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RESEARCH ARTICLE

THE VULNERABILITY ASSESSMENT OF THE ZIZ BASIN TO POLLUTION BY STUDYING THE INFLUENCE OF WATERSHED CHARACTERISTICS

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ABSTRACT

The inevitable changes in land management systems are driven by the challenges of the population explosion and climate change facing the Drâa-Tafilalet region. At the same time, natural and human processes are having an impact on the capacity of production systems. As a result, the degradation of natural resources is expected in many regions, as is the loss of land productivity and biodiversity, which has already occurred in the Ziz basin. The resulting soil vulnerability map should reveal homogeneous zones for priority intervention. The aim of our work is to assess the influence of watershed characteristics on the vulnerability of the Ziz basin. To this end, an analysis is carried out to complement the field surveys, and a computerized and logical methodology is presented. We have identified the factors that determine soil vulnerability. And to combine these different factors, we used a partition space made up of regular grid cells.

KEYWORDS

Bassin Ziz, environment, Vulnerability, watershed, pollution

1. INTRODUCTION

It is clearly evident that the overall level of pollution has become critical, especially in urban and industrial areas (Hamza et al., 2007). Among the sources of pollution affecting soils, the most important are undoubtedly those associated with large urban and industrial centers. Pollutant inputs from rivers, when draining heavily industrialized regions with intensive agriculture (Marrauld et al., 2021; Oberson and Lafon, 2010; Féret and Douguet, 2001). Vulnerability is a relative concept, difficult to quantify, and for several years now we have been attempting to standardize the criteria used to draw up pollution vulnerability maps (Peres, 1978; Livet, 2004). This concept is generally characterized by the estimation of a number of parameters of varying importance, notably relating to groundwater cover (soil and unsaturated zone) and the saturated zone itself (Diendere et al., 2015). Soil erosion by rain and runoff is a widespread phenomenon in different Mediterranean countries (Holman et al., 2003). It results from agricultural intensification, land degradation and, very strong climatic variations. In Morocco, the mountain regions present an important socio-economic stake (agriculture, forest, heritage, ...). They are very vulnerable to the phenomenon of water erosion. The relationships between vegetation, soil and water are largely disturbed (Xu et al., 2008). In some places, erosion has reached a level of irreversibility and in some places it has transformed the landscape. The effectiveness of agricultural and pastoral measures in catchments where the risks of soil erosion are most intense will be increased if the factors of the natural environment are well known. However, the problem of soil depletion is not as acute in the different parts of the the different parts of the zone (Shumilovskikh et al., 2016; Taillefumier and Piégay, 2003). In fact, soil vulnerability can be considered as its fragility in the face of external aggressions such as climate and anthropic actions. It therefore depends on both intrinsic and extrinsic factors (Silva et al., 2019). It can be ranked according to the degree of vulnerability. Soil erosion thus depends on many factors (Hurst, 2020). These same authors agree in considering the above-mentioned erosion triggers as the most relevant and discriminating. Indeed, precipitation is the essential climatic element due to its spatio-temporal variability, both annually and monthly. It is the raindrops and runoff water on sloping land that loosen and carry away soil particles, promoting soil closure and the formation of capping. For the study area, the northern slopes are more watered than the southern slopes (Sharkhuu et al., 2016).The Ziz drainage basin at the Foum Tillicht station has a certain reserve that allows it to regulate its regime in periods of low water. The reserves are located in a superficial zone of the multilayer aquifer of the Middle Jurassic (Dogger: marly limestone). This allows surplus years to compensate for deficit years. The regime of this system is regularized and perennial. The Sidi Hamza system is the seat of two types of flows: a fast surface flow (sharp hydrograph) with a low regulating power, and a groundwater flow (spread hydrograph) with a high regulating power (Nouayti et al., 2017). The phenomenon of erosion manifests itself in the Isser watershed every year during the winter rainy episodes, when the soils are still poorly covered, or during the violent storms at the end of summer and autumn on soils that the harvests also leave poorly covered. Crop residues and vegetation protect the soil from the impact of raindrops, tend to slow down the speed of runoff and allow for better infiltration (Talbi et al., 2021). In addition to the factors favoring runoff, the entrainment of soil particles is facilitated by soil characteristics such as texture, mineralogy and structural stability. Lithology is considered the main factor controlling slope stability. The succession of hard and soft rocks; where the rocks are resistant, one finds the steepest slopes and low sediment transport; but on soft clayey rocks and marls one can find relatively moderate slopes and abundant sediment transport (Van Dijk et al., 2005). Where soils are susceptible to capping, a small local increase in slope can cause a significant increase in the erosion hazard. The length of the slope is less important than its inclination and

