The Use of Geotechnologies In the Environmental Vulnerability Diagnosed in Sustainable Use Conservation Unit

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Abstract

The misuse of agricultural activities has been a cause for concern as to the risks of contamination of soil and water, with possible health and environmental impacts. The objective of this study was to verify the environmental vulnerability of water resources in the Environmental Protection Area of the Uberaba (APA). The condition of risk and fragility that the environment is found was determined using the multicriteria modeling

of morphometric parameters and soil occupation, and data analysis was performed in a geographic information system (GIS) platform. The intervening factors selected for analysis were: drainage density, slope, soil classes, distance of water lines and land use and occupation. It was possible to jointly evaluate the different information plans and to generate from the multicriteria the vulnerability of the water resources in the APA.

Keywords: information system, morphometry, conservation planning, multiple criteria.

Introduction

Environmental vulnerability refers to the risk of degradation of the natural environment, related to soil erosion, loss of biodiversity, soil and water resources contamination and loss of vegetation cover exacerbated by anthropogenic factors, which may result in the loss of biodiversity and compromise the quality and quantity of natural resources (COSTA *et al.*, 2007).

Multicriteria decision modelling (MCE) based on the geographic information System is the basis of decision-making, and the weighted Linear combination (WLC) is one of the basic methods, which makes Exchange of factors “with each other”. Modeling is an important tool for the study of environmental analysis (VELDKAMP, LAMBIN, 2001). This methodology provides alternative techniques to incorporate decisions preferences in the environmental assessment process. Thus, the objective of the use of MCE model is to find solutions to the problems of decision making characterized by multiple alternatives, which can be evaluated by using decision criteria (PINTO, 2010, BOTTERO *et al.*, 2013).

Fuzzy logic, drawn by Zadeh (1965) became an important topic of research

during the Decade of 1980 for use in GIS and environmental adequacy analysis. Consists in algebraic logic analyses of maps, sustained by the similarity Bayesian probability and Boolean, generating maps by map cumulative algebra through the standardization of the variables used, converting the data values unique in fitness values to the desired purpose.

Several researches in different areas were developed using MCE. Such studies in agriculture (AKINCI *et al.*; 2013, DRAGINCIC *et al.*; 2015;), soil conservation and fitness (VALLE JUNIOR *et al.*; 2014;), irrigation (CHEN, PAYDAR 2012), conservation of water resources (VALLE JUNIOR *et al.*; 2015; CALIZAYA *et al.*; 2010), conservation of natural resources and forestry (Bottero *et al.*; 2013; KAYA and KAHRAMAN 2011), transport and industrial projects (MACHARIS *et al.* 2012), Economics (MARTIN-ORTEGA, BERBEL 2010; ZUBARYEVA *et al.*; 2012) among others, showed the functionality of the multi-criteria analysis in decision making in different application areas.

The APA of Uberaba River just had a recognition and concern in 2003, in which in the Alegria, this basin in the APA, there was a derailment of a freight train, and this accident is considered

the largest environmental disaster of the Triângulo Mineiro until the present day. The charges were made up by the octanol ($C_8H_{18}O$), methanol (CH_4O), ISO-butanol ($C_4H_{10}O$) and potassium chloride (KCl) in which, with the accident, an explosion occurred and which devastated more than 1000.0 m of native vegetation, as well as deposit and disperse more than 670 kg of contaminants in soil and water. Public water supply was interrupted for more than 5 days and it was decreed a State of public calamity. In this period the lack of water was supplied by water trucks, however, insufficient. More than 250,000 inhabitants were impacted by the lack of water due to this accident and the contamination of water resources.

The aim of this paper is to draw up the diagnosis of environmental vulnerability of water resources from the multi-criteria

modeling of physical parameters and microbasin in the APA morphometric of Uberaba River, through the use of GIS.

Area of study

Their diagnosis of vulnerability of water intercepted by highways in Environmental Protection Area APA of Uberaba River (Figure 1) which is part of the Uberaba River basin, located between the geographical coordinates 19.51° and 19.74° South and 47.64 and 47.98° West of Greenwich in the city of Uberaba-MG.

With a total area of 525.27 km², the APA of Uberaba River has 62 microbasins, bounded from the main course, which contribute significantly to the quantity and quality of water resources which supplies the city of Uberaba.

Figure 1 – APA of Uberaba River. Source: Siqueira.

The climate of the region is classified according to the Köppen type Aw-hot humid tropical, with cold winter and dry, being the domain ranking the humid climate with 4 to 5 dry months (ABDALA, 2012). The average annual precipitation varies between 1300 and 1700 mm in the rainy period corresponds to the warmest period of the year. Therefore, there is a characteristic rainy scheme from October to March and a dry season from April to September. The months of December and January are the rainiest.

