PRIORITY AREAS FOR FOREST CONSERVATION, AIMING AT THE MAINTENANCE OF WATER RESOURCES, THROUGH THE MULTICRITERIA EVALUATION[1]

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Abstract – Replacing the original land cover by other land uses, especially when it is associated with inadequate management practices, can cause changes in runoff and rainwater infiltration. This can result in above normal levels of soil erosion and sediment-carrying to the rivers and streams. The original land cover conservation in the watersheds is, therefore, essential for the maintenance of its water resources. In this context, the main objective of this study was to prioritize areas for forest conservation in two watersheds, aiming at maintaining the water availability, in terms of quantity and quality, for the public supply. The watersheds were selected considering their regional importance and because they are similar in terms of land use / land cover. The study was developed in the Multicriteria Evaluation (MCE) context, which permits the integration of different landscape characteristics (i.e. factors), in order to obtain a solution for the decision-making process. The following criteria were selected by considering the expert's opinions: slope, flow accumulation, aspect, and land use / land cover. Their relative importance (i.e. factor weight) was defined through the Pairwise Comparison Method. The criteria maps units were normalized by a common scale and then aggregated through an MCE method named Weighted Linear Combination (WLC). Pearson correlation was used to evaluate the criteria contribution on the final map. The watershed 1 was classified in approximately 14% of its area as very high priority; 27% as high; 19% as medium; 21% as low; and 18% as very low. The watershed 2 obtained, respectively, 17%; 29%; 17%; 21%; e 17%. We conclude that the WLC method supports the definition of priority areas for forest conservation in the watersheds, in order to have an appropriate design of actions for forest conservation.

Keywords: Weighted Linear Combination; Geographic Information System; Decision-support.

AVALIAÇÃO MULTICRITERIAL NA PRIORIZAÇÃO DE ÁREAS À CONSERVAÇÃO FLORESTAL VISANDO À MANUTENÇÃO DE RECURSOS HÍDRICOS

RESUMO – A substituição da cobertura original do solo por outros usos, em especial quando se tem práticas inadequadas de manejo, pode causar alterações entre o escoamento superficial e infiltração da água das chuvas. O resultado pode ser o processo de erosão do solo e carreamento de sedimentos aos canais de drenagem em níveis acima do normal. A conservação da cobertura original de uma microbacia é, portanto, essencial à manutenção de seus recursos hídricos. Neste contexto, o principal objetivo do trabalho foi a priorização de áreas à conservação florestal de duas microbacias, visando à manutenção da disponibilidade de água, em quantidade e em qualidade ao abastecimento público. As microbacias foram selecionadas por sua importância regional e por possuírem semelhanças quanto ao uso e cobertura do solo. O estudo realizou-se no contexto da Avaliação Multicriterial (AMC), que permite a integração de diferentes características da paisagem (i.e.

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fatores), na proposição de uma solução para um processo decisório. Com a consulta à especialistas selecionou-se os seguintes fatores e, por meio do método da Comparação Pareada, definiu-se suas importâncias relativas (i.e. pesos de fator): declividade, fluxo acumulado, orientação das vertentes e, uso e cobertura do solo. Os mapas de fatores tiveram suas unidades normalizadas para uma escala comum e, em seguida, foram agregados por meio do método de AMC denominado Combinação Linear Ponderada (CLP). O teste de correlação de Pearson foi usado para avaliar a contribuição dos fatores no mapa final. A microbacia 1 apresentou cerca de 14% de sua área com muito alta prioridade à conservação florestal, 27% com alta, 19% com média, 21% com baixa e 18% com muito baixa. Para a microbacia 2 obteve-se valores, respectivamente, de 17%, 29%, 17%, 21% e 17%. Conclui-se que o método CLP permite a priorização de áreas à conservação florestal das microbacias de forma a se ter um direcionamento adequado das ações de conservação florestal.

Palavras-chave: Combinação Linear Ponderada; Sistema de Informação Geográfica; Suporte à Decisão.

INTRODUCTION

Pressure on water resources generates demands for planning and environmental management, which aim at the maintenance of these resources to meet immediate and future needs, such as maintaining the capacity of the water supply in the long term (Foley et al., 2005; Padowski and Gorelick, 2014). Environmental planning of the recharge areas of the springs is necessary, aiming at the planning of the space and activities to be carried out, having as a main objective the best performance of these areas regarding their natural vocation, and respecting the environmental restrictions (Francisco et al., 2008).