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shape. The analysis variables are known at various scales and according to various spatial divisions; in order to homogenize the assessment of the parameters, we opted for a division of the territory into regular meshes; this type of division has been tested for other regions and several themes (Haselberger et al., 2021; Johns and Moore, 1988). This enabled us to produce a map showing homogeneous intervention zones in order of priority. This model has not yet been applied at the level of the studied hydrological basin.

In this connection, the present survey aims to produce a soil vulnerability map and its components in the Ziz Basin. The risk can be defined by the intersection of two dimensions of vulnerability. The Ziz watershed is the random physical phenomenon, by definition because of the distance of any facility or human stake. This last aspect is translated by the vulnerability which is the counterpart, in economic terms or in terms of human lives.

2. Materials And Methods

2.1. Study Area

The Ziz basin covers an area of 14411km². It is limited to the North by the massifs of the Eastern High Atlas, to the West by Jbel Ougnane (1189 m), Jbel Al marka (1164 m), Jbel Adrar (1030 m) and the watershed of Ghéris, to the South by hills (whose altitude exceeds 800 m), and to the East by hills (whose altitude exceeds 1100 m) and the watershed of Guir.

2.2. Collection processing and of data

There is no single standard method for assessing the vulnerability of surface waters to pollution. According to scientific researchers, to guarantee a reliable determination of the areas that influence the vulnerability of these resources, it is preferable to require an effective method based on a minimum of information, the basis of our work being the most significant are those that allow the incorporation of topographical, geological and hydrological data (Ambade et al., 2021). In this work, the territorial unit used is the watershed, and perfect knowledge of it and the activities that take place there is essential for assessing the Ziz basin's vulnerability to pollution. To this end, only factors identifiable at this scale are used.

2.2.1. Identification and classification of parameters

In this study, taking into account some authors such as BRGM working group, Anoh et al, (2012), Eba et al, (2013) (Anoh et al., 2012; Phillips et al., 2013). and according to the availability of data, five parameters were retained, namely; slope, land use, soil type and density of the hydrographic network.

2.2.2. Determination of weights by AHP of Saaty

The methodology used to determine the weights of the parameters is Saaty's Analytic Hierarchy Process (AHP) multi-criteria method. This method allows to make efficient decisions on complex problems by simplifying and accelerating the decision-making process (Kamaruzzaman et al., 2018). The approach adopted by the AHP multi-criteria method can be summarized in two steps.

a) Creation of binary combinations

When binary combination is applied, the individual values are compared in pairs depending on their magnitude. These pair-wise comparisons produce square reciprocal matrixes. The results of the these parameters taken two by two is done on the basis of the Saaty scale, a scale used (Kouamé, 2007) and several other authors. Indeed, according to this comparison, when two parameters have the same importance in the studied phenomenon, the Saaty scale gives these two parameters the value1. However, if a parameter is more significant than another, it is assigned a greater value from 1 to 10, and the other the inverse of this number. This produces a standardized weight with a sum value of 1. The resulting matrix of pairwise parameter values is presented in the following table:

Table 1 : Comparison of parameters (original matrix)

	P	O	S	R	D
P	1	3	3	5	7
O	1/3	1	3	4	5
S	1/3	1/3	1	3	4
R	1/5	1/4	1/3	1	3
D	1/7	1/5	1/4	1/3	1
$\sum ai$	2	4.78	7.58	13.33	20

With: P= Slope; O= Land occupation; S= Soil type; R= Runoff; D= Drainage density and Σai = sum of values in column i

After the binary combinations, a check of the consistency of the judgments (logical consistency) is performed. And also, this square matrix will allow to make the combinations for the determination of the weights.

b) Determination of parameter weights and verification of logical consistency

- Determination of the Parameter Weights or Weighting Factor (WF))

The coefficient of each parameter represents the degree of its effect on the vulnerability of the resource to environmental contamination. They are established in two phases:

- Determine the Eigenvector (Vp) of each parameter

$$V_p = \sqrt[k]{W_1 \times W_2 \times \ldots \times W_k}$$

With W1, W2,..... WK the individual values given to the different comparison variables and k the total quantity of the parameters compared.

