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# Mapping of priority areas for environmental recovery of Rio Pomba city, Minas Gerais

Jaqueline Aparecida de Oliveira [1] *, Jeniffer Barroso da Silva [1], Kleber Mariano Ribeiro [1], Flávia Monteiro Coelho Ferreira [1], Roselir Ribeiro da Silva [1]

[1] Agricultural and Environmental Department / Federal Institute of Education, Science and Technology of Southeast of Minas Gerais - Rio Pomba College. Rio Pomba, 36180-000, Minas Gerais, Brazil. Electronic mail: jaqueline.agroecologia@gmail.com, jeniffer.agroecologia@gmail.com, kleber.ribeiro@ifsudestemg.edu.br, flavia.coelho@ifsudestemg.edu.br, roselir.silva@ifsudestemg.edu.br.

* Corresponding author

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**A B S T R A C T**

The present paper aimed to map the priority areas for environmental recovery of Rio Pomba city, Minas Gerais, as part of the creation of a strategic plan for environmental actions. In order to carry out the proposed approaches, the information layers (IL) geology, climate, land use, pedology and geomorphology of study area were mapped individually and transformed, by multicriteria analysis, in a single database using the geographic information system (GIS), resulting in the mapping of natural vulnerability to soil loss. The results showed that areas vulnerable to erosion processes, and priority to environmental restoration actions, were concentrated in declivity regions of study area, while regions classified as stable accumulated in permanent preservation areas (PPA) marginal to water resources. These results diverged from the field observations and the addition of an IL that demarcates the PPAs in multicriteria analysis was proposed as alternative. The new results were satisfactory, closer to the field inspections and this new methodology can be used in management of environmental restoration actions of city, in which should begin with the marginal PPAs and in the northern region.

Key words: strategic plan, degraded areas, soil loss

# Mapeamento das áreas prioritárias à recuperação ambiental no município de Rio Pomba, Minas Gerais

**R E S U M O**

O presente trabalhou buscou mapear as áreas prioritárias à recuperação ambiental do município de Rio Pomba, Minas Gerais, como parte da criação de um plano diretor para ações ambientais. Para o cumprimento das abordagens propostas, os planos de informação (PI) geologia, clima, uso da terra, pedologia e geomorfologia do município foram levantados individualmente e reunidos, via análise multicritério, em uma única base de dados utilizando o sistema de informação geográfica (SIG), resultando no mapeamento da vulnerabilidade natural à perda de solo. Os resultados mostraram que as áreas vulneráveis aos processos erosivos, e prioritárias as ações de recuperação ambiental, concentraram-se nas regiões declivosas da área em estudo, enquanto que os terrenos classificados como estáveis acumularam-se nas áreas de preservação permanente (APP) marginais aos recursos hídricos. Esses resultados divergiram das observações de campo e a adição de um PI que demarque as APP's na análise multicritério foi proposta como alternativa. Os novos resultados foram satisfatórios, mais próximos das inspeções de campo e essa nova metodologia pode ser utilizada no gerenciamento das ações de restauração ambiental da cidade, que devem iniciar pelas APP's ciliares e na região norte.

Palavras-chave: plano estratégico, áreas degradadas, perda de solo

## Introduction

The human intervention in environment has been of a long period, bringing positive impulse, such as environmental recovery activities and the adoption of soil conservation practices, and negative impacts, such as the reduction of land cover and pollution of soil, water and air (Nascimento et al., 2014; Mattielo et al., 2017). Unfortunately, positive actions are timid in face of environmental damage, and maintaining this scenario tends, in long-dated, to reduce biodiversity and limit the availability of natural resources (Borges et al., 2016; Jorge et al., 2017; Vieira et al., 2017).

In this context, it is necessary to reflect about economic activities developed by man, in order maintain the development and environmental for present and future generations (Fengler, 2015). Thus, it is necessary to evaluate the activity developed and the environmental impacts generated by them, to define the environmental recovery project.

In environmental recovery processes, planning and managing materials and actions are very important to achieve the proposed objectives with the expected quality, on time and with predefined budgets, and the mapping of priority areas for environmental recovery is a first step in this route.

According to Brazilian Forest Code (Law no. 4771/65), fragile areas - such as marginal areas of natural, perennial and intermittent water resources, areas with a slope above than 45% and hill top areas - have priorities for environmental preservation to conservation of natural resources, biodiversity and maintenance of human populations welfare.