Studies, such as those performed by (Uriarte et al. (2011), Attanasio et al. (2012) and Pinto et al. (2013)), point out the importance of maintaining the vegetation cover to conserve water resources, as a way of guaranteeing the quality and availability of water for the population and biological communities. The vegetation ensures the fractionation of rain before it contacts the ground via the interception process, thus influencing the water flow and infiltration into the soil processes (Sousa et al., 2011). Natural vegetation has been identified as the most important soil cover in relation to other covers in hydrological processes, for its positive influence on water infiltration (Mingoti and Vettorazzi, 2011).

Spatialization of conservation actions can be accomplished through the prioritization of areas, which is one of the most effective and economical methods in the management. The interaction of different information plans in Geographic Information Systems (GIS) guarantees good results, making it possible to obtain maps of priorities in a short time and with reliability (Valente and Vettorazzi, 2008). Phua & Minowa (2005), Valente & Vettorazzi (2005; 2008) and Francisco et al. (2008) carried out the integration of information plans in a GIS environment to define priority areas for forest conservation through Multicriteria Evaluation (MCE).

Valente & Vettorazzi (2013) defined priority areas for forest restoration, aiming at the sustainable management of water resources in the Corumbataí river basin, while Silva (2010) identified areas of environmental fragility associated with water quality in the São Bartolomeu river basin. The two studies used MCE, as did Liu et al. (2013), which identified priority areas for the conservation of ecosystem services in China. Malczewski (1999) already emphasized the possibility of using MCE in the creation of maps for decision making, combining and transforming spatial data through decision rules that will define the relationships between the input data and the final maps.

In this context, the present study aimed to prioritize areas for forest conservation of two watersheds to maintain the water availability in quantity and quality to the public supply. One of its specific objectives was to evaluate the Weighted Linear Combination (WLC) method in the aggregation of criteria. The WLC method is one of the MCE decision rules and is considered flexible when it comes to evaluating environmental management alternatives (Malczewski, 2000). One of the advantages associated with the method/rule is the ability to associate weights with the criteria, considering the relative importance that exists between them in the decision-making process.

Another specific objective of the study was to evaluate the importance and the influence of the criteria set, which were selected to represent landscape characteristics and/or processes, which directly influence the maintenance of water quality and quantity of watersheds. For this reason, the watersheds chosen for the study, in addition to their regional importance as a source of water for the public supply of downstream municipalities, present similarities regarding their land use/land cover.

2. MATERIAL AND METHODS

2.1. Study area

The study watersheds are located between coordinates 23°40'1,04"/23°44'0,56" S and 49°53'57,38"/ 49°54'6,35" W, in the Piedade county, southeast of São Paulo State. They have a drainage area of 549 ha (Watershed 1 – W1) and 598 ha (Watershed 2 – W2), respectively, located on the east boundary of Piedade, close to Ibiúna country (Figure 1).

The region is under the influence of Cwa climate (humid summer and dry winters), with the annual precipitation between 1354.7 mm and 1807.7 mm, and an average temperature of 22.8°C in the hottest months and 15.8ºC in the coldest months (CEPAGRI, 2014). The altitude varies from 850 m and 1,200 m above sea level with an average slope of 25%, which features an undulated to strongly undulated relief, with some mountainous areas (Embrapa, 1999).

The study region presents 25% of native forest cover (Atlantic Forest) (SOS MATA ATLÂNTICA, 2013), classified as the transition vegetation between dense ombrophilous forest and semideciduous seasonal forest (IBGE, 2012). Another characteristic of the study area is the proximity to two protected areas – Itupararanga Environmental Protection Area and Jurupará State Park.

Agriculture is the backbone of the Piedade economy, especially the production of onions, potato, artichoke, pumpkin, khaki, sweet potato, strawberry and others (Piedade, 2014). According to the land use/land cover map created by on-screen digitizing of SPOT images (2.5m-spatial resolution; panchromatic band, year: 2010 – Source: SMA-CPLA), the watersheds present agricultural lands, however, forest cover represents 55% and 58% of the total area of W1 and W2, respectively (Figure 1). Agricultural lands cover 27% of W1 and 23% of W2. The watersheds also have other uses as pasturelands (W1=11.5%, M2=12%), planted forest (W1=3%, W2=2%) and urban (residential) areas (W1=1%, W2=3.5%). Wetland areas cover about 2% of the watersheds (Figure 1).