- Calculate the weighting coefficient (Cp) of each parameter:

C_p=V_p/∑▒V_p =V_p/(V_p1+V_p2+⋯+V_pk)

$$C_p = V_p / \sum V_p = \frac{V_p}{V_{p1}+V_{p2}+\cdots+V_{pk}}$$

With Vp the Proper Vector of the parameter whose Cp is to be calculated and Vp1, Vp2,. Vpk the different Proper Vectors of each parameter. The sum of the Cp of all the parameters of a matrix must be equal to 1.

- Verification of the Logical Coherence or Coherence Ratio (CR) of the matrix

The logical consistency is a ratio that allows to verify or validate the consistency of the original matrix. This ratio can be interpreted as the probability that the matrix is completed in a random way. Indeed, AHP does not require that the judgments be consistent or transitive. However, the value of the consistency ratio. In the case where the value of the consistency ratio exceeds 10%, the judgments may require some revisions. Thus, the formula is written as follows:

RC=IC/IA

where IA is the aleatory index and IC is the coefficient of variation.

The probability index is calculated as a percentage of the parameter number compared and these values have already been determined by Saaty. The following table presents these different values. In this study, AI =1,12, corresponding to 5 compared parameters.

Table 2 : Index randomized by the number of parameters									
N of comparative elements	2	3	4	5	6	7	8	9	10
IA	0	0.58	0.9	**1.12**	1.24	1.32	1.41	1.45	1.49

In addition, the Value of IC is to be determined. And the formula is as follows:

$$IC = \frac{\lambda_{max} - Nbre\ elements(k)}{Nbre\ ands\ coma\ after - 1}$$

With the IC methodology known, the last part is to calculate the Coherence Ratio (RC), RC = IC/IA

-If RC ≤ 10, The models are then referred to as self-consistent
-If RC > 10% the template is then not consistent and should be updated.

2.3 Vulnerability Assessment

For a vulnerability assessment, the rule base occupies a strategic place, because it contains all the logic necessary to establish the links between the parameters and the elements of the fact base. From the application of these rules, a whole process of reasoning will follow which will lead to the characterization of vulnerability to the consequences of environmental changes. The methodology of vulnerability used, is the one already tested by Olivry (2012) [25] for the analysis of the vulnerability of ecosystems in a context of climate change. To better describe and quantify the problems faced by the ecosystems of the basin, served as a basis for the analysis of the results from the field work, statistical and cartographic treatments. After determining the weights, the sensitivity index map (Iv) is determined by the calculation formula below:

Vulnerability Map = 0,47 × (P) + 0,27 × (O) + 0,15 × (S) + 0,07 × (R) + 0,04 × (D)

In addition, the classification of vulnerability indices leads to the determination of the pollution vulnerability map of the Ziz basin. For the determination of the ranges of the different vulnerability indices, the method applied in the work of Jourda et al. This method allows the conversion of vulnerability indices into percentages in order to better understand the expression of the classification of degrees of vulnerability. It allows to set the limits of the intervals of the determined indices and to match the vulnerability classes to these indices. The the conversion of the indices into a function of the percent values is calculated using the equation below:

$$I_v = \frac{(Ii - Imin) \times 100}{Imax - Imin}$$

Where Ii = the value to be determined, Imax = the max. index and Imin = the min. number.

The connection by superimposing the different thematic maps and point data obtained in a GIS has allowed the establishment of a map of vulnerability indices to pollution of the Ziz basin, then from this map, the map of different classes of vulnerability.

