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Priority areas for forest restoration aiming at the conservation of water resources

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ABSTRACT

Allocation of forest in a river basin is a complex management problem, with conditions that may encourage conflict, in particular among groups with different interests, due to the diversity of the objectives. Aiming at the conservation of water resources, the main objective of this study was to assess the performance of Ordered Weighted Averaging (OWA), a multicriteria decision analysis, in the prioritization of areas for forest restoration. The study area is a Brazilian river basin, originally covered by Atlantic Forest. The relevant criteria to this decision-making process were identified as land-use suitability, soil erodibility, erosivity, proximity to roads, and proximity to surface water. We proposed three order weight sets, based on the decision strategy space, with medium-to-high risk-taking and medium tradeoff among the criteria (OWA1); medium risk-taking and total tradeoff (WLC), representing the traditional Weighted Linear Combination method; and medium-to-low risk-taking and medium tradeoff among the criteria (OWA2). Then, using an OWA operator (as a GIS routine), we produced maps for the three solutions, which were reclassified in five priority levels (very low, low, medium, high and very high). We did the cross tabulation among the solutions, for areas classified as high and very-high priority, and some environmental characteristics, intrinsically related to the criteria: land-use/land-cover, soil erodibility, distance from the surface water, soils and slope. WLC resulted in 54% of the Corumbataí river basin with high priority to forest restoration; 37% with very-high priority; and 9% with medium priority, and the spatial distribution of classes was intrinsically related to two main criteria: proximity to surface water and soil erodibility. OWA1 resulted in one alternative with 80% of the basin classified as very-high priority to forest restoration and 20% as high priority. Such classes' distribution is the result of the distribution of order weights, to obtain the desired risk level. In OWA2, due to the distribution of order weights among the criteria, the prioritization of areas occurred differently from the previous alternatives, with no predominance of one or more criteria. Under this scenario, the river basin presented 1% of this area with very low priority for forest restoration; 17% with low; 63% with medium; 10% with high; and 9% with very-high priority. OWA is suitable for the prioritization of areas, once it allows us to control the criteria influence on the final solution, through the tradeoff. This implies, however, the method's ability to normalize the criteria to a continuous scale, since the categorization in the criteria maps affects the spatial distribution of the alternatives.

1. Introduction

Many developing countries have investigated water resources projects to satisfy their demand for water. The problem lies not only on the quantity of water, once the major challenge, in several regions of the world, rests in terms of the water quality (Randhir, 2012). It has been widely reported that the relationship existing among the quality of water (superficial and subterranean) and the replacement of the original soil cover by agricultural crops, results in soil erosion and sediment being carried away to the rivers and streams (Randhir et al., 2001; Seguí, 2011; Ngetich et al., 2014).

The allocation of forest in a river basin is a complex management problem, with conditions that may encourage conflict, based

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on the diversity of the objectives, in particular among groups with different interests.

Forest restoration actions account for the most feasible of the solutions for water quality and quantity issues (Kangas et al., 2000; Holl et al., 2003; Wang and Medley, 2004; Aronson and Alexander, 2013). The relationship between the landscape structure and effectiveness of the restoration process can be influenced by several factors (Leite et al., 2013). Factors, thus, represent the critical characteristics of the landscape, especially those that influence the objective of the restoration process. In fact, Cassiano et al. (2014) considered the factors such as slope, soil texture and stream distance in order to propose a method that assessed the contribution of the forest patches to water conservation and defined the priority areas for forest restoration. Zhu and Li (2014) defined forest restoration, aiming at conservation and the more efficient use of water, based on the actual land use and the efficiency of the irrigation systems employed in the region studied. Orsi and Geneletti (2010) identified the priority areas in the landscape for forest restoration, utilizing a set of ecological and socioeconomic criteria.

Restoration, from the landscape perspective, requires the implementation of multiple criteria (i.e. factors related with the restoration objective) and methods that involve the integration of those criteria, in order to define the sites, i.e. priority areas, for the actions in the landscape (Geneletti, 2004; Phua and Minowa, 2005; Valente and Vettorazzi, 2008; Orsi and Geneletti, 2010).

Multicriteria Evaluation (MCE) is one of the decision-making processes used to define the priority areas for forest restoration (Valente and Vettorazzi, 2011; Patel et al., 2015). It is considered a process that combines and transforms both spatial and non-spatial data (input) into a result decision (output). Malczewski and Rinner (2015) cite that MCE involves a set of alternatives that are evaluated on the basis of conflicting and incommensurate criteria, according to the decision maker's preferences, based on specified decision rules (i.e. MCE is a method for combination of criterion maps). Thus, MCE can provide a framework to represent the decision group into a single process. Nowadays, studies have been developed in two main issues: Operations Research and Management Sciences and Landscape Architecture. The first is related to mathematical-based problem solving methods and approaches to decision-making, and the second aims to apply scientific principles to the planning, designing, and managing of natural and built environments Malczewski and Rinner (2015).