The drainage basin in the Piedade country is comprised by the Pirapora and Sarapuí rivers, located in the Water Resources Management Unit number 10

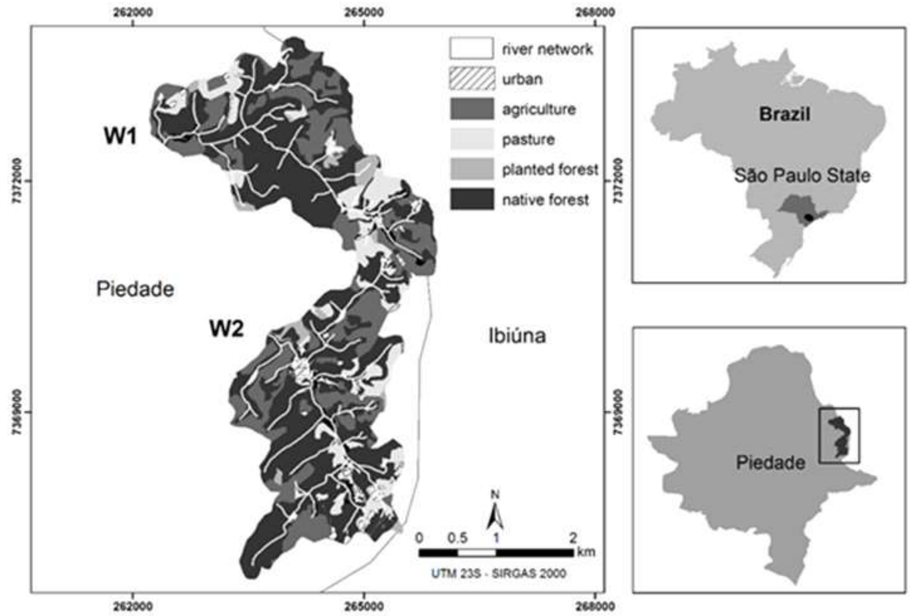

Figure 1 – Location and land-use/land-cover of the watersheds in the Piedade municipality, Sao Paulo State.
***Figura 1** – Localização e uso e cobertura do solo das microbacias, no município de Piedade, estado de São Paulo.*

(UGRHI-10), also Peixe and Turvo rivers of the UGRHI-11. Our study watersheds (W1 and W2) are located in the upper Pirapora river, an important water source for the region, which supplies Piedade, Salto de Pirapora, and Araçoiaba da Serra countries. The study watersheds are located on the east boundary of Piedade county, close to Ibiúna country.

In this context, the study watersheds have an important role in providing water and maintaining natural forest patches. They are located in the Environmental Conservation Zone (ZCA) of the Master Plan of Piedade, where its water resources are important for food production. The water demand for the Pirapora river is above 50% of its recovery capacity. Thus, water offer is considered critical and could affect the water supply of Piedade (IPT, 2008).

2.2. Priority areas

The study was developed in the GIS environment (ArcGIS 10.1), normalizing the cartographic database for the 2.5 spatial-resolution; projection UTM (zone 23S) and; datum SIRGAS 2000. So, the decision-making process was organized considering this database and the follow steps.

Criteria definition

The criteria, that are the basis of the decision-making process, are traditionally divided into factors and constraints.

Constraints are responsible for placing spatial limits on priority areas, indicating the places when they should not occur. In this study, the constraints were watersheds limits and their drainage network (Figure 1).

Factors represent characteristics of the landscape and/or process, that should be considered in the study. Aiming at the definition of these factors, considering the main study objective, we consulted experts and the literature.

The 15 experts we consulted are related to areas such as forest hydrology, soil management, forest restoration, landscape ecology, irrigation, and geoprocessing. They received the project abstract and followed these requests: (i) the indication of the criteria important for the decision-making objective; and (ii) the criteria ranking, considering their relative importance.