The municipality of Uberaba is located in Sandstone Plateau Basalt relief of the Paraná basin with soil showing varied characteristics. Most have average texture, ranging from sandy to clay and are classified, in general, as the presence of microaggregates showing varying degrees of fertility, with a predominance of Red Latosol Distroférrico medium-textured, Red Latosol typical and Acrisol Red-Yellow Latosol (NISHIYAMA, 1998).

Cruz (2003) points out that the topography is characterized by flat or slightly wavy surfaces, geologically formed by sedimentary rocks, basically the sandstone, the Cretaceous Bauru formation.

Materials and Methods

Multi-Criteria Analysis

The Idrisi GIS features integrated image processing feature for analysis and visualization of spatial data, developed by researchers at CLARK LABS, Department of geography, Clark University, Worcester,

MA. In addition to the GIS analysis modules, image processing, surface analysis, change and time series analysis and modeling, the Idrisi provides a set of useful tools to support the decision-making process. In particular, it provides functions to implement the objective evaluation weighting procedure multi-criteria, standardization and diffuse set of criteria for aggregation. The Weighted Linear combination (WLC) present in the module, multiple criteria evaluation (MCE) of Idrisi Jungle, made it possible for this type of work (EASTMAN, 2012).

Second Malczewski (1999) and Garfi et al., (2011), multicriteria methodology, the developed model follows three phases: (1) selection of the criteria (factors and constraints) for the analysis and creation of raster maps; (2) assignment of weight to each criterion; (3) combination of criteria and creating the final suitability map. In general the methodological process of multi-criteria analysis can be observed as shown in Figure 2.

Data acquisition and choice of factors and constraints

It was determined for this study of environmental vulnerability of water resources in APA of Uberaba River the acquisition and preparation of thematic mapping of physical factors and watershed morphometric totaling 5 (five) factors (drainage density, distance from watercourses, slope of the land, use and occupation of the soil and soil classes) and 1 (one) constraint (drainage networks). The restriction was used to the water courses were not classified in classes of vulnerability.

Figure 2 – Methodological process of multi-criteria analysis. Source: Adapted from Siqueira *et al.* (2017).

The map of the drainage network (Figure 3) in the area under study was drawn from the Digital Elevation Model-DEM, rendered image of the Aster GDEM Sensor (Digital Global Elevation Model), at the geographic information System – GIS. The vector file of drainage was exported to the “Google Earth”, which has made checking and modification, when necessary, of the respective watercourses. Subsequently, exported the vector file (drainage network) for the GIS Idrisi Jungle, being this the Cartographic base for the development of the database.

The demarcation of the microbasin of the study area were performed from

the DEM, in GIS Idrisi Jungle, through the “Watershed”. Once generated the information flow was traced the point closest to the exhalating (mouth) of each watershed with the main course of the Uberaba River and using “Watershed” was bounded each hydrographic watershed.

Drainage density corresponding to relative to the total length of the channels ($\sum L$) in (km) and the area of the watershed (ABH) in (km²) (CHRISTOFOLETTI, 1980), was calculated on the following formula:

$$Dd = \sum L / ABH \quad \text{Eq. 1}$$

Figure 3 – Map of the APA of Uberaba River drainage.

The data were obtained from the morphometric study of the APA of Uberaba River microbasin. Using vector files of drainage networks and proceeded to read of the lengths of each strand of microbasins in AutoCad software by the command "Modify-Lengthen." The area of the basin was automatically calculated in the GIS with the tool "area".

The values of the density of each drainage basin of the APA were classified according to the criteria described by Vilela and Mattos (1975), such that the index of Dd varies from 0.5 km.km⁻², for with poor drainage basins, the 3.5 or more, for exceptionally well drained basins. Was held on Standardization of information plans

where the drainage density values were reclassified as shown in Figure 4.

The map of the distance from the waterline (Figure 5), drawn from the drainage networks, originated from GIS Idrisi Jungle by distance operation menu "Buffer". Generated from the "Buffer" command the matrix file from distances of 30, 50, 100, 150 and 200 meters.

The map of slope land was drawn from the DEM where was applied in the GIS image clipping of the study area. With the use of the "Slope" tool in the GIS were generated in percentages the land slope classes. After raised the percentages of declivity was conducted the reclassification

of slope classes using the reference ranges of EMBRAPA (1999) described in Table 1 and illustrated in Figure 6.

Figure 4 – Map of drainage density of the APA of Uberaba River.

Figure 5 – Map of the distance from the waterline.

Table 1 – Class intervals of slope and its corresponding reliefs.