Several methodologies are available in literature to mapping of these different levels of environmental fragility and the protocol based on soil loss natural vulnerability, proposed by Crepani et al. (2001), has been well accepted. Papers as the developed by Rockett et al. (2014) and Rovani e Vieira (2016) validate the potential of methodology.

In the methodology proposed by Crepani et al. (2001), the natural vulnerability to soil loss can be mapped through multicriteria analysis of 5 physical environment components: geomorphology, geology, pedology, use and occupation of soil and climate.

The 5 information layers (IL) are analyzed individually and the subareas receive vulnerability indexes in ranging from 1.0 - areas classified as stable to erosion process - up to 3.0 - regions considered vulnerable to soil erosion. Afterwards, arithmetic mean is performed on the 5 IL using geographic information system (GIS) and the result is a new matrix that show the spatial variability of natural vulnerability to soil loss. Stable regions to erosion process are represented by lowest values (close to 1.0) and erosion susceptible areas by highest values (next to 3.0). Thus, the priority areas for environmental recovery are those estimated as unstable on map of natural vulnerability to soil loss.

In this context, the present paper aimed to map the priority areas for environmental recovery in Rio Pomba city, administrative area of Minas Gerais, as part of planning of environmental activities and as a basis for execution of environmental actions.

## Materials and methods

The selection of priority areas for environmental recovery was conducted for Rio Pomba city, municipality has area of 253.42 km² and located in the UTM zone 23K, under coordinates 688940 E, 7646327 N and altitude of 441 meters, in the Minas Gerais administrative state (IBGE, 2016).

The present study was divided into three stages for the accomplishment the approaches proposed in work area, being:

a) Mapping of geomorphological, climatic, geological, pedological and land use data of Rio Pomba city;
b) Multicriteria analysis of information layers selected and identification of priority areas for environmental recovery of Rio Pomba city;
c) Analysis and interpretation of results.

*Mapping of geomorphological, climatic, geological, pedological and land use data of Rio Pomba city*

*Information layers of geomorphology and climate*

TOPODATA database, available in Remote Sensing Department of Brazil Institute of Space Research (INPE), was used for geomorphological study of work area. The selection of TOPODATA data is justified because this information is corrected by INPE before to its sharing with the user and by it is suitable for rugged relief regions (Landau e Guimarães, 2011), such as Rio Pomba.

Otherwise, the analysis of annual mean precipitation and the rain season time - called of climatic unit - was performed by time series obtained at the Brazil Institute of Meteorology (INMET) via BDMEP Historical Data section.

*IL geology and pedology*

The geological information of city was acquired on the Geology Map of Minas Gerais state, developed by Brazilian Geology Program (Pinto e Silva, 2014), while the observations of local soil type were obtained via Digital Map of

Soils, developed by Embrapa Solos (Santos et al., 2013).

*IL use and occupation of soil*

Mapping of soil cover was carried out by digital image of Landsat 8 satellite, OLI sensor, dated July 25, 2016. The scene selected presents cloud coverage of less than 10% and the free access the images motivated the choice of Landsat 8 satellite for this paper. In addition, Rodrigues (2016) and Chiarello et al. (2017) presented good land use mapping with this database.

Digital image fusion was applied to scene selected for better targets visualization and, in sequence, estimated the normalized difference vegetation index (NDVI), as described mathematically in Eq. 1.

$$NDVI = \frac{NIR - R}{NIR + R} \quad (1)$$

In which:

NIR - reflectance in near infrared band of Landsat 8 images;

R - red band reflectance of Landsat 8 images and;

NDVI - normalized difference vegetation index, with values between -1 and 1.

NDVI image resulting was classified, using supervised method, into seven classes (pasture in production, degraded pasture, agriculture, water resources, urban area, exposed soil and forest species) for mapping of use and occupation of soil.

*Multicriteria analysis of information layers selected and identification of priority areas for environmental recovery in Rio Pomba city*

The five information layers described in previous section were individually transformed into matrices of vulnerability scales, according to methodology proposed by Crepani et al. (2001), with numerical values between 1.0 and 3.0. In each IL, the erosion stable regions were assigned values close to unity, while areas susceptible to erosion had higher values (close to 3.0).

