluating values to the unknown points using values from a dispersed number of known points site. It is adopted by Li and Heap, 2008; Gooverts 2000; Noori et al., 2014; Naoum and Tsanisis, 2004; Dirks et al.,1.998; Chu et al, 2008; and

Noori 2014 who shows that this method is the better and the less computationally demanding that can be used to provide a great resolution without interpolation.

The damage indices Ii will be assigned to the elements at risk maps Ei to elaborate elementary consequences maps Ci. Then these elementary consequences maps will be combined in ArgisGIS to obtain as results the total consequence C_T map.
This mapping requires a damage scale classification for different levels according to table 2.

The consequence class values were based on an existing consequence classification system previously applied by Berggren et al., 1991; Alén et al., 2000; Hultén et al, 2007; Andersson-Sköld et al.2014 .

The resulting landslide consequence map, displaying the resulting consequence classes, illustrates the estimated loss should a landslide (Andersson-Sköld and Falemo, 2014) directly affect that entire cell.

Table 2. **The consequence class values**

Classes	**Consequences values**	**Consequence**
Level 1	**C0**	**Negligible or Very low**
Level 2	**C1**	**Low**
Level 3	**C2**	**Medium**
Level 4	**C3**	**High**
Level 5	**C4**	**Very high**

3. Landslides inventory and elements at risk

In this study, we apply the proposed method for one of the most exposed area to landslides in Algeria, which is the Wilaya of Tizi ouzou (figure1). Overall, this wilaya is about 135 088 of population in 2008 with great of loss. This population varies from a density of about 37 inhabit. /km^2 in ZEKRI to 1320 inhabit. /km^2 in the Municipality of Tizi-Ouzou. A number of 197,410 ordinary and collective households (an average of 5.7 persons per household) per dispersal area shows: 53.28% households for agglomerations chief towns, 38.68% households for secondary agglomerations and 80.19%.

Infrastructure of the wilaya includes a road network extending over 4 965 kms of which 12.28% national roads (N-R), 13.14% wilaya roads (W-R) and 74.58% communal roads (C-R) serving several villages and agglomerations in mountainous areas in bad conditions. This network covers in linear 4,38 kms for 1000 inhabitants with a density of 1.68 kms of roads for one km2 of surface. While for the port infrastructure, which is limited to a few old equipment on two coastal sites (Azeffoun and Tigzirt). For the other infrastructures the electricity network presents a rate of electrification of 95%; the gas network with a connection of 35 %; the Drinking Water

Supply is 1,998 km of supply, about 2,745 km of distribution and 145 L/d/inhabitant of average staffing; The sanitation is 2 100km of length including 6 sewage treatment plants.

The land use / land cover is characterized by an agricultural area, which represents only 33% of the surface of the wilaya where its great part is located in mountainous area (slopes more than 12%). At the scale of the wilaya of Tizi-Ouzou, the forest cover extends over 112,000 ha (38% of the area), part of which is integrated into the Djurdjura National Park. The Wilaya also contains wetlands, the main ones being the SEBAOU valley and the TAKSEBT dam, the main source of drinking water in the Wilaya, is withdrawn from: The alluvial water of Oued Sebaou: 36% Superficial resources: 58% Superficial sources, water intake: 5%. The urban network which has been enriched, and which militated in favor of exceeding the rigid framework of the administrative boundaries, it is among wilayas having recorded the highest rates of urbanization 45.15 and Rhythm of town planning 4.26, and it is the 3 rd wilaya predominantly rural (strong 58.95%).

In the number of landslides 84 reported by Kab et al., 2018 from historical documents and fieldwork in the study area, during the last years localized as shown in the figure 2, a database construction processed according to the parameters of at risk (Human or population, infrastructure and land uses / cover) described into subclasses in table 1 is thus established for this study.

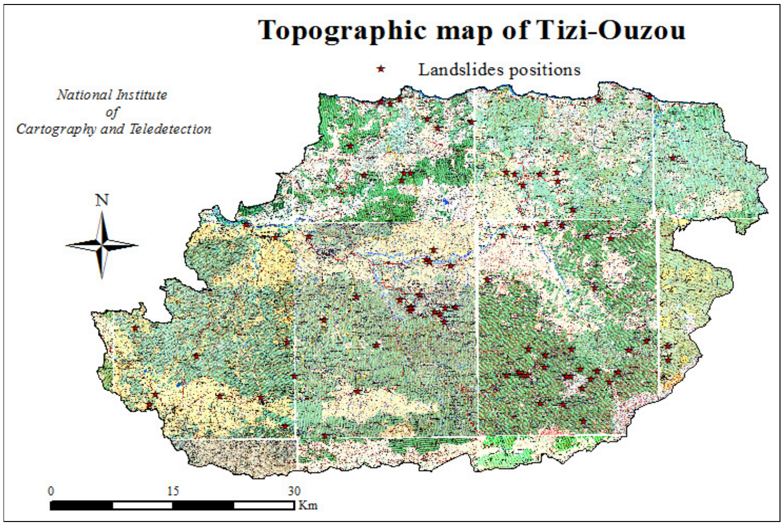

Fig.2. Localization of inventoried landslides in the topographic map of Tizi ouzou region.

