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Permanent Preservation Area (PPA) on Top of Hills Mapping Based on Legal Devices of Rio de Janeiro State

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ABSTRACT

The Brazilian Forest Code implemented in 2012 kept the definition of preservation areas established in the former Forest Code (1965) but changed the delimitation parameters especially for Permanent Preservation Area (PPA) on the top of hills. In Rio de Janeiro, The State Environmental Institute (Inea) established a Resolution in 2014 to guide PPA delimitation in the state. This resolution follows most of the policies implemented by the Brazilian Forest Code of 2012 but defined new parameters for determining the hills bases. This study's goal consists on mapping the PPA on top of hill according to both legal devices and assessing the extension and connectivity of the preservation areas on São João river basin, RJ. Following the Forest Code of 2012, 60 fragments of PPA were delimited, with 553 ha of total area and distributed without any connectivity on higher altitudes. Meanwhile, following Resolution of 2014, 324 fragments of PPA were mapped, totalizing 8,420 ha, situated along the watershed and middles altitudes and enhancing connectivity. We conclude that the alteration of the delimitation parameters has an influence on the extension and connectivity of the PPA on top of hills. Our results suggest the need of deeper evaluations in order to guarantee that methodologies for PPA delimitation on top of hills embodied in legal instruments meet the environment functions clearly established for PPA in the 2012 Brazilian Forest Code.

Keywords: Forest Code, Protected areas, Forest fragmentation, Geoprocessing

Mapeamento das Áreas de Preservação Permanente (APP) no Topo de Morros de acordo com os Dispositivos Legais do Estado do Rio de Janeiro

RESUMO

O Código Florestal brasileiro implementado em 2012 manteve as áreas de preservação estabelecidas pelo Código Florestal de 1965, no entanto os critérios de delimitação foram alterados, principalmente, da Área de Preservação Permanente (APP) no topo de morros. O Instituto de Ambiente do Estado do Rio de Janeiro (Inea) estabeleceu uma resolução em 2014 para normatizar a delimitação de APP no topo dos morros. A Resolução de 2014 segue as principais diretrizes pelo Código Florestal de 2012 no entanto define novos critérios para determinar a base do morro. O objetivo do presente trabalho consiste em mapear as APP no topo de morros de acordo com ambos dispositivos legais, avaliando a extensão e a conectividade das áreas de preservação na bacia hidrográfica do rio São João, RJ. Conforme o Código Florestal de 2012, foram delimitados 60 fragmentos de APP, com o total de 553 ha, distribuídos sem qualquer conectividade nas maiores altitudes. Enquanto isso, de acordo com a Resolução de 2014, foram mapeados 324 fragmentos, totalizando 8.420 ha, localizados ao longo dos divisores d'água melhorando a conectividade entre eles. Conclui-se que a alteração nos parâmetros de delimitação influencia na extensão e conectividade da APP no topo de morros. Os resultados sugerem a necessidade de aprofundar as avaliações para garantir que as metodologias de delimitação das APP no topo de morros municiadas por instrumentos legais atinjam efetivamente as funções ambientais estabelecidas para APP no Código Florestal de 2012.

Palavras-Chave: Código Florestal, Áreas protegidas, Fragmentação florestal, Geoprocessamento.

Introduction

In Brazil, the natural resources policy of preservation exists since the Empire period, 19th century, with actions of reforestation and forest conservation in the purpose to protect the natural springs that supply water to the Rio de Janeiro city (Abreu, 1994).

In 1934, the Federal Decree 23,793 of the Forest Code, defined the guidelines for the protection and exploration of forests and other kinds of natural vegetation. The Protector Forests, precursor of the Permanent Preservation Area established by the Code, had the function to preserve and conserve forest areas with the main goal to conserve the water flow, avoid the soil erosion by natural agent, fix dunes and help boundaries defense in a necessary way to the military authorities assure the public wholesomeness conditions (Brasil, 1934).

In 1965, the Law 4,771 established the new Forest Code. Highlighting the preservation and use of the forest resources, that code declares the forests area in the national territory and many kinds of vegetation for the interest of all Brazilian inhabitants. It also introduced the term: Permanent Preservation and established the delimitation parameters for forests and any other vegetation's preservation. However, the code considers as Permanent Preservation only the forests and other natural vegetation, creating an ambiguity in the juridical interpretation, because places originally defined as Permanent Preservation areas, but not overlaid by vegetation, were out of the law protection (Borges, 2011).

In the beginning of the 21th century, there were promoted many huge alterations in the Forest Code of 1965, specially the introduction of the term PPA (Permanent Preservation Area). With this alteration, all the areas with or without vegetation cover would be considerate as Permanent Preservation. In 2012, the Forest Code from 1965 was repealed and the new Code was instituted in the Federal Law 12,651.