2.4. Assignment of different parameter classes

The reference used for the attribution of the different scores to the different classes is based on the work of the BRGM working group on the evaluation of the vulnerability of surface waters (Schoen et al., 2001). However, the effective rainfall factor used by this group has been replaced by permeability in this study. Indeed, the scores vary from 1 to 4, and the value of the score assigned is a function of the importance of the different classes in the process of the phenomenon studied. Thus, taking into account the slope parameter, a score of 3 was assigned to the class of slopes greater than 7% because this class is supposed to have an important capital in the study of vulnerability to surface water pollution. The following table summarizes the different parameters and their classes, as well as the different scores attributed to these classes.

Table 3 : Parameters, classes, and scores for the different factors		
Parameters	**Classes**	**Notes**
Slope	< 5%	1
	5 %– 14%	2
	> 14%	3
Occupation of the soil	Dense vegetation	1
	Light vegetation	1
	Habitat	2
	Bare soil	3
	Culture	4
Type of soil	Type A	1
	Type B	2
	Type C	3
	Type D	4
Permeability (CN)	36-65	1
	65-75	2
	75-85	3
	85-100	4
Drainage density	0-0.069	1
	0.07-0.18	2
	0.19-0.41	3

3. Results And Discussion

3.1. Slope (P)

Slope is considered a very important factor in the transfer of pollutants to surface waters. It conditions the circulation of water on the surface and has a direct effect on the transfer time. It intervenes in erosion phenomena and favours the transport of active substances fixed on suspended matter (Bony et al., 2013). The slope represents, in any case, the areas that can be favored for runoff or infiltration. The gradient map was created by treating a Digital Elevation Modelling (DEM) map of the Ziz drainage basin with ArcGis. Next, grading was conducted by using the "Spatial analyst tool" of the same software. We obtain a map whose dominant class is between 5 and 14%.

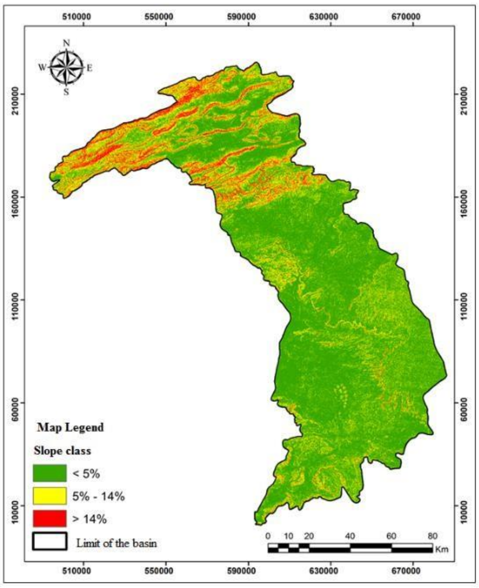

Figure 1: Map of the slopes of the Ziz basin

We note that the slope is relatively steep in the upstream part of the basin, compared to the downstream and this is due to the location of the basin in the High Atlas, where the high altitudes culminate (Fig. 1). The slope becomes less and less steep as we move towards the Anti Atlas in the south, where the altimetry is relatively lower.

3.2. Land occupation (O)

Land use refers to all activities on the land surface. It contains the potential sources of pollution of the water reservoirs. Indeed, these potential sources of threat concern the discharges of anthropic activities likely to generate pollutants. This parameter was obtained from a satellite image and mosaicked from scenes downloaded from the USGS site. The acquisition of the land cover map of the study area from this satellite image was possible thanks to the supervised classification under the ERDAS software.

The map below shows the uneven distribution of the different classes, we notice that the bare soil dominates almost the entire surface of the basin. The development of vegetation is rare due to the arid climate in the southern part of the basin. The presence of habitat is rare but often along the wadi Ziz example (Rissani, Erfoud.).