4. Statistical evaluation of potential damage indexes

In this part, we are interested in studying the links that can exist between the elements at risk considered as statistical variables. A Multiple Correspondence Analysis (MCA) in Statistica software, covering more than two qualitative variables (A. Baccini, 2010), leads the statistical extraction of the correlations between the exposed elements. The MCA can be made from a particular data structure, called Burt's Table having a row and a column for each category of the studied variables.

For the 84 landslides recorded (n = 84) and three categories of exposed elements (considered as a qualitative variable p = 3), the variables are taken as follows: land use with 5 modalities, infrastructure with 5 modalities, human with 4 modalities.
The characterization of the three elements at risk for landslides analysis are shown in table 3.

Table 3. **Active nominal variables**

VARIABLES	ASSOCIATED MODALITIES
Land use / occupation: LU	4 MODALITIES
Infrastructure: INF	3 MODALITIES
Human: HUM	3 MODALITIES

After launching the statistical MCA calculation, the first indication will be the active nominal variables, which is a recapitulation of only the variables that participated in the analysis (table 4).

Table 4. **Effectives for the observed variables.**

	LU1	LU2	LU3	LU4	INF1	INF2	INF3	HUM2	HUM3	HUM4	Total
LU:1	5	0	0	0	3	2	0	1	3	1	**15**
LU:2	0	22	0	0	6	15	1	0	21	1	**66**
LU:3	0	0	28	0	3	18	7	0	28	0	**84**
LU:4	0	0	0	29	3	25	1	0	29	0	**87**
INF:1	3	6	3	3	15	0	0	0	14	1	**45**
INF:2	2	15	18	25	0	60	0	1	59	0	**180**
INF:3	0	1	7	1	0	0	9	0	8	1	**27**
HUM:2	1	0	0	0	0	1	0	1	0	0	**3**
HUM:3	3	21	28	29	14	59	8	0	81	0	**243**
HUM:4	1	1	0	0	1	0	1	0	0	2	**6**
Total	**15**	**66**	**84**	**87**	**45**	**180**	**27**	**3**	**243**	**6**	**756**

Eigenvalues are used to account for the relative importance of each dimension in the proportion of statistical information taken into account by the solution and their relation to the total of these eigenvalues is called the inertia rate. These eigenvalues take values in the interval [1; 0].

The MCA analysis, shows that considering a two-dimensional solution is the most adequate (the first given dimension is of an eigenvalue: 0,547; inertia rate: 0.234 and the second given dimension is of an eigenvalue: 0,454; inertia rate: 0,194). Thus, the two dimensions selected make it possible to take into account 43% of the total inertia through a plane graphical representation interpretable in terms of distances between observations.

The table 5 shows correlation reports between the initial qualitative variables and the main axes (Interclass variance over total variance).
The modalities that have most influenced the construction of the axes are those with the highest contributions.

Table 5. **Coordinates columns and contribution to inertia.**

	Coord. Dim.1	**Coord. Dim.2**	**Masse**	**Quality**	**Relative Inertia**	**Inertia Dim.1**	**Cosinus^2 Dim.1**	**Inertia Dim.2**	**Cosinus^2 Dim.2**
LU:1	-3,333	0,573	0,020	0,724	0,134	0,403	0,703	0,014	0,021
LU:2	-0,212	0,147	0,087	0,024	0,105	0,007	0,016	0,004	0,008
LU:3	0,325	-0,928	0,111	0,483	0,095	0,021	0,053	0,210	0,430
LU:4	0,421	0,686	0,115	0,342	0,094	0,037	0,094	0,119	0,248
INF:1	-1,099	-0,010	0,060	0,262	0,117	0,131	0,262	0,000	0,000
INF:2	0,273	0,357	0,238	0,505	0,041	0,032	0,187	0,067	0,318
INF:3	0,010	-2,362	0,036	0,669	0,128	0,000	0,000	0,438	0,669
HUM:2	-4,771	2,554	0,004	0,353	0,141	0,165	0,274	0,057	0,079
HUM:3	0,148	0,025	0,321	0,608	0,005	0,013	0,592	0,000	0,016
HUM:4	-3,612	-2,269	0,008	0,444	0,139	0,189	0,318	0,090	0,126

The table 5 contains a maximum value of 0.403 (LU 3) for the first dimension and 0.438 (INF 3). In addition, the dimensions measures for MCA are presented in the figure 3 where each value of element contribution to inertia is plotted in form of diagram.