On five matrices of vulnerability scales was applied multicriteria analysis, as described in Eq. 2 (Crepani et al., 2001), and the result was a new matrix, with the spatial distribution of soil loss natural vulnerability.

$$V = \frac{G+R+S+Ve+C}{5} \quad (2)$$

In which:

V - map of natural vulnerability to soil loss;

G - geology information layer;

R - geomorphological parameter;

S - pedological layer;

Ve - land use layer;

C - climate unit observations.

In final matrix, map of natural vulnerability to soil loss, the areas with the greatest potential to erosion processes were classified as priority for environmental recovery and regions with the lowest susceptibility to erosion were subsequent in environmental recovery order.

It should be noted that all the processing was done using the free GIS QGIS 2.18 (QGIS, 2011) and its internal libraries GRASS GIS 7, SAGA and Semi Automatic Classification plugin.

*Analysis and interpretation of results*

It was carry out qualitative and quantitative analysis for the comparison of the results and support in results interpretations. In numerical evaluations, the contribution of each of the five initial IL (geomorphology, climate, geology, pedology and land use) in final map of soil loss natural vulnerability was measured through a covariance matrix. In addition, the areas of each class in IL were quantified to support the discussions.

Regarding the qualitative analyzes, it used the researchers experience to carry out the analyzes and interpretations.

## Results and discussions

*Mapping of geomorphology, climate, geology, pedology and land use of Rio Pomba*

The climatic unit for study area was of 230.66 $mm.m^{-1}$, which confers a vulnerability coefficient of 1.80 for information layer, according to Crepani et al. (2001). The absence of meteorological points distributed in geographic space makes it difficult to study the spatial variability of climatic unit and therefore the vulnerability coefficient was considered representative of all city, as realized by Andrade et al. (2005).

Similar to climatic data, the geology of city was also homogeneous and the vulnerability scale was extended to all geographic space. All study area is on gneiss rocks of magmatic and/or sedimentary origin (Pinto e Silva, 2014), which gives to the IL a vulnerability index to denudation of rocks equal to 1.30 (Crepani et al., 2001).

The information of climate and geology of city was not presented in this document due the homogeneity of these parameters, only the IL geomorphology, pedology and land use were illustrated in Figure 1, 2 and 3 with the main overlapping water resources.

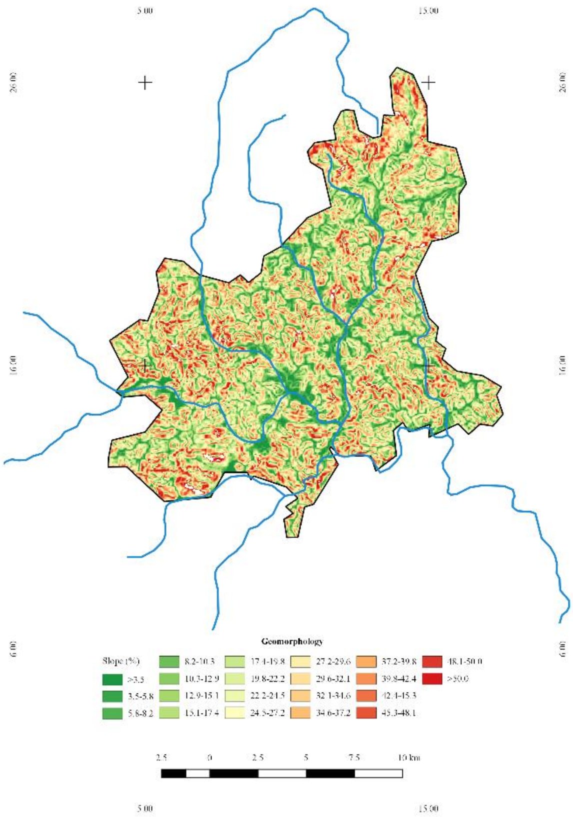


Figure 1: Spatial distribution of geomorphology in Rio Pomba city.