In this context, four criteria (Figure 2) represented the group consensus, according to the study scope:

(1) Slope: it is the main factor related to soil erosion (Valladares et al., 2012) and, commonly, the regions associated with high levels of slope are more susceptible to the erosion process, depending on the management practices. The erosion can intensify the drainage network sedimentation, reducing the eutrophic layer and increasing the suspended sediments associated with pollutants, affecting the water quality (Rickson, 2013; Nacinovic et al., 2014). The factor map was generated from Digital Elevation Model (DEM), that was produced from the topographic map (IGC; 1:10.000; from Piedade county) through the Triangular Irregular Network (TIN) method. Thus, firstly we digitalize the topographic contours from the topographic map to obtain the DEM. The slope map was reclassified as proposed by Embrapa (1999) (Figure 2a) and it was normalized by a common scale 0–1, using a linear monotonically increasing function. This way, the highest values of the slope were associated with the highest values of the common scale.

Independent of the method employed, normalization is a necessary step in the MCE because the criteria maps should be aggregate, despite having distinct units. Thus, the criteria are converted to the same unit through normalization, respecting the importance of the variable that the map represents, for the definition of priority areas.

(2) Flow accumulation: the water drains through the landscape, carrying agrochemicals, organic matter, inorganic pollutants, and microorganisms (Silva, 2010). The water velocity and volume are directly related to its route, wherein an energy increase in the process results in the increase of erosion and the sediments movement in the landscape (Silva, 2003). Thus, we can say that the flow accumulation directly influences the erosion process. DEM was the main layer to produce this factor but its edition was necessary, excluding its spurious depressions that could cause a disconnected drainage network and, consequently, an error in the definition of flow contribution area. After using a GIS function, we generated flow direction, which establishes the flow for each cell potentially surrounded by eight neighboring cells. This second map permits, through other GIS function, the identification of cells that accumulate water flow (Figure 2B). A linear monotonically increasing function was used in the normalization the factor map for the 0-1 scale.

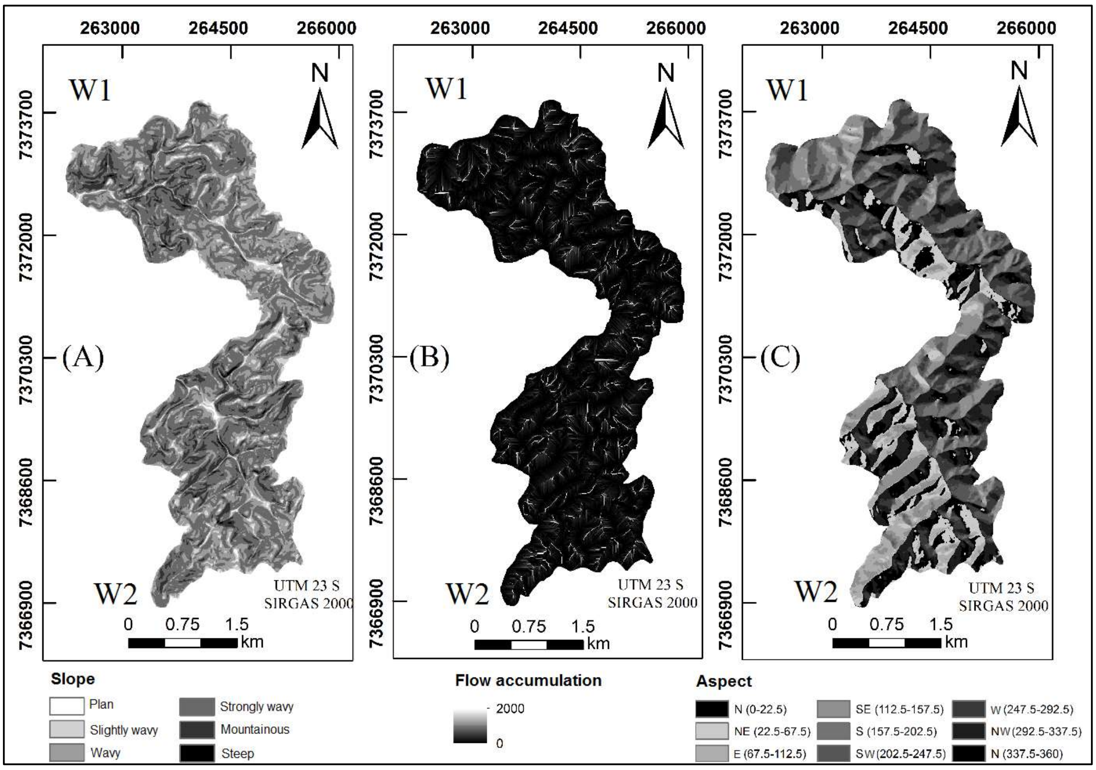

Figure 2 – Factors selected to MCE: (A) slope, (B) Flow accumulation and (C) aspect.
***Figura 2** – Fatores selecionados para a AMC: (A) declividade, (B) fluxo acumulado e (C) orientação de vertentes.*