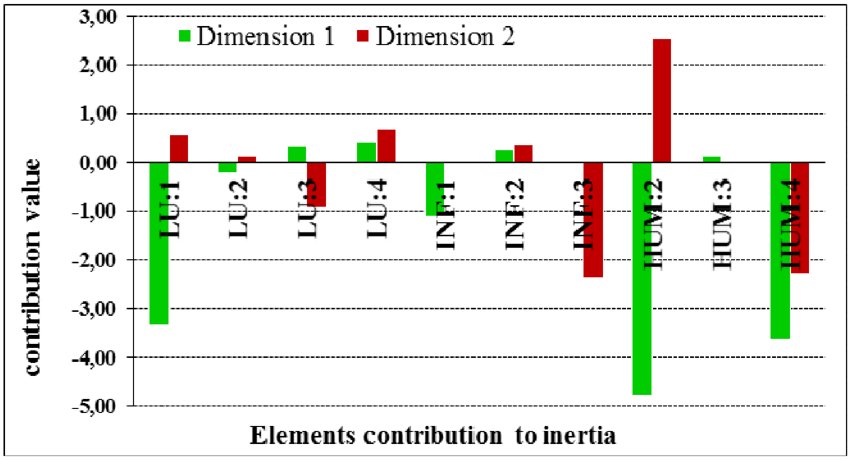

Fig.3. MCA dimensions measures.

From the contribution results, we conclude the damage indices for this analysis that will be used in our evaluation and mapping consequences, which are expressed in the table 6.

Table 6**. Damage indices values used for the analysis corresponding to each element at risk.**

Element at risk categories	**Damage indices value**
Land use / occupation "LU)	0,134
Infrastructure "INF"	0.128
Human or population "HUM"	0.139

5. Mapping landslides consequences

In this section we proceed to establish the damages related to the phenomenon of landslides in the region of Tizi ouzou by combining weightening indexes to the exposure elements at risk. We present in this sectionthe maps of the potential consequences for each element at risk over these areas.

Mapping the damages related to the occupation of soils C_{LU}, the infrastructure C_{INF} and the human loss C_{HUM} are shown in the figure 4 and we discuss them in the contrast of the topographic map presented in the figure 2.

The consequence C_{LU} and C_{INF} maps, shows that a high level of damage is caused in water exploitation zones and forests and comes last the damage on the urbanized zones, also we distinguished that the greatest damages is provoked on the secondary road infrastructures that generated on the buildings and constructions.

This is explained by the original nature of the wilaya characterized by large expanses forester and rich outcrops of water that is certainly connected by most of the time by road grapes which makes the human injuries, exposed population consequences (figure 4-1) more preponderant, and is more dominant by deaths in the more urbanized zones.

Then in Figure 5, we present the total potential landslide damage C_T map over the studied area. The elementary consequences C_{LU}, C_{INF}, C_{HUM} are analyzed and combined in order to elaborate the final consequence map of the association of the effect of different elements at risk.

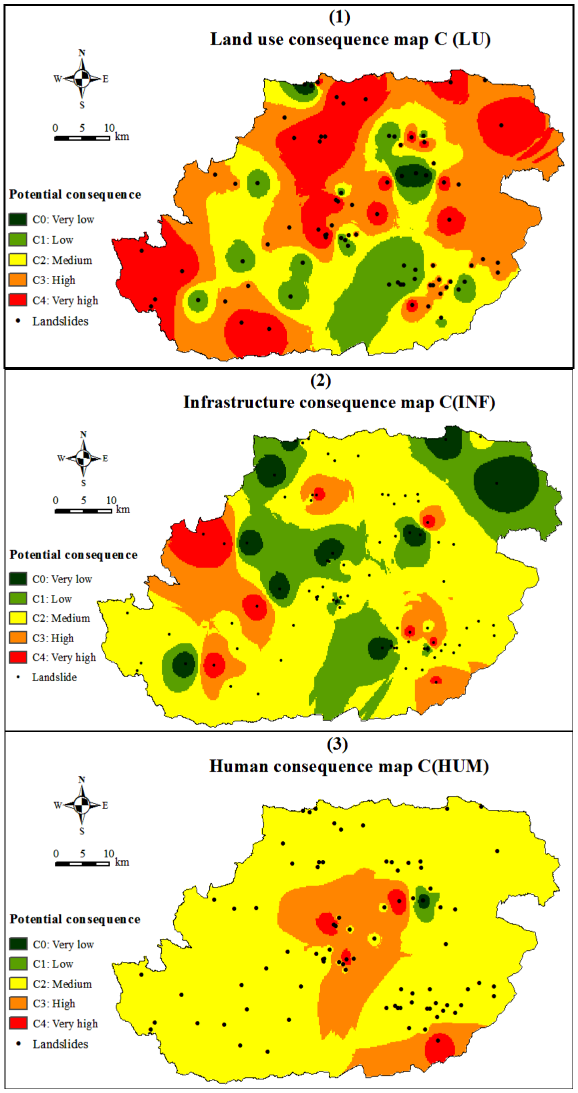

Fig. 4. (1) Land use consequence map CLU, (2) Infrastructure consequence map CINF, and (3)Human consequence map CHUM for the Tizi Ouzou region.