Chung and Lee (2009) and Randhir (2012) highlight that the MCE procedures are widely accepted as highly useful in resolving water management related conflicts. The authors cite that the usefulness of these procedures depends on the logical structure of the valuation processes as well as on the common language developed for defining and discussing complex water problems. These procedures have also been found to be useful tools for communication between the decision makers and those affected by them.

There are two fundamental classes of MCE methods (MCEM): the non-compensatory method (i.e. Boolean overlay operations) and the compensatory method (taking into account the trade-offs among criteria), which is more flexible in terms of evaluating management alternatives (Malczewski, 2000).

Ordered Weighted Averaging (OWA) is a compensatory method and represents a generalization and extension of the traditional Weighted Linear Combination (WLC) (Jiang and Eastman 2000). OWA concept was developed in the context of Fuzzy Set Theory (Yager, 1988). However, the use of these operations is not limited to fuzzy sets (Malczewski et al., 2003). OWA involves two sets of weights: the weights of relative criterion importance (i.e. factor weights) and the order weights. By specifying an appropriate set of order weights one can generate a wide range of outcome maps (i.e. decision strategy solution/alternatives) (Malczewski, 2006). According to Valente and Vettorazzi (2008) the method is flexible, easily implemented and, mainly, permits the inclusion of the opinions of the decision-makers and experts, as well as the characteristics of the landscape, in the decision-making process. Consequently, the appropriate solution represents the decision-makers' preferences and the best relationship among the criteria set and the objective of the decision-making process (Boroushaki and Malczewski, 2010a). Gorsevski et al. (2012) highlight that the purpose of the approach was not to identify a single "optimal" solution, but to reveal other strengths associated with the weighting flexibility of the OWA approach, including the one obtained by the Weighted Linear Combination method (traditional MCEM).

OWA is a concept with several applications in the GIS environment (Mendoza and Prabhu, 2000; Gkaraveli et al., 2004; Sweeney and Czapka, 2004; Silveira et al., 2008; Sadiq et al., 2010; Gorsevski et al., 2012; Amiri et al., 2013). Among them, we highlight the study of Krois and Schulte (2014) which identified and ranked the potential sites for the application of soil and water conservation techniques in a watershed.

In this context, the main objective of this study was to assess the performance of OWA method in the prioritization of areas for forest restoration, aiming at the conservation of water resources. We defined the criteria under the perspective of landscape restoration and used a Brazilian river basin, originally covered by Atlantic Forest, as study area. Thus, the paper is an application of the OWA method, with the purpose to have a decision-making support model for river basins with problems related to water supply.

2. Material and methods

2.1. Study area

The study area was the Corumbataí river basin, located in the Central-Eastern region of the state of Sao Paulo, Brazil, with approximately 170,000 ha (Fig. 1). Local mean annual rainfall is 1367 mm and the climate is considered humid subtropical, according to Köppen classification.

The Corumbataí river basin covers eight municipal districts, being a strategic water source even for municipalities beyond their limits. We can highlight the Piracicaba municipality, with only 6.6% of its territory within the basin, but with a water withdraw, for public supply, of 95% from the Corumbataí river. Thus, there is an intense effort from local, state and national government agencies, universities and research institutes, and NGOs to study the components of that basin and to define actions for its restoration, thinking at the production of good-quality water for human consumption.

Mostly Atlantic Rainforest originally covered the basin. Human intervention was responsible for the conversion of the forest into a mosaic with different land-cover patches and remnants of the original forest. Nowadays, pastures and sugarcane are the main land uses present in the landscape (Fig. 1), with the first covering 43% of basin, especially in it upper portion. Sugarcane plantations occupies around 28% of basin, in its lower portion.

Annual crops and orange orchards are other covers present in the basin. Annual crops comprise small areas of beans, corn and vegetables (totaling around 1% of the river basin area), which are concentrated in the central portion of the basin. Orange orchards belong mainly to juice companies and are located in the northern portion of the basin, occupying 4% of study area (Fig. 1).

Semideciduous Seasonal Forest and Savanna (Fig. 1), classified here as native forest, occupy, respectively, 11% e 1% of the basin. Fig. 1 shows that the representative patches, in terms of size, are associated with pastures, as mentioned by Valente and Vettorazzi (2002).

Finally, we can mention the urban area of municipalities, which occupy around 3% of basin.