Slope	Discrimination
0-5	Relief plan the gentle wavy
5-10	Gently rolling relief the wavy
10-20	Wavy to moderately undulating relief
20-47	The rugged mountainous relief
> 47	Mountainous relief

Source: EMPRAPA (1999).

Figure 6 – Map of declivity of the APA of Uberaba River.

The map of soil use and occupation (Figure 7) has been developed using the supervised classification with use of the tool "Maxlike" of the GIS were used images from the Landsat 8 satellite Sensor "OLI-TIR" collected by the geological survey of the United States dated 06 February 2014, with spectral resolution of 30 metres. Were used for the colour composition bands 4 (R), 3 (G) and 2 (B) in which these scenes were

cut individually in GIS. Following devised the Landsat 8 RGB composition with the use of "Composite" tool. Were classified as to the use of the soil the following vegetable toppings: pasture, forests and annual crops.

The map of soil classes was generated from the cut in the soil of the State of Minas Gerais provided by UFV *et al.* (2010), illustrated in Figure 8.

Figure 7 – Map of soil use and occupation of the APA of Uberaba River (2014).

Figure 8 – Map of soil classes of APA of Uberaba River.

The maps generated in this study adopts the system of Universal Transverse Mercator projection (UTM); 23 zone; Datum horizontal alignment 2000 SIRGAS (Geocentric Reference System for the Americas).

Standardization

The standardization of the criteria analyzed followed a byte-level range (0 to 255), assigning the level 0 less importance and 255 greater importance. The construction of decision rule was executed by means of the functions of relevance to the whole "fuzzy". The slope, drainage density, distance of water courses, classes of soil and the use and occupation of the soil were analyzed as continuous maps in "raster" format.

Sensory analysis and assignment of weights

Possession of the structured criteria in database in GIS, sensory analysis of these criteria, which consisted of bibliographic surveys and discussions with multidisciplinary team about the importance of each factor in the process of vulnerability of water resources. Sought in the discussions with the various forms of interpretation and of values assignments and importance in the different criteria used in these studies (Table 2).

Importance values used in this study was also observed in research developed by Abbaspour *et al.* (2011), Pinto (2010) and

Valle Junior (2014) related to environmental vulnerability.

Depending on the use of several factors for surface analysis of water resources vulnerability and whereas these have different weights in the decision-making process was established the routine WEIGHT ("Weighted Linear Combination"-WLC) from Idrisi, a weighting of variables, according to your degree of relative importance on the decision. Through a paired comparison technique, developed by Saaty (1980), in the context of a decision-making process known as analytic hierarchy process (AHP), which consists of the categorization problem in linear hierarchical levels of importance in relation to each environmental factor (Table 3).

Based on the scale of comparators in Idrisi were adopted 3 (three) different weighting factors scenarios by assigning greater importance to the criterion value of slope of the land (scenario 1), drainage density (scenario 2) and soil class 3 scenario (Table 4). This procedure was used to compare and identify, after the assignment of weights in different scenarios, which criteria indicates the areas of vulnerability of water resources.

The routine of the MCE of Idrisi, once assigned importance values, determined the statistical weights for each factor (Table 4) and calculated the consistency index. Indicates the probability of the consistency of the points array to be generated at random and shall be less than 0.1 for model be considered acceptable (EASTMAN, 2012).

Table 2 – Criteria identified for the study of environmental vulnerability.

Criteria (factors)	Assigned	Values
Drainage density (Km/Km ²)	Too Low	5
	Low	25
	Media	75
	High	125
	Too high	255
Away from the water lines (m)	Distance (30 m)	255
	Distance (50 m)	175
	Distance (100 m)	115
	Distance (150 m)	75
	Distance (200 m)	50
Slope of the land (%)	Slope (0 to 5%)	25
	Slope (5 to 10%)	75
	Slope (10 to 20%)	125
	Slope (20 to 47%)	175
	Slope (47%) >	255
Soil class	The presence of microaggregates	100
	Argissolos	200
	Gleyssolos	255
Soil use and occupation	Forest Fragments	255
	Pasture	125
	Annual Crops	75

Table 3 – Scale of comparators with the respective weights of importance – fundamental Scale Saaty (1980).

Values	Mutual importance
1/9	Extremely less important than
1/7	Very strongly less important than
1/5	Strongly less important than
1/3	Moderately less important than
1	Equally important to
3	Moderately less important than
5	Strongly more important than
7	Very strongly more important than
9	Extremely important that

Source: Saaty (1980).

Table 4 – Paired comparison matrix which is part of the analytic hierarchy process-AHP (SAATY, 1980).