The methodologies will be further extended, and their application to the study area will be finalized by testing the sensitivity of the attributes and the weights to observed damage. Afterwards, the maps produced with the two methods for corresponding scenarios will be compared and evaluated.

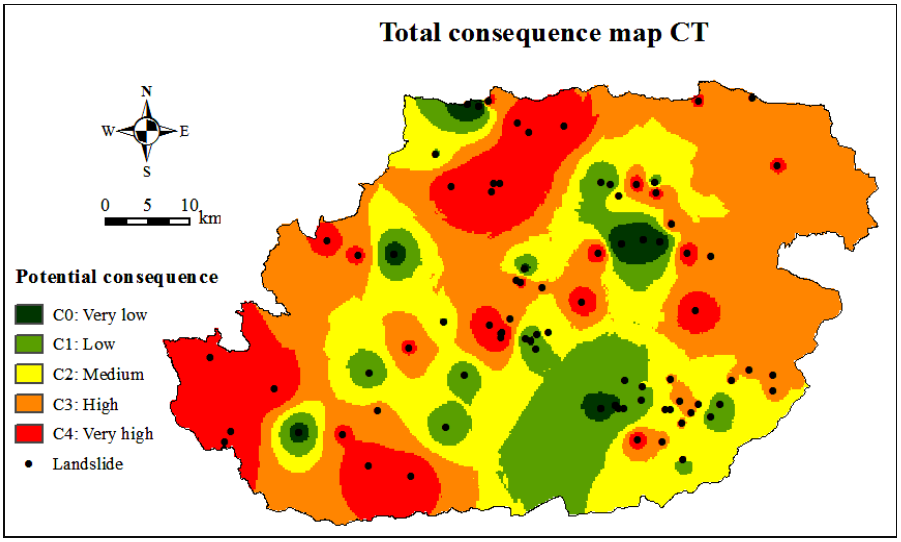

Fig. 5. Total consequence map C_T for Tizi ouzou region.

The validity of the analysis is guaranteed by a plot of landslide frequencies in each consequence class presented in figure 6. This graph shows the percent landslide rates present for each class representing a certain level of damage ranging from very low to very high. Therefore, for an area with a high number (rate) of landslides will be subject to a high level of damage that is explained by the graph; therefore, an area of very high class of consequence (C4) has a rate of 39.29% and that of a very low class (C0) has a rate of 13.10%. However, concerning the moderate class area a low landslide frequency is observed due to the dispersal of the population and the infrastructure in these locations.

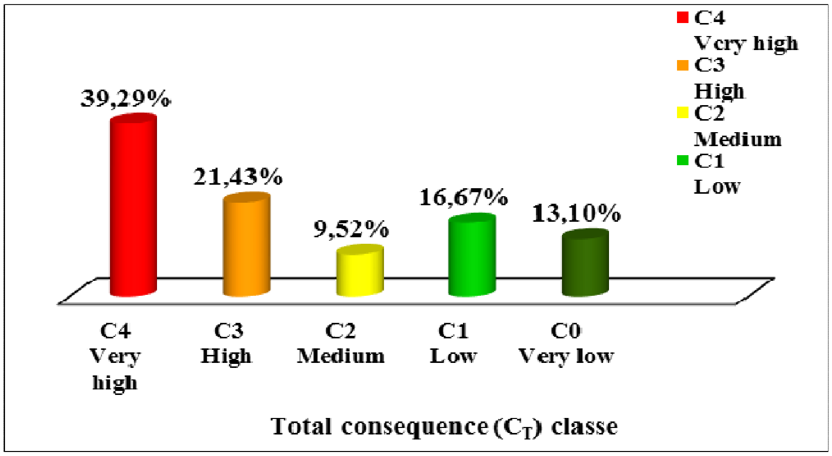

Figure 6. Total consequence density graph for Tizi ouozu region.

6. Conclusions

This study analysis and proposes a statistical based methodology to assess and map landslide consequences by the statistical calculation of an index of potential consequences. The proposed methodology is very appreciate due to the use of an existing Inventory data base to locate the very sensitive zones, and can be employed independently landslide hazard types and the environmental and socio-economic context.

The ability of the statistical analysis to synthesize the correlation between data, the multi-criteria analysis is one of the methods that identify the contribution of each variable; and the availability of informatics tools to generate maps led to use this methodology.

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