(3) Aspect: the aspect facings of the terrain that receive the most quantitate of energy from the sun are associated with the highest values of temperature and rates of evapotranspiration and minor values of soil and air humidity (Rosenberg, 1974). North- and west-facing aspects, in the Southern Hemisphere, receive a higher energy quantitative than south- and west-facing aspects. So, the last group tends to conserve the highest quantity of humidity in the soil, and the first group tends to disperse this humidity (Tonello et al., 2006). Through the factor, the priority areas consider areas with the lower moisture retention. Cardoso et al. (2006) also considered the factor as important in the prioritization of areas for forest conservation aiming at the water recharge in watersheds. Based on DEM, the factor map was produced and normalized following the decrease in importance rank: north-west, north-east, south-west, south-east (Figure 2C).

(4) Land-use / land-cover: the inadequate land use affects the watershed hydrology, altering the water quality, especially in areas that suffered from the transformation of natural landscapes into others land uses (Farina, 1998; Galbraith and Burns, 2007; Baker and Miller, 2013; Tu, 2013). The land-use accordance with the landscape characteristics is essential for the ecosystems quality and process, and the maintenance of ecological services. The ideal land uses for landscapes, thinking about water in terms of quality and quantity, do not generate negative impacts such as erosion, sediments, and silting. In this context, the land-use/land-cover map (Figure 1) was normalized, considering native forest associated with 1, in the common scale; wetland with 0.83; eucalyptus with 0.67; pasture with 0.50; agriculture with 0.34 and; urbanization with 0.17.

Pairwise comparison matrix

The matrix (Table1) was elaborated to obtain the factor weights, considering the importance rank of criteria as proposed by the Pairwise Comparison Method, developed by Saaty (1980) in the context of the Analytic

Hierarchy Process (AHP). Eastman (2011) highlighted that the factor weight represents the criteria importance in the decision process.

According to the method, the factors are compared (two-by-two) based on a continuous scale, where the value 1 indicates that two criteria are "equally" important to the study and, the value 9 implies that one criterion is "extremely" more important than the other.

The comparisons values are entered into the matrix and the factor weights are calculated (Table 1). One matrix characteristic is to be symmetric and, in this way, only its upper triangular part should be full.

The matrix showed in Table 1 represents the consensus experts, having an adequate Consistence Ratio (CR). Saaty (1980) cited that CR less than 0.10 indicates good consistency and, in cases of inconsistency, the pairwise comparison should be reassessed.

Criteria aggregation

The Weighted Linear Combination (WLC), that is the MCE most employed in different studies (Malczewski, 2000), was used to aggregate the criteria maps, producing the mapping of priority areas for forest conservation.

Through WLC the criteria are multiplied, respectively, by their weights and then combined by a value function. We would like to highlight two WLC characteristics. Firstly, that WLC is a method based in an operation pixel-by-pixel, permitting criteria with continuous variation per the landscape (e.g. slope). Secondly, that WLC aggregate a criteria group differently from the traditional Booleans algorithms, which aggregate criteria two-by-two. Voogd (1983) presented WLC theoretical conceptualization but, nowadays, it is a routine in the most part of GIS.

Finally, we evaluated the histogram frequencies of the priority map, defining five priority classes: very low, low, medium, high and very high.

2.3. Evaluation of priority map

We evaluated the criteria importance in the final map using a Pearson correlation test.

Firstly, a 500-point stratified random grid was generated for W1 and W2, considering its limits as a basic layer. The grid was overlaid with priority maps (W1 and W2) and their respective criteria maps.

After, we registered the pixel values (in scale 0–1) of the priority and criteria maps and produced the correlation analysis.

The sampled number, of 500-point by watershed, was defined as proposed by Valente and Vettorazzi (2013).

3. RESULTS

The priority areas map (Figure 3) obtained from the aggregation of criteria maps through the WLC method of MCE, indicated that 14.4% of the W1 was classified as very high priority and 26.6% as high priority for conservation. In the same way, W2 presented 16.6% of very high priority and 29.2% of high priority. Thus, W1 and W2 have, respectively, 41% and 45.8% of their total areas associated with the highest levels.