The modifications in the delimitation of PPA introduced by the Forest Code of 2012 induced the reduction of preserved areas by the modification of the devices from the 1965 Code that regarded the parameters, definitions and boundaries of the PPA on top of hills. Those changes promoted great area reduction and almost eliminates this kind of permanent preservation (Soares-Filho et al., 2014; Silva et al., 2015;

Tambosi et al, 2015; Oliveira & Filho, 2016; Silva et al., 2017).

Soares-Filho et al. (2014) applied the new parameters for PPA delimitation on top of hill. The results indicated 87% reduction in the category for the national territory. Trevisan et al. (2016), in a study case at Santa Catarina state, concluded that the new parameters reduced 82% of the on top of hills PPA areas in the state. Silva et al. (2015) and Silva et al. (2017) emphasizes the 100% reduction in the river basins of *ribeirão Ubá e córrego dos Bois*, both in Minas Gerais state.

The Forest Code of 2012 considers PPA on the hills only for features with minimum 100 meters high and mean slope greater than 25 degrees. In these cases, PPA are defined to occupy 2/3 of minimum height in relation to the base. The lowlands or the water bodies are considered as the base to determine the horizontal plain and, in case of wavy relief, the saddle point nearest from the elevation is used instead. The former Forest Code, implemented in 1965 and in force until 2012, considered as parameter the minimum height of 50 meters and slope of 17 degrees, in addition, the base in wavy relief was the lower depression in the landscape. The line of hilltops with two or more hilltops with 500 meters of maximum distance was considered as PPA.

The parameters' alterations implemented in the Forest Code of 2012 provoked a drastic PPA on top of hills reduction. As a result, the Rio de Janeiro State Environmental Institute (Inea) established the Resolution of 2014. It specifies the parameters for the delimitation of PPA on top of hills in Rio de Janeiro state. The main alteration is the base of the hills definition, that starts by the level where the water erosion does not act (e.g. sea, lake or rivers) and not the saddle point. However, the other parameters Resolution of 2014 are defined as indicated by the Forest Code of 2012.

As an approach to evaluate the effects of legal agencies policies to delimitate PPA on top of hills, this study has the main aim to map the PPA on top of hills the São João river basin, located in the coastal lowland of the Rio de Janeiro state, Brazil. This mapping study was carried out considering parameters from the Forest Code of 2012 and the Resolution of 2014. Therefore, from a comparison between the resulting maps, it is analyzed the extension and connectivity of PPA in the river basin with multiple relief units.

Material and methods

Study Area

The study area corresponds to the São João river basin. It encompasses 57,700 ha drainage basin and it is based upstream from the Juturnaíba reservoir, Silva Jardim city, RJ. The area is located in the Atlantic Forest, which is a wide forest complex with high level of endemism and biodiversity. This forest represents 8% of the Brazil's original land cover with spread spots leftover through the coastal area (Bovo et al., 2018;

Magnago et al., 2015). The study area is characterized by the following diverse landscapes units according to Dantas (2001): (1) mountainous landscape and escarpment uplands, (2) alkaline intrusion uplands, (3) degraded escarpment uplands and steps in edge of plateau, (4) alignment uplands and structural steps, (5) isolated hills, (6) dissected hills landscape, low hills and high hills, (7) fluvial-marine plains, and (8) fluvial-lake plains (Figure 1).

Figure 1. landscapes of the São João river basin.

The methodology purposed by Oliveira & Filho (2016) was used to map PPA on top of hills (according to the Forest Code of 2012 and Resolution of 2014).

The Digital Elevation Model (DEM) was created using the algorithm purposed by Hutchinson (1989). The resulting DEM, with 10 meters of spatial resolution, was generated from vector archives of hydrography and contour lines (equidistance: 10 meters) from the Brazilian Institute of Geography and Statistics (IBGE) with 1:25,000 scale, meeting Inea Resolution of 2014.

The Forest Code of 2012 does not set up a methodology to estimate the terrain's slope (Oliveira & Filho, 2016). Considering there are many automatic methods to estimate the relief slope by GIS techniques, for this study, it was used the slope estimation algorithm purposed by Valeriano (2002) which considers all directions around a cell of the DEM. Valeriano's method is

based on Moretti et al. (1989) who indicates the vector method for the mean slope estimation, considering the difference of altimetry on the perpendicular axes of 3x3 grid, that is, the directions east-west and north-south, according to equation 1:

$$S = 100 (D_x^2 + D_y^2)^{\frac{1}{2}} \text{ (Equation 1)}$$

where: $D_x = (d_1 + d_2) / (2r)$

$$D_y = (d_3 + d_4) / (2r)$$

Where: d1 and d2 are the difference of altimetry in east - west direction, d3 and d4 are the difference of altimetry in north and south direction, and r is the difference of altimetry (DEM spatial resolution).