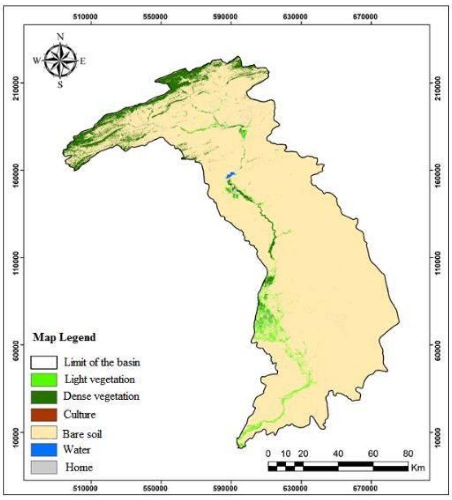

Figure 2: Land occupation map of the Ziz watershed

3.3. Type of soil (S)

This parameter corresponds approximately to the first meter of deposition from the soil surface (Quideau et al., 2001). The vulnerability of the environment to the transfer of phytosanitary products to water depends on the characteristics of the soil, which is the receptor of these products. The characteristics of the soil condition the partition of water between infiltration to groundwater and runoff to surface water.

Based on the geological and lithological map, we could deduce the soil type map. The number of the NRCS curve is related to the soil type, the infiltration capacity of the soil, the land use and the depth of the high season water table. To account for the infiltration capacity of different soils, the NRCS has divided soils into four hydrologic soil groups (HSGs). They are defined as follows.

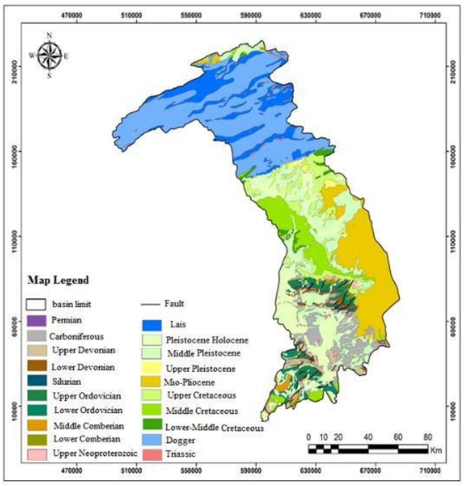

Figure 3: Geological map of the Ziz watershed

The geology of the region varies from the Precambrian in the Neo-Proterozoic detrital volcano series in the Western Anti Atlas through the Paleozoic cover that begins with the Cambrian and ends with the Permian. The dominance of Secondary lands is noticed in the High Atlas, mainly the lower and middle Jurassic, the Tertiary and Quaternary are little present in the hamadas of the Guir for the Tertiary, and the alluvium of Wadi Ziz for the Quaternary. The soil type map has been elaborated by exploiting the pedological sketch of Morocco at the scale 1/500 000 as well as the geological map. The result is presented in the map below:

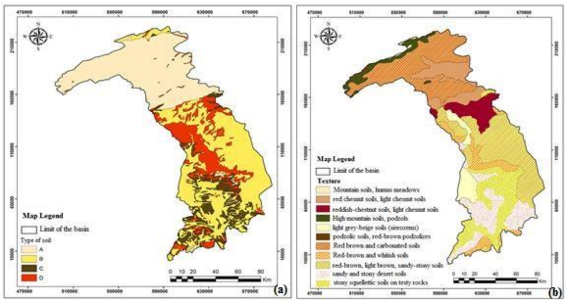

Figure 4: (a) Soil texture of the Ziz watershed; (b) Soil texter

HSG Group A (low Runoff potential): Soils with high infiltration rates even when thoroughly wet. These consist mainly of deep, well-drained sands and gravels. These soils have a high-water transmission rate (final infiltration rate greater than 0.30 mm per hour).

HSG Group B Soils with moderate infiltration rates when completely wet. These are primarily moderately deep to deep, moderately well-drained to well-drained soils with moderately fine to moderately coarse textures. These soils have a moderate water transmission rate (final infiltration rate of 0.15-0.30 in (3.8-7.6 mm) per hour).

HSG Group C: Soils with slow infiltration rates when completely wet. These consist primarily of soils with a layer that prevents downward movement of water or soils with moderately fine to fine textures. These soils have a slow water transmission rate (final infiltration rate of 0.03-0.15 mm (1.3-3.8 mm) per hour).

HSG Group D (high Runoff potential): soils with very low infiltration rates when well-wetted. These consist mainly of clay soils with high swelling potential, soils with a permanent water table, clay soils at or near the surface, and shallow soils on nearly impermeable materials. These soils have a very slow water transmission rate (final infiltration rate of less than 0.05 inches (1.3 mm) per hour).