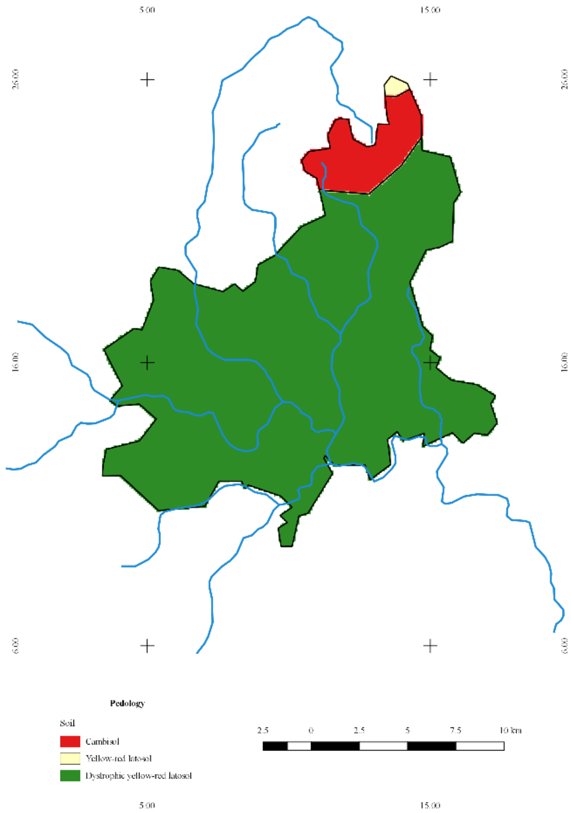


Figure 2. Spatial distribution of pedology in Rio Pomba city.

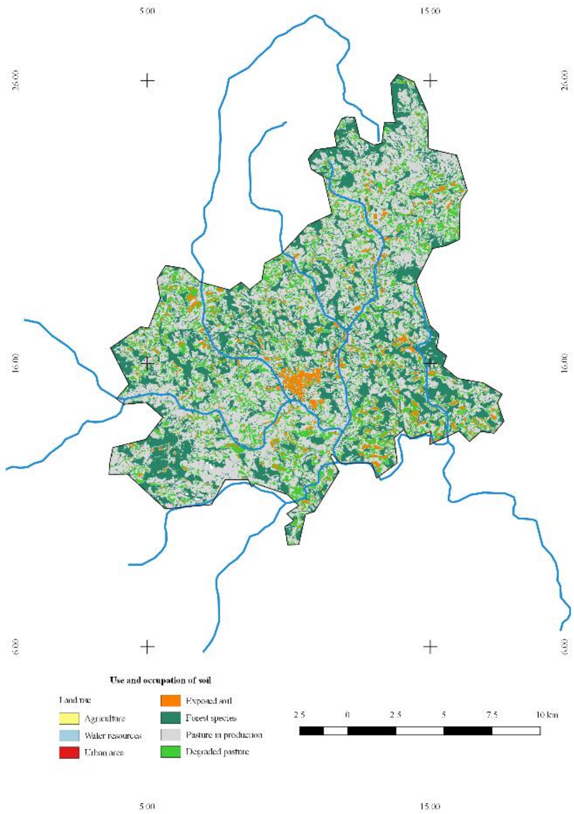


Figure 3. Spatial distribution of use and occupation of soil in Rio Pomba city.

The geomorphology of city is heterogeneous, as illustrated in Figure 1, with slope classes from flat to mountainous, according to patterns proposed by EMBRAPA (1979). These data configure 21 vulnerability indexes to the geomorphology information layer, with values between 1.0 and 3.0.

High slopes allows a fast transformation of potential energy of water in kinetic energy, and it favors the sediments transport and, consequently, the erosive processes (Schneider et al., 2014). Thus, regions around the Rio Pomba city, in special the south, west and north regions presented in Figure 1, contribute the erosion processes.

Regarding the pedology of city, there were observed dystrophic yellow-red latosol (92.3%), cambisol (7.3%) and yellow-red latosol (0.4%) - represented, in order, by green, red and yellow colors in Figure 2 - in the study area. These soil classes receive soil stability indexes equal to 1.0 for latosols and 2.5 for cambisol, according to methodology of Crepani et al. (2001).

Latosols are mineral soils characterized by good drainage and depth, while in cambisols the impermeable layer is closer to surface (Andrade et al., 2005). In this context, in 92.7% of city area the pedology does not benefit the sediments transport since its good drainage, however the cambisols area beside the drainage limitations and it is located on north region of study area (high slope region), and both parameters potentiate the soil erosion.

Finally, the Figure 3 presents the occupation of soil, with great spatial variability of 7 classes estimated and assigning different vulnerability indexes to IL. The exposed soil, agriculture and urban areas classes were estimated as an only class and there are all represented in orange color, while forest species are symbolized in dark green color. In gray and light green are production pasture and degraded pasture classes, in order.