However, the slope calculation purposed by Valeriano (2002) also considers the difference

of altimetry on the perpendicular axes of the 3x3 grid, that is, the northeast - southwest and southeast -northwest direction. In this method the maximum slope value is chosen among the maximum values of the four respective orthogonal and diagonal axes. Thus, the slope calculation is based on diagonal and orthogonal direction in a 3x3 grid, adopting the same weight for the maximum slope value estimation.

PPA on top of hills delimitation

The First step for the automatic delimitation of PPA on top of hills is to distinguish every hill through the identification of top and base levels. According to the Forest Code of 2012, in wavy relief the base corresponds to the saddle point, also named as *col* by Guerra (2011), which corresponds to the lowest quota between two hills or the point between two closed contour lines with the same quota (Rocha, 2008). However, the Forest Code of 2012 defines that the base must be considered by the quota from the nearest saddle point to the elevation. After the identification of hills is already completed, it must be verify if all the parameters defined by the laws are being attend. That is, hills must have 100 meters high or more and mean slope more than 25 degrees. Finally, PPA on top of hills are delimited considering the 2/3 high in each hill. Then, according to Oliveira & Filho (2016), the following steps are necessary for the PPA on top of hills delimitation based on Forest Code of 2012:

- a) **DEM correction** – Initially, DEM is preprocessed for the anomaly and distortion elimination and the spurious depressions removal.
- b) **Hill limit identification**– For hill delimitation, of the runoff flow direction is obtained from the invert DEM. In the original DEM, that corresponds to the river basin limits.
- c) **Saddle points identification** – Saddle points are identified as maximum elevation values of the watershed, obtained from the original DEM.
- d) **The top points identification**–Top points are determined by the maximum elevation value defined by the river basin limits, obtained from the original DEM.

- e) **Height of the hills estimation** – First, each top must be associated to its respective saddle point, which requires to identify the nearest saddle point. The height calculation is based on the top elevation minus the saddle point elevation. In case of the result is more or equal than 100 meters, the elevation is considered as hill.
- f) **Hill slope calculation** – Each mean hill's slope is calculated by overlapping the hill's polygons to the slope map.
- g) **Permanent Preservation Areas delimitation** – PPA are delimited in the hills that present both conditions: hills higher than 100 meters and with mean slope over 25 degrees. If so, the PPA extends from the hill's top until 2/3 part of the hill's height.

In agreement with Resolution of 2014, PPA on top of hills are delimited following the same automatic processes uses formerly, under Forest Code of 2012 assumptions. However, in this case, hill's base in wavy relief is delimited using the plain relief or water bodies (e.g. sea, lake, river confluence, whether they were perennial, intermittent or ephemeral water bodies). Due to the landscape of the study area, the river confluence was considered as a parameter for the hill base delimitation. According to Guerra (2011), the river confluence corresponds to the place where two or more rivers meet each other, and according to Andreu (2015), it refers to the join of two or more watercourses.

Results

The automatic mapping procedure for delimiting PPA on top of hills, following the policies established by the Forest Code of 2012 result in 60 PPA's patches, encompassing 553 ha (Figure 2). This size corresponds to 1% of the basin's drainage area. PPA are predominantly located in the highest altitudes, that is, the watershed located in the mountains of the river basin. Besides that, the dissected hills and low hills up to 100 meter, which encompass an area about 14% of the basin area excluding low lands are not considered by the Forest Code of 2012. On the other hand, most of these features were included as

PPA in the Forest Code of 1965, where elevation over 50 meters was used as threshold.

Figure 2. PPA on top of hills according to the parameters of the Forestry Code of 2012 of the São João river basin.

The automatic extraction of PPA on top of hills, following Resolution of 2014, pointed the occurrence of 324 fragments, with 8,420ha of total area, which correspond to 15% of the basin's area.

Results show connected fragments through the watershed of São João river and its sub-basins (Figure 3).

Figure 2. PPA on top of hills according to the parameters to the 93/2014 Inea Resolution of the São João river basin.

Discussion

When the automatic mapping is analyzed it is possible to observe an increasing of the top of

hills PPA area between the map studies made according to the parameters of Forest Code of 2012 and Resolution of 2014. This difference of about 1,500% shows that the substitution of the reference

parameter for the hilltop definition (corresponding to the saddle point from the Forest Code of 2012 and the confluence river point of the Resolution of 2014) changes meaningfully the size of areas occupied for the PPA on top of hills.