	Distance from watercourses	Use of soil	Soil class	Slope of the land	Drainage density	Weight
Distance from watercourses	1	1/3	1/5	1	1	0.0863
Use of soil	3	1	1/3	1/5	1	0.2702
Soil class	5	3	1	1/3	1/5	0.4658
Slope of the land	1	1/3	1/5	1	1/3	0.0863
Drainage density	1	1/5	1/3	1	1	0.0913

The AHP was implemented by the module of weight of the IDRISI Junglesoftware. To this set of factors, the consistency index calculated was 0.07 in scenario 1, 0.07 in scenario 2 and 0.04 in scenario 3 considered acceptable for all scenarios adopted.

Aggregation

The data were aggregated on weighted linear combination (WLC) ("Weighted Linear Combination") of the Idrisi, considering their respective weights resulting in a map from 0 to 255. It was necessary to combine the data, in order to achieve the General map of vulnerability. In this case, a weighted linear combination was used, which combined the criteria and restriction maps according to the following formula:

$$S_j = (\sum W_i X_i) \Pi(C_k) \quad \text{Eq. 2}$$

Where:

- S_j: represents the risk to pixel j;
- W_i: represents the weight of the factor i;
- X_i: represents the criterion score of factor i;
- C_k: represents the constraint criteria score k and;
- Π: is the symbol of the product.

The factors were combined in applying weights following adequacy calculated from the product factors to the restrictions. The map was reclassified (Table 5) in five classes of vulnerability of water resources: Invulnerable, Moderately Vulnerable, Vulnerable, Heavily Vulnerable and extremely vulnerable and their respective areas were spatialized and calculated.

Table 5 – Range defined for classifying degree of vulnerability.

Risk classes	Range of Classes
Invulnerable	0-50
Moderately Vulnerable	50-100
Vulnerable	100-150
Heavily Vulnerable	150-200
Extremely Vulnerable	200-255

Results and Discussion

Sensitivities of the factors and assignment of weights

The importance of soil class, factor weights were the 0.0863 (distance of watercourses), 0.2702 (soil use and occupation), 0.4658 (soil class), 0.0863 (slope of the land) and 0.0913 for drainage density; being the relationship of consistency of 4%. However, for similar weights for the same scenario 3 noted that the consistency index was the same obtained by (VALLE JUNIOR *et al.* 2014). In this manner, appending the drainage density factor the consistency index remained the same.

The vulnerability in the APA

The map of vulnerability of water resources based on weighted linear combination (Eq. 2) of the factors referred to above is illustrated in Figure 9, with the values of the vulnerability described in the Table 6. The results of the vulnerability represent am the high potential risk of contamination of water resources therefore strongly classes and extremely vulnerable occupy a portion of (16.39%, 7.12%) of the APA and the vulnerable class (49.89%) total 73.4%. The most plausible cause for this fact is the occupation of the areas Gleysolos, Argissolos and the presence of Microaggregates coupled with land use factor that were reclassified with a very high note until 255 byte.

Figure 9 – Map of vulnerability of water resources in APA of Uberaba River.

Table 6 – Areas of vulnerability in the APA of Uberaba River.

Risk classes	Area (km ²)	Percentage of area (%)
Invulnerable	0.00	0
Moderately Vulnerable	138.438	26.6
Vulnerable	259.690	49.9
Heavily Vulnerable	85.340	16.4
Extremely Vulnerable	37.061	7.1
Total	520, 529	100

With this study it was possible to determine in the APA of Uberaba River the vulnerability environmental. According to morphometric and physical parameters of the catchment area and with the use of the Geographical information system

it was possible to evaluate jointly the different levels of information.

Because it is a conservation area the area of Environmental protection, whose activities must be sustainable and use their water resources (main course of

the Uberaba River) bein the supplying the population of Uberaba, thereis a need for studies that seek to assess the environmental quality of the existing natural resources as well as propose measures of preservation and conservation.

Environmental vulnerability occurs in the area studied, which indicates the risk of degradation of the natural environment, related to soil erosion, loss of biodiversity, contamination of soil and water resources and vegetation cover loss aggravated by roads and misuse of the soil.

The dominant factor in the transport of contaminants to the water courses is the runoff, being the same powered by declivities, uses presented soil and physical characteristics of the same. In this way the classes of soils prone to shallow streams generation given its characteristics, the

topography, the distance of the courses of the rivers interfluvial (drainage density and uses data to soils) should be strongly considered as elements of decision making for the management of water resources of this area, in order to promote the maintenance of them quantitatively and qualitatively.

Conclusion

The use of multi-criteria analysis applied to the study of vulnerability of water resources can be employed in several studies since thereis a correlation to the factors involved.

Morphometric and physical aspects of influence in basin environmental vulnerability.

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