The image used in land use study was acquired in July, period it is common in Rio Pomba region the end of maize harvest used in animals feeding and the agricultural areas are exposed, with spectral behavior similar to exposed soil. In addition, in urban areas it is common ceramic roof, which presents incident wave reflectance close that observed in the exposed soils, which makes it difficult to separate the targets and help explain the classification of 3 variables as a single component (Pinho et al., 2009).

Moreover, in mapping of priority areas to environmental recovery, the difficulty here found in supervised classification of the exposed soil, agriculture and urban area is not detrimental because all three classes present the same vulnerability index (3.0).

More about the land use, pastures (in production and degraded) are predominant in landscape, representing 66% of city total area. This value is similar to that observed in watershed in which the Rio Pomba is inserted, in which Silva (2014) observed 63.9% of watershed area occupied with pasture.

The pastures presence is common in region because of economic importance of dairy cattle and the Figure 3 shows pastures areas around of most of main water resources in study area, results which are close to those described by Jacovine et al. (2008), that reported an occupation of permanent preservation areas (PPA) in Pomba river watershed.

This replacement of natural areas by other land uses must be planned and controlled so that the environmental impacts caused do not limit the available natural resources in future, keeping a sustainable activity. In addition, pasture areas around the water resources, if located in high slope regions tend to increase erosion soil vulnerability and the environmental impacts, compromising the economic viability of activity over time.

Forest species cover 28.4% of city area, value higher than observed for Pomba river watershed, in which Silva (2014) estimated, 16.9% of forest cover.

This result is encouraging because it shows that Rio Pomba city has a greater preservation of forest species than the watershed in which it is located and also above the reference value defined by United Nations for development of an agriculture sustaining ('Wolski, apud Quinteiro, 1997 cited by Nascimento et al., 2006). However, these forest species are distributed in small fragments along the perimeter studied and are not always located in priority areas, such as river banks, in hill top or high slope areas.

*Mapping of priority areas for environmental recovery in Rio Pomba city*

The Figure 4 shows the spatial variability of natural vulnerability to soil loss in Rio Pomba city, resulted from multicriteria analysis with the 5 IL previously described.

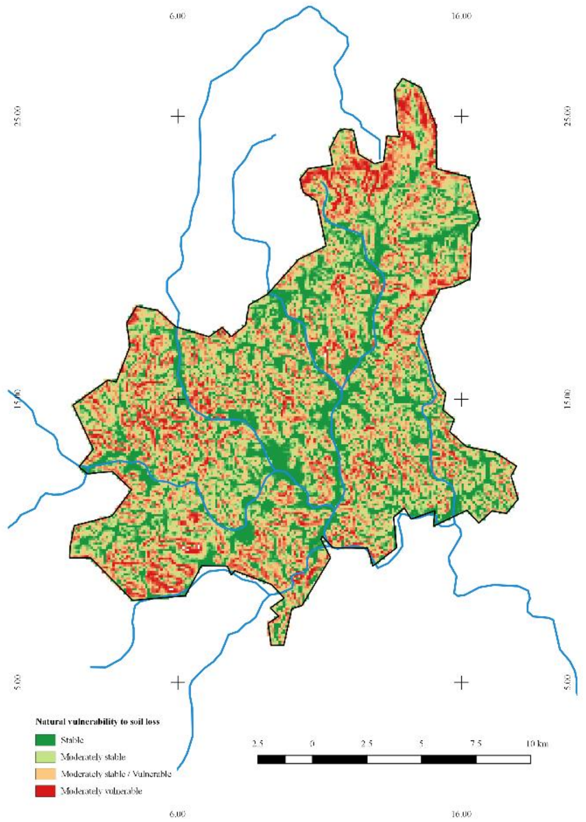


Figure 4: Spatial distribution of natural vulnerability to soil loss in Rio Pomba city

The areas illustrated in red color represent unstable regions to the soil erosion processes and were classified as preferential in environmental recovery process. The opposite extreme, there are stable regions to the soil natural loss, represented in green color, which are called of non-priority to environmental recovery activity.

The mapping reveals that priority areas for environmental recovery in Rio Pomba are located in high slope regions, which highlights the importance of geomorphology variable in soil loss processes. Valladares et al. (2012) and Machado et al. (2017) consider the topography as one of main responsible for erosive processes and the similarity between the two maps - Figures 3 and 4 - shows this.

In order to support the visual observations made, numerical analysis, through a covariance matrix, was conducted to know the contribution of other information layers in final result. The values found - which can also be understood as the correlation index between the final map and the IL - were null for climate and geology information layers, 0.023 for use and occupation of soil, 0.170 for pedology and 0.956 for geomorphology, reaffirming the similarity between the Figures 3 and 4.