The map shows the soil type according to the coefficient of runoff potential. The formations of the High Atlas are almost all characterized by type A and reflects a high infiltration rate, this is explained by the physico-chemical properties of Jurassic land and are mainly carbonates. It is true that the latter do not have a good primary permeability, but the secondary permeability is very important, and constitutes real underground drains. The lands of the Anti-Atlas are in turn constituted by a diversity of soils ranging from type B for the hamadas of Guir to type D for the clay soils of the Paleozoic of the Anti-Atlas.

3.4. Soil permeability (R)

This parameter is highly dependent on the physical and morphological factors of the watershed, including the relief, geological context, vegetation cover, shape, orientation and density of the river system (Singh et al., 2003). Thus, raw water quality is the result of mineralization processes that occur as water flows over the land (Decho, 2010). This final map is the result of superimposing the land use map with the soil type map, and this to generate the coefficient CN and varies between 36 up to 100, the high value indicates a low infiltration rate and therefore a high runoff and vice versa. We can deduce that the atlasic chain is favorable from the point of view of permeability, while the High Atlas chain/ Anti-Atlas chain represents the opposite with impermeable land. The map of soil permeability of the Ziz watershed is presented below:

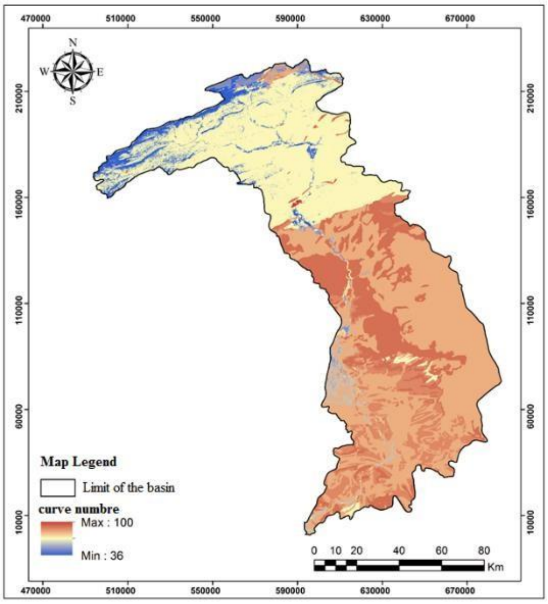

Figure 5: Soil permeability of the Ziz watershed

3.5. Density of the hydrographic network (D)

The pollution of surface water resources (lakes, dams, rivers, etc.) is also linked to the density of the hydrographic network that underlies these resources. Indeed, the hydrographic network collects all the waters of a same basin with the possibility of contamination by polluting products to lead them to the outlet. The denser the hydrographic network per management unit, the higher the vulnerability to pollution of the resource (Hamouda et al., 2009). For this study, the Digital Elevation Model was used under ArcGis environment to obtain the density map of the hydrographic network of the Ziz watershed.

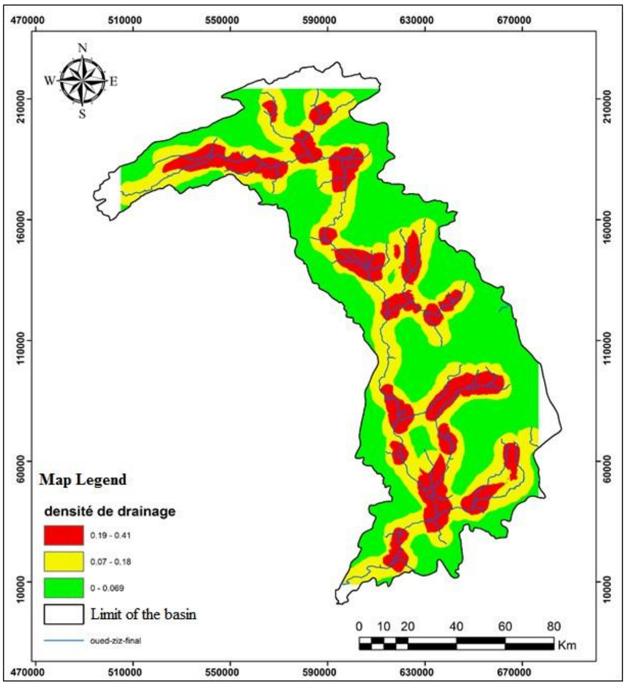

Figure 6: Density of the hydrographic network in the Ziz watershed

According to the calculations made IA = 1.12 and IC = 0.05 and RC = 0.04. The consistency ratio is less than 10% (Rc =4%). Therefore, the assigned judgments are good. All the results obtained are recorded in the table below.