These results are in agreement with other published studies for different places in Brazil under specific geomorphological domains, which point out a considerably reduction in area of PPA on top of hills when the Forest Code of 2012 parameters are applied. Soares-Filho et al. (2014), Silva et al. (2015), Trevisan et al. (2016) and Silva et al. (2017) studies point out the decrease of the spatial distribution of connectivity between PPA's fragments in river basins. Results showed the lack of connectivity between PPA on top of hills and PPA on the marginal band of watercourse.

The hill base identification with the saddle point and confluence river point parameters are directly associated with the cartography base used in the mapping. Regarding the saddle point, Oliveira & Filho (2016) argue that the DEM's spatial resolution can modify the estimation of PPA area. Because of its larger detailing, DEM with higher resolution present elevations of micro relief, which may make it unfeasible for PPA on top of hills mapping. On the other hand, Guimarães & Guimarães (2016) say that the use of DEM with lower resolution can reduce the size of PPA on top of hills because the generalization of relief features, which reduces saddle point quantity. According to Oliveira & Filho (2016), an official government database regulation would allow to avoid the subjectivity in the saddle point mapping.

In order to identify the confluence river point, the drainage network density is essential. The hydrography delimitation obtained through systematic mapping is based on a visual interpretation of a stereoscopic model and depends directly on the photointerpreter experience (Furtado et al., 2015). Then, the map obtained using visual interpretation can generate drainage's networks with different densities. Also DEM with different spatial resolutions and the application of different algorithms for extracting drainage's network can also generate different densities of hydrographic networks (Ariza-Villaverde et al., 2015; Morais & Sales, 2016; Schmidt et al., 2017). On plain areas, this difference can result in discontinuity or inconsistency on the drainage lines

(Freitas et al., 2016; Zhang et al., 2017), which can affect directly the PPA on top of hills delimitation in regions of isolated hills. Morais & Sales (2016) argue that is necessary to compare the drainage network from automatic extraction with the observed data to eliminate nonexistent watercourses.

The methodology used to estimate slope can also modify the PPA delimitation result. Magdalena's (2016) study case evidences differences of 20% in the size of PPA on top of hills between results applying both approaches purposed by Horn (1981) and Valeriano (2002). The method purposed by Horn (1981) estimates mean slope values between east-west and north-south direction, that is, four cells displayed in cross around the analyzed cell, in a DEM with 3x3 grid. The method from Valeriano (2002), used in this study, uses the maximum slope value between eight cells around the analyzed cell, displayed in orthogonal and diagonal direction in a 3x3 grid.

These results confirm that the absence of specific guidelines for the cartographic bases and the approaches used to estimate parameters for the mapping of PPA on top of hills can cause inconsistent results (Ariza-Villaverde et al., 2015; Oliveira & Filho, 2016; Morais & Sales, 2016; Schmidt et al., 2017). For the Rio de Janeiro state, the results indicate a meaningful reduction on the size of PPA when the Forest Code of 2012 parameters is followed, even in diverse types of landscape. These result also highlights a reduction on distribution and connectivity of fragments of PPA on top of hills in the river basins, in agreement with those from Soares-Filho et al. (2014), Silva et al. (2015), Trevisan et al. (2016), and Silva et al. (2017).

Conclusion

The experiments carried out in this work show that alteration on the reference parameters to identify the hill base, namely, the saddle point, in the Forest Code of 2012, and the river confluence point, in the Resolution of 2014 affected directly the quantity, distribution and the connectivity of fragments PPA on top of hills in the of São João river basin. The results obtained applying Forest Code of 2012 parameters results in few fragments without connectivity, distributed on developed highest altitudes in the watershed of the

hydrographic basin. On the other hand, criterion from the Resolution 2014 significantly increases the size of PPA on top of hills in the basin. Besides, fragments are connected through the hilltops located in high and middle altitudes, where the watersheds of the basin and sub-basins are located.

It was also verified that both legal instruments, the Forest Code of 2012 and the Resolution of 2014, applied to map PPA on top of hills, do not consider polices that allow the delimitation of PPA in geomorphological features as low hills once these features are lower than 100 meters high. This suggests the need to review the minimum height threshold in order to incorporate these geomorphological units.

Both cartographic base and mapping methodology are important to delimitate the PPA on top of hills. The Resolution of 2014 is more specific because it specifies the cartographic base that must be used and the method to be adopted. However, some lacks of parameters estimation still persist in this resolution, as the methodology to estimate slopes, for example. Therefore, it is verified the needs for a more explicit definition of the methodology to be applied in automatic PPA mapping with legal devices. The lack of this information can cause some divergence in the results depending on the applied methods.

Finally, the expressive reduction of the size of PPA on top of hills, driven by the Forest Code of 2012 policies, can determine not only the hilltop preservation, but also the fragments connectivity between the watershed and valleys. It threatens the water balance of the basin but also the biodiversity and the genic flux related to the environmental functions of the PPA.

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