Identification of Hydrologically Sensitive Areas present in the Santa Maria-Torto sub-basin.

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ABSTRACT

The Santa Maria-Torto sub-basin, located in Brazil, is of great importance for the region, given that it is responsible for part of the region's water supply. Despite the utmost importance of this area, some problems have already arisen. An assessment of the hydrological situation of this sub-basin is extremely important to preserve the region's natural resources. Therefore, in order to evaluate the preservation and improve the management of water resources, the methodology that uses the concept of Hydrologically Sensitive Areas (HSA) was chosen. This concept is used to identify critical areas for preservation of water supply sources, as well as evaluate and prevent negative impacts on water quality. The basis of the HSA concept is explicitly hydrogeomorphological since it emphasizes the dependence between hydrological processes and local pedological and geomorphological characteristics. In this study, the HSA was considered a good environmental management tool for evaluating areas with potential runoff generation, which might help to reduce environmental liabilities.

INTRODUCTION

The Hydrographic Unit (HU) called Santa Maria-Torto, located in Brasilia, Brazil, is of great importance for the region, given that it covers the Santa Maria reservoir, responsible for 25% of the region's water supply. In addition, this HU includes a large portion of the Brasilia National Park, a conservation unit that contributes to preserving Santa Maria-Torto water supply system, protecting and avoiding erosion and sedimentation. The selected study area can be visualized in Figure 1.

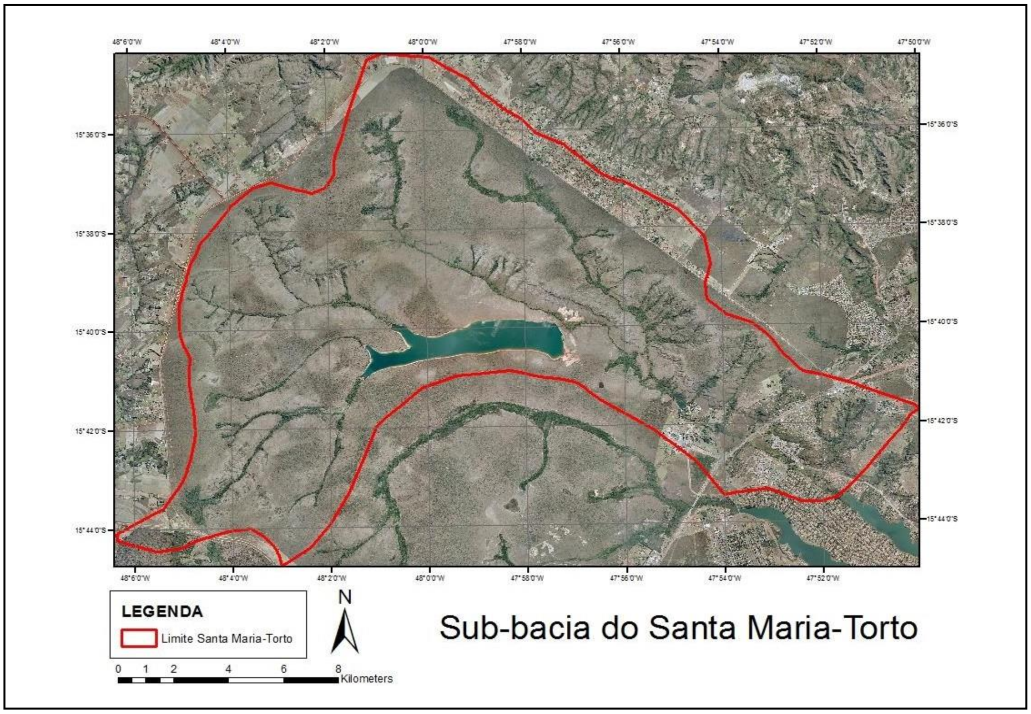

Figure 1. Santa Maria-Torto Sub-basin (study case area).