The multicriteria analysis consists of an arithmetic mean (Eq. 2) and since the vulnerability scales associated the IL geology and climatic unity were constant in all geographic space studied, a null contribution to spatial variability of data was expected.

The land use IL presented a small correlation with the final mapping ($R^2$ 0.023) and the spatial occupation of soil observed in the city helps to explain what occurred. The areas occupied with forest species are fragmented and there are considerable areas occupied with pastures (Figure 3), which reduces the soil natural protection and favors the morphogenic processes, turning into erosion, as emphasized by Andrade et al. (2005) and Ribeiro et al. (2016).

And the participation of IL pedology in mapping of soil loss vulnerability was greater in northern region of city, where there is cambisol (Figure 2) present in a high slope area (Figure 1). The combination of these two variables tends to amplify the soil erosive potential and made this region susceptible to erosion, as observed in Figure 4.

These results still reveal that the multicriteria analysis in this work scale can be simplified, using only the information layers that contributed with the evaluations, in this case the IL geomorphology, pedology and land use. The use of simplified model in analysis of environmental fragility depends of determining characteristics of each region and papers that do not apply all the geographic variables are recurrent (Oliveira, et al., 2009; Mesquita et al., 2010; Francisco et al., 2013).

In this context, a new mapping of soil loss natural vulnerability was carried out using only IL geomorphology, pedology and use and occupation of soil. The correlation index between this new map and that presented in Figure 4 (with 5 IL) was 0.999, showing that the maps are equivalent and confirming the possibility of using simplified models.

The areas classified as stable to erosion processes (Figure 4) are notable for their concentration in regions of small slope and around of main water resources of Rio Pomba city, showing ideal conditions of environmental conservation. The curiosity here is due to fact that in these rivers marginal regions there is a predominance of degraded and production pastures (Figure 3), similar to that observed by Jacovine et al. (2008) for the Pomba river watershed, and this type of soil use contributes to soil erosion processes, contrary to the observed mapping.

Table 1 presents data that complement the discussion, with the percentage of 4 classes of soil loss natural vulnerability and of 7 classes of land use observed in marginal PPA to the most relevant rivers of Rio Pomba city (considered a range of 50 meters from each side of water resources).

Table 1. Percentage of natural vulnerability classes to soil loss and land use classes in PPA near of main water resources of Rio Pomba city.

| Soil loss vulnerability | | Land use | |
|---|---|---|---|
| 1. Stable areas | 42.26 % | 1. Degraded pasture | 20.73% |
| 2. Reasonably stable areas | 24.00 % | 2. Pasture in production | 62.93% |
| 3. Moderately stable areas | 20.61 % | 3. Forest species | 16.31% |
| 4. Moderately vulnerable areas | 13.13 % | 4. Agriculture, urban areas, exposed soil and water resources | 0.03% |

The values presented in Table 1 reaffirm the visual analyzes discussed and presented in Figures 3 and 4, in which 42.66% of all marginal PPA of main water resources were classified as stable and non-primordial regions to environmental recovery process, but 83.66% of these same areas are currently occupied with degraded and production pastures, with conflicting information.

The water resources of Rio Pomba city are located in areas of small slope (Figures 1, 2 and 3), which explains the fact that part of marginal PPA are classified as stable to soil loss and reaffirms the great contribution of geomorphology in erosive processes.

The observations here presented allow a reflection on simple and direct application of methodology proposed by Crepani et al. (2001) for mapping of priority areas to environmental recovery, especially in permanent preservation areas. The PPA in which they are necessary an environmental recovery was classified as stable regions and, therefore, non-preferential to reforestation activities.

An alternative to these limitations observed in identification of priority areas for environmental recovery is the use of different weights for IL in multicriteria analysis, as highlighted by Andrade et al. (2005), or also the modification of methodology proposed by Crepani et al. (2001), with the insertion of a new IL in data analysis, the information layer PPA (hill top, marginal areas to water resources and regions with declivity above 45%) associated to vulnerability scales equal to 3.0, for example.