Comparing the final maps (Figure 3) with the criteria maps (Figure 2), we can observe that for both watersheds, the two highest priority classes are spatially distributed on areas primarily covered by native forest and with steep areas (undulating or mountainous lands). It is not observed as a predominant pattern between the

Table 1 – Pairwise comparison matrix between the factor maps for the watersheds, in the Piedade municipality, Sao Paulo State.
Table 1 – *Matriz de comparação pareada entre os mapas de fatores, para microbacias do município de Piedade, SP..*

Criteria	A	B	C	D	Factor weight
Land-use / land-cover (A)	1				0.4159
Slope (B)	1	1			0.3846
Flow accumulation (C)	1/4	1/3	1		0.1257
Aspect (D)	1/5	1/5	1/2	1	0.0738
Consistence Ratio (CR)= 0.0078					

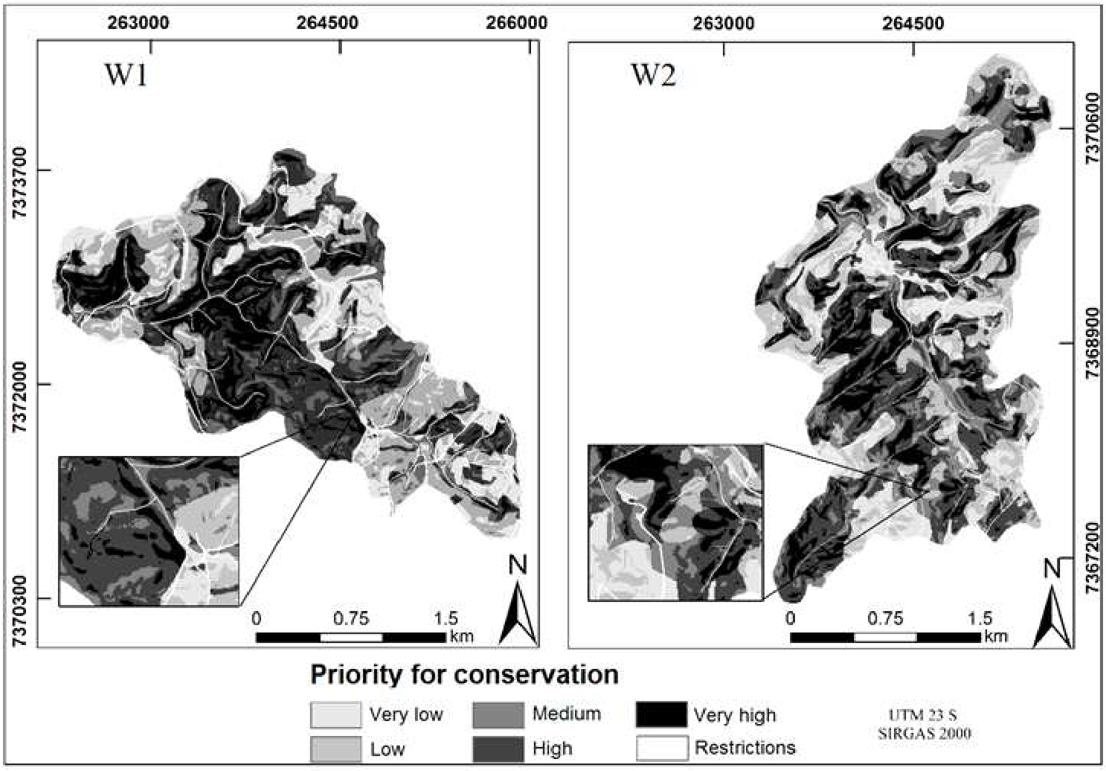

Figure 3 – Priority areas for forest conservation to maintenance of water resources in watersheds 1 and 2.
Figura 3 *–- Áreas prioritárias para conservação florestal, visando à manutenção dos recursos hídricos, nas microbacias (W1 e W2), do município de Piedade, SP.*

final maps and the criteria maps of flow accumulation and aspect. However, the subsequent analysis of the sampling points showed the contribution of these criteria for the areas prioritized.