Table 4 : Results Of The Different Calculations

	P	O	S	R	D	Vp	Cp	Cpx 100	ΣL IG	[c]	[D]	[E]	λ max	IC	RC
P	0.5	0.63	0.4	0.38	0.35	3.16	0.47	47	2.26	0.45	2.42	5.38	5.21	0.05	0.04
O	0.16	0.21	0.4	0.3	0.25	1.81	0.27	27	1.32	0.27	1.36	5.03			
S	0.16	0.07	0.13	0.23	0.2	1.05	0.15	15	0.79	0.16	0.5	5			
R	0.11	0.05	0.04	0.07	0.15	0.54	0.07	7	0.42	0.08	0.41	5.12			
D	0.07	0.04	0.03	0.02	0.05	0.29	0.04	4	0.21	0.04	0.22	5.5			
Σ	1	1	1	1	1	6.85	1	100	5	1	4.91	26.03			

3.2. Assessment of the vulnerability of the Ziz basin to pollution

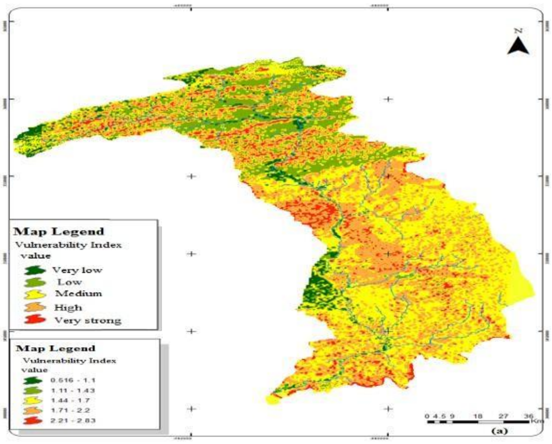

Figure 7: Vulnerability indices and pollution in the Ziz basin

Pollution vulnerability indices for the Ziz basin range from 0.51 to 2.8. These indices highlight the areas from which the basin is at risk. In addition, vulnerability ranges are obtained and divided into 5 classes that vary from "very low" to "very high" and the degree of vulnerability increases with the index. The index values are in the following table:

Table 5 : Pollution vulnerability indices for the Ziz basin

Pollution Vulnerability Index Classes	Percentage	Degree of vulnerability to pollution
0.51-1.1	0-48	Very low
1.11-1.43	48-62	Low
1.44-1.7	62-74	Medium
1.71-2.2	74-96	High
2.21 - 2.8	96-100	Very High

4. Conclusion

The survey examined how morphometry, land use and slope affect vulnerability to flooding in downstream areas of the Ziz watersheds. In fact, the Ziz watershed has a more rugged and topographically uneven terrain, with large areas of flat or almost-flat land. This topographical condition has a significant influence on the watershed's flow regimes, making the basin more vulnerable to flooding. On the other hand, the basin's lag time is shorter. These results lead to the conclusion that, during periods of heavy rainfall, the downstream part of the Ziz catchment is particularly vulnerable to flooding. In addition, the differential topographical distribution has different influences on water and sediment transport. Soil degradation involves various parameters (natural or man-made) whose representativeness in space is conditioned both by the measurement (at any point in space in the case of images, or at particular points in the case of acquisition stations) and by the final estimate, most often in the form of data series. As a result, the regions considered to assess the factors are different and therefore not comparable. Furthermore, impacts on the soil vary enormously and are linked, among other things, to the amount and structure of precipitation. The present research strongly suggests that the different characteristics of the catchment's geography, morphometry, topography and land use have a significant effect on the system's hydrological function and response. As far as instrumentation and ground data are concerned, these are robust and reliable indicators for deriving hydrological information, including flooding and vulnerability to flooding at watershed scale.

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