Thus, the areas protected by legislation (Law no. 4771 / 65) of Rio Pomba city were mapped, there were atributed vulnerability scales equal to 3.0 for these regions and a new simplified multicriteria analysis was performed to map the priority areas to environmental recovery. The delimitation of marginal PPA to the water resources considered 50 meters in each side of the main rivers of city, the hill top areas were estimated according to the guidelines of Silva et al. (2016) and, finally, those areas with a slope greater than 45% in IL geomorphology were reclassified with vulnerability indexes 3.0. Figure 5 illustrates the modified methodology for mapping the priority areas to environmental recovery.

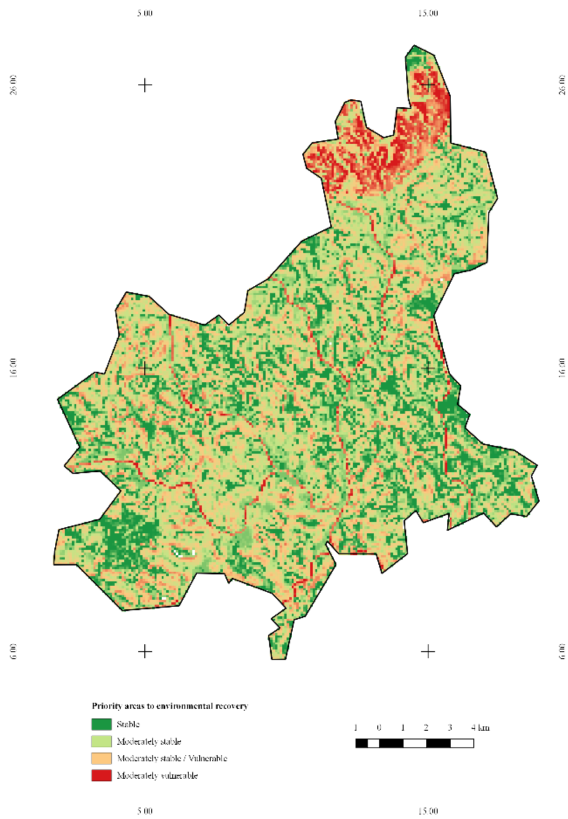


Figure 5. Mapping of priority areas to environmental recovery of Rio Pomba city after insertion of PPA information layer in multicriteria analysis.

In mapping of areas protected by law, it was not identified PPA from hill top in Rio Pomba city.

In Figure 5, the priority regions to environmental recovery actions of modified multicriteria analysis are shown in red, whereas the areas not preferred to environmental recovery processes are represented in green color.

The adapted methodology, with the insertion of information layer PPA in simplified multicriteria analysis, presented results closer to those observed in field. Figure 5 shows that areas where the main water resources of city are now identified as preferential to environmental recovery, as expected, and it was not seen in Figure 4. In addition, the northern region of city was highlighted as priority to environmental actions, a region in which the high slope associated with the presence of cambisol increases the soil loss natural vulnerability and therefore deserves attention.

According to the criteria adopted in this study, an environmental recovery plan for Rio Pomba city would start with the areas protected by legislation and by the northern region of city most susceptible to erosion (Figure 5). This management strategy will contribute to reduction of erosion processes, with the conservation of flora and fauna biodiversity in landscape context, ensure an increase in forest remnants area, greater connectivity between themselves and consequently a greater gene flow and stability of different species. Here, it is important to emphasize the recovering these ecosystems using native flora species, especially fruit species for attractiveness of fauna, and to use respecting the particularities of each area recovered.

The contribution of each IL in modified methodology was also interesting. The new values observed in covariance matrix were 0.64, 0.40, 0.37 and 0.36 for land use, PPA, geomorphology and pedology IL, in order. These results show a greater contribution of IL to final result presented (Figure 5), which is consistent since the soil natural loss is a function of several factors, not just one, as observed in the simple and direct use of proposed methodology by Crepani et al. (2001) in identification of priority areas.

The application of modified methodology for identification of priority areas for environmental recovery in other experimental areas is necessary for validation of protocol proposed here and remains as a suggestion for future work.

## Conclusions

1. The insertion of PPA information layer in multicriteria analysis presented improvements in relation to simple and direct use of methodology proposed by Crepani et al. (2001) in identification of priority areas for environmental recovery, with results close to those observed in the field.
2. The application of modified methodology, proposed in the present paper, in new experimental areas is necessary to ratify the protocol of identification of priority areas for environmental recovery.
3. The environmental recovery plan for Rio Pomba city can be based on the mapping presented here, in which the marginal areas to main water resources and the northern region of city will receive priorities in actions to reestablish the environmental balance.

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