There was a correlation between the priority and the criteria values. The correlation levels followed the order of importance of the criteria that was pre-established by the decision-making process. Thus, the values from the map of priority areas presented a correlation of 91% with the map of land use / land cover factor, 52% with slope, 20% with flow accumulation, and 1% with aspect. Therefore, the level of coincidence between the final maps and the factors maps (a pairwise comparison) was higher for the criteria with greater importance than for the other criteria selected for the objective of this study.

4. DISCUSSION

The spatial distribution of the priority areas (Figure 3) proposed the targeting of forest conservation actions aiming at water resource preservation. The very high priority class presents one of the lowest percentages for both watersheds (W1= 14.4%; W2=16.6%). The final map (Figure 3) allows us to identify focus areas represented by the very high priority. They are grouped in some regions and are surrounded by areas of high priority. Thus, the areas of high priority comprise an extension of the regions classified as very high priority. In the same way, the areas of medium priority surround the areas of high priority, followed by the areas of low priority. Therefore, there was a spatial continuation according to the priority classes, which can optimize the process of forest conservation.

This spatialization agrees with what was defined by the decision-making process, once the priority areas are close to the forest remnants, on sensitive lands (undulating or mountainous lands) and, in general, close to sites of great water accumulation that are nearest to water courses (Figure 3). Another important aspect is that the conservation of sensitive areas and regions close to the existing forest fragments are based on the landscape restoration concepts (Valente and Vettorazzi, 2013), which are related with the reestablishment of the ecosystem process that occurs in a landscape, as for example the forest connectivity and the genetic flow.

In this context, it is possible to reestablish the ecological functions of the landscape over time, even if it is not in the same stage that it was before the anthropogenic process of land use. We also can have the landscape with the greatest capacity to restore its resources and services (Wang et al., 2007; Valente and Vettorazzi, 2008; Leite et al., 2013).

The accordance of the prioritization with importance of the criteria was obtained by the correlation test between the priority map and the criteria maps. According to our results, the final map presented a correlation of 91% with land use / land cover, 52% with slope, 20% with flow accumulation and only 1% with aspect. Thus, when there is a spatial intersection between the sites with the greatest values for most of the criteria (values close to 1 according to the normalized scale), we have areas classified as very high priority.

The aspect factor only had a local influence due to its low importance, which was attributed by the decision-making process (factor weight = 7.38%). It can be observed by comparing two areas in the final map (Figure 3). They have the same conditions of land use, slope, and flow accumulation but present different faces of exposure to the sun, consequently, the area associated with the greatest priority value was that one correlated to the most important aspect (south-east).

Considering the final map, we would like to highlight another characteristic related to WLC method, that is the presupposition of the total tradeoff among criteria (Malczewski et al., 2003). The main consequence is that there is no control over the influences of each factor in the decision-making process, which can direct the spatialization of the priority areas. Even under these conditions, WLC is considered a robust method, and among those that do not include factor compensation, it is often used for different applications (Malczewski, 2000).

Authors as Malczewski et al. (2003), Boroushaki & Malczewski (2008), Valente & Vettorazzi (2008; 2013) indicated that maps developed by WLC have a tendency toward generalization with a high percentage of their area classified as medium priority. For this reason they present “non-risky” solutions to the decision-making process. The final map of priority areas (Figure 3) indicated, as it was discussed, priority areas for forest conservation in specific regions. The class of medium priority represented by 19% and 17% of W1 and W2, respectively, which represents non-generalist spatialization areas, even though it did not use the MCE compensatory methods employed by other authors as Boroushaki & Malczewski (2008; 2010), Valente & Vettorazzi (2013), Ferretti & Pomarico (2013), and Silveira et al. (2014).

The identification of priority areas in this study used a geographic database with a spatial resolution of 2.5 m (the same resolution of the SPOT images). In this way, the database detailing collaborated to minimize the generalization tendency of WLC, which is the generating a high percentage of areas classified as medium priority. Thus, using WLC we obtained a priority mapping that allows “directed” decisions in the field.

5. CONCLUSION

We can conclude, based on the results, that the WLC method of MCE allows the prioritization of areas for forest conservation in the watersheds to have an appropriate direction for forest conservation actions. The priority classes represent the criteria importance defined for the study, consequently, regions associated with the highest priority classes are correlated to those sites with greatest values in the criteria maps.

We also conclude that the spatial resolution of the criteria maps influences the priority map when using the WLC method.

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