The Brasilia National Park has a very important conservation role in the Santa Maria-Torto HU, his main objective is to preserve a representative sample of natural formations and ecological processes, as well as the protection of the fauna, flora and genetic resources present in the Brazilian savanna. It is possible to note that a significant number of species which are on the list of species threatened with extinction could be found in this area. The list includes species like Galito (*Alectrurus tricolor*), Tico-tico-do-mato (*Coryphaspizamelanotis*), Gato-maracajá (*Leoparduspardalismitis*), Tamanduá-bandeira (*Myrmecophagatridactyla*), Quail-buraqueira (*Nothuraminor*), Tatu-canastra (*Priodontesmaximus*), Inhambu-carapé (*Taoniscusnanus*) and Gray-winged eagle (*Harpyhaliaetuscoronatus*). The elevated species number shows the considerable levels of biodiversity in the region.

The Brasilia National Park also aims to promote a scientific approach to the knowledge and evolution of existing natural resources; contribute to the monitoring of environmental and anthropic processes, generating parameters for management and mitigation of environmental impacts; the protection of the recharge areas of the water resources at the Torto and Bananal sub-basins and the techniques of degraded areas recovery (IBAMA, 1998).

Despite the utmost importance of the Brasilia National Park above mentioned, some problems have already arisen. One of the big issues in the area is related to the construction of the Santa Maria reservoir, which has 6.1 km² flooded area. Since the implantation of the reservoir, it has been verified problems associated with the movement of land, which is evidenced by the erosions and the deforestation next to the containment dam. Another effect of the reservoir construction is related to the change in the base level of the Santa Maria stream, which has been presented worrying upstream dimensions in the reception basin. This stream base level change could modify the vegetation ecological condition along the dam banks and drown the Vargem Grande stream path.

In this context and take into a count the Brasilia National Park objective, an assessment of the hydrological situation of the Santa Maria-Torto HU is extremely important to preserve the region's natural resources. Therefore, in order to evaluate this preservation and improve the management of water resources, it was chosen a methodology that uses the concept of Hydrologically Sensitive Areas (HSA), which corresponds to areas with a higher propensity to generate surface runoff due to soil saturation. This concept is used to identify critical areas for preservation of water supply sources, as well as evaluate and prevent negative impacts on water quality (Mehta *et al.* 2004; Walter *et al.* 2000; Agnew *et al.* 2006).

The HSA evaluate and prevent the negative impacts on water quality by means of the soil saturation probability (Agnew *et al*., 2006). Therefore, the basis of the HSA concept is explicitly hydrogeomorphological, since it emphasizes the dependence between hydrological processes and local pedological and geomorphological characteristics (Siefert, 2012). The results of the HAS methodology can be applied as an effective environmental management tool, which can enable the evaluation of potential runoff generation areas and help reduce the environmental liabilities caused by rainwater sediment and pollution, as well as the urbanization near the water bodies.

Because of the benefits provided for the HSA methodology, this article has as its principal objective the identification of HSA located in the Santa Maria-Torto sub-basin. As mentioned above, the Santa Maria-Torto sub-basin has a great importance for Brasilia, since nowadays it is one of the responsibilities for the water supply. The implementation of the HAS methodology in this sub-basin is strategic for the land use plan and its relation to the quality of the Santa Maria Reservoir. Finally, the proposed methodology for the Santa Maria-Torto sub-basin is based on the identification of the HSA from a topographic index. In order to perform this methodology, the ArcGIS tool was used. Initially, the land use was classified. Then, the topographic index, composed of the moisture and the storage indexes, was calculated. Finally, using some thresholds, the HSA were identified. In this study, the HSA was considered a good environmental management tool for evaluating areas with potential runoff generation, which might help to reduce environmental liabilities.

METHODOLOGY

The methodology done in this paper was based on the methodology developed by Bueno (2016) in his master's thesis. The Geographic Information System (GIS) software used for the identification of HSA was ArcGIS. The methodology is divided into three stages: classification of land use; calculation of the topographic index; and identification of hydrologically sensitive areas. Figure 2 shows the flow chart of the methodology.

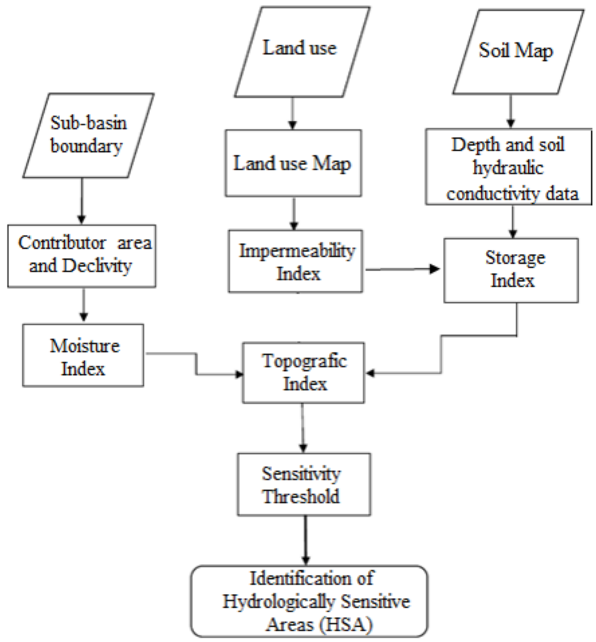

Figure 2. Flow chart of the methodology.

LAND USE CLASSIFICATION AND THE IMPERMEABILITY INDEX.

The first step of the methodology was made a land use classification, using the LANDSAT 8 image. In the classification file, the projection selected was SIRGAS 2000 - Zone 23S (Universal Transverse Mercator Projection System - UTM). This projection was chosen due to the official Brazilian technical standards related to the geodetic system. The class colors were selected based on the Geography and Statistics Brazilian Institute - IBGE (2013). Figure 3 shows the land use classification.

The next step was obtaining the impermeability index. Consequently, the soil impermeability index was determined for each class from the definition of impermeability coefficients, these values were based on the flow coefficients used in the rational method. The impermeability coefficient follows only a qualitative logic, where each type of land use receives a value that demonstrates the difficulty of the soil not allowing the water infiltration and, subsequently, generates a runoff. These values with the respective classes are shown in Table 1. The impermeability index is fundamental for the HSA definition since it is used to calculate the water storage capacity in the soil, which is successively used to calculate the topographic index.

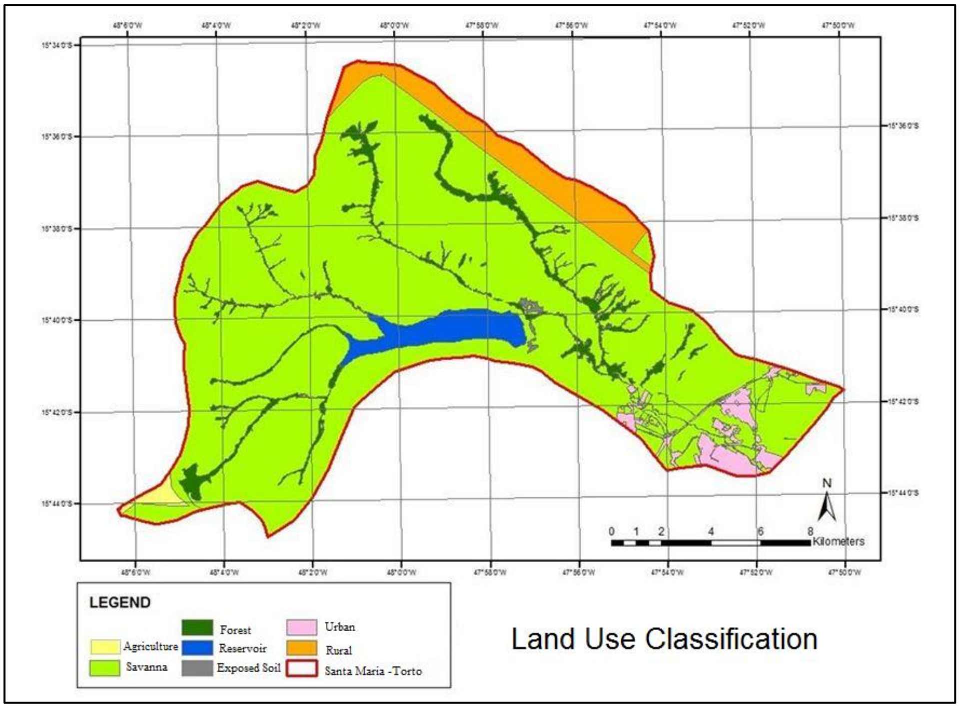

Figure 3. Land use classification.

Table 1. Impermeability coefficient values (Bueno modified, 2016).

Land use class	Impermeability index
Urban	0.85
Agriculture	0.5
Forest	0.1
Exposed soil	0.5

CALCULATION OF THE TOPOGRAPHIC INDEX

The topographic index is composed for two terms: the moisture index, the first term, and the storage index, the second term of the Equation 1.

$$IT = \ln\frac{\alpha}{\tan(\beta)K_s D} = \ln\left(\frac{\alpha}{\tan(\beta)}\right) - \ln(K_s D_{I_i}) \quad \text{(Eq. 1)}$$

Where IT is the topographic index, α is the specific contribution area (m^2/m) calculated dividing the contributor area by the basin perimeter, β is the slope present in the basin (rad), K_s is the saturated soil hydraulic conductivity (m / day) and D_{Ii} (m) is the relative depth. The relative depth is calculated as Equation 2.

$$D_{Ii} = D - (D \times I_i) \quad \text{(Eq. 2)}$$

Where D is the depth and I_i is the impermeability index created in the previous steps. The digital elevation model (DEM) and a file with information about the soil type present in the area were necessary to do the Santa Maria-Torto topographic index, which is composed by the impermeability, moisture and storage index. The DEM used was produced in the SRTM topography mission by NASA and made available by the United States Geological Survey-USGS (NASA and USGS, 2013), and has a 1 arc-second spatial resolution, which is approximately 30 meters per pixel. The soil map used was available in the database of the Water Regulatory Agency of the Brasilia (Adasa, 2011).

The storage index, the second term of the topographic index equation (Equation 1) was created with the association of the depth values (D) and the types of soils present in the sub-basin. After the association between the soil type and the depth value, the relative depth (D_{Ii}) were calculated, using the value of the depth (D) and the impermeability index (I_i). The saturated hydraulic conductivity of the soil (K_s) was also calculated associating the value of this parameter with the soil type present in the sub-basin. Then, the storage index was calculated from the natural logarithm of the division between the saturated hydraulic conductivity of the soil (K_s) and the relative depth (D_{Ii}). Figure 4 shows the storage index. The soil depth information and soil hydraulic conductivity were based on Lima *et al.* (2013), which detailed information about K_s and D for the savanna.

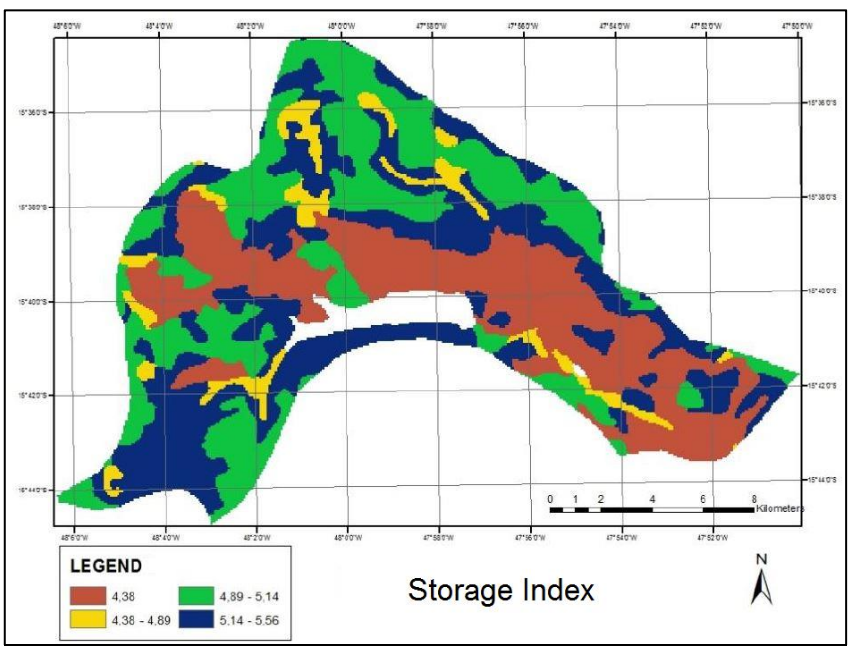

Figure 4. Storage Index.

The other term of the topographic index, the moisture index, was made by the creation of the slope map (β), using the DEM file. The slope calculation was done from the DEM_Fill file created by the "Slope" function present in the "Surface Analysis" tool of the "Spatial Analysis" extension. The slope was classified according to the EMBRAPA (1979) classification. The area and perimeter were obtained through the attributes table of the basin delimitation file present in the database of the Integrated Management Plan for Water Resources - PGIRH (Adasa, 2011). There, the moisture index was calculated with the slope in radians, the contour area and perimeter of the sub-basin (Figure 5).

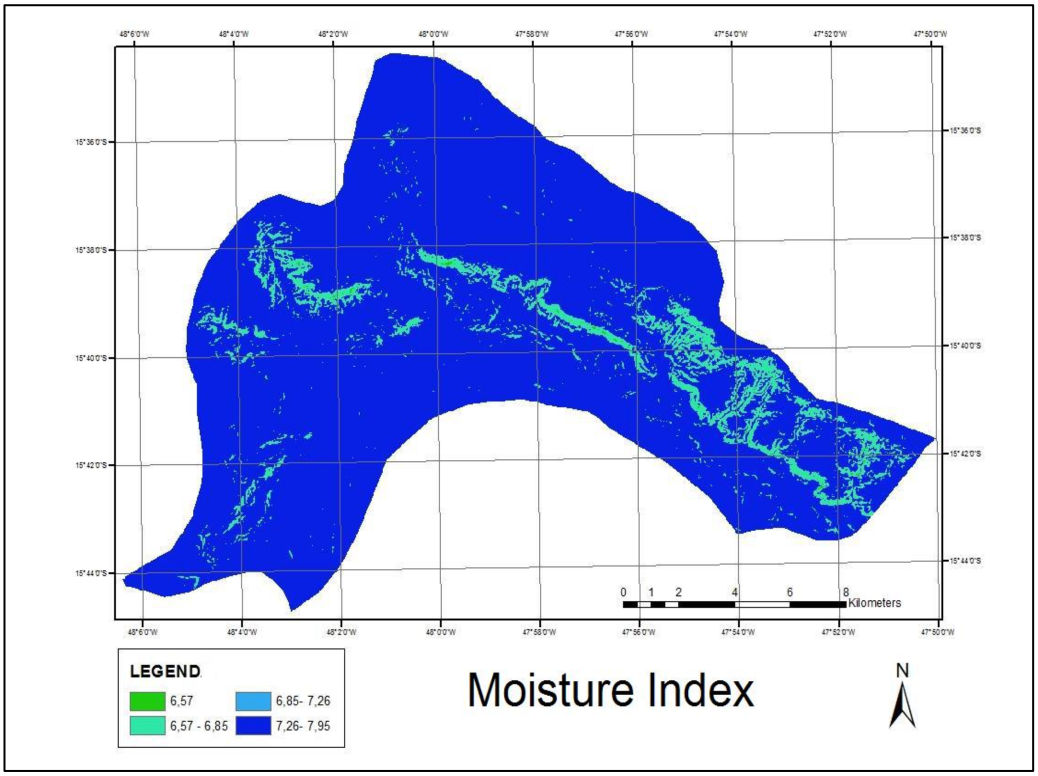

Figure 5. Moisture Index.

After obtaining the two-component indices, the topographic index can be calculated by subtracting the moisture index and the storage index. The result of the topographic index is shown in Figure 6, which resulted in IT values of 1.01 to 3.57.

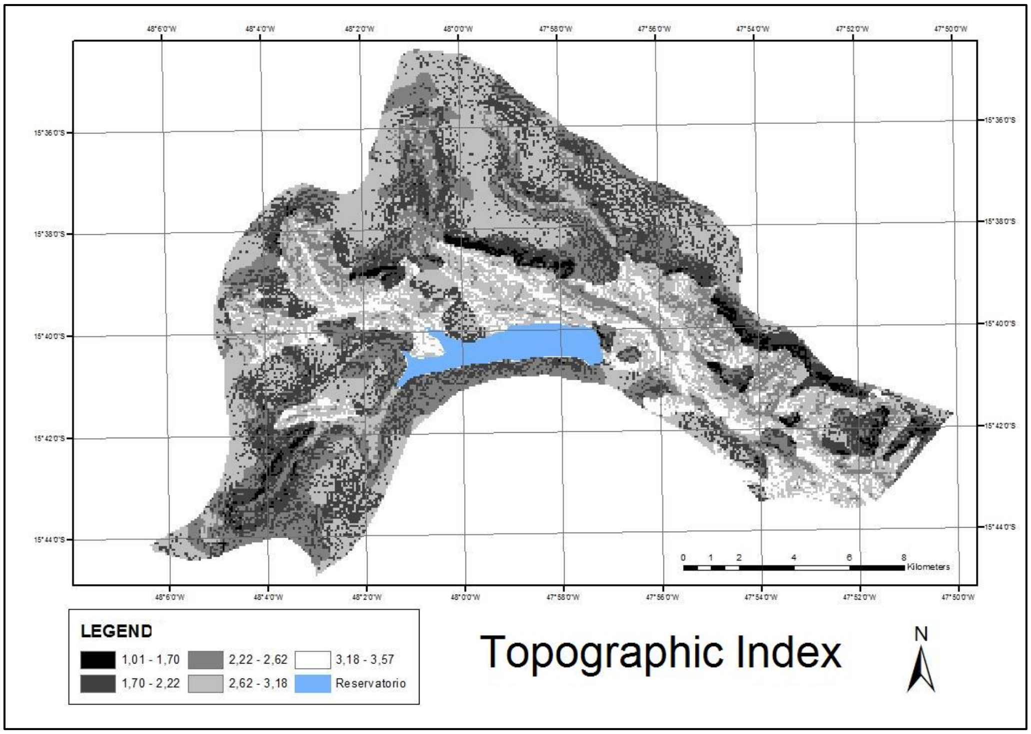

Figure 6. Topographic Index.

With the results obtained from the topographic index, it is possible to identify the Hydrologically Sensitive Areas (HSA). One arbitrary threshold value was defined, so any value above this would be considered an HSA. Thus, different thresholds were used to identify the HSA. The values used to define the threshold were: 2.22, 2.62 and 3.18. It was possible to note that the best threshold for the region studied would be 3.18; in another word all areas above 3.18 would be considered hydrologically sensitive areas (HSA).

RESULTS AND DISCUSSION

The hydrologically sensitive areas (HSA) can be seen in Figure 7. The HSA's spatial distribution and the location are related to the history of occupation and land use present in the Santa Maria-Torto sub-basin. It is possible to observe that the HSA are mostly located in the urban zones, near the reservoir and in some points of a riparian forest. The hydrologically sensitive areas which are located near the riparian forests, it is recommended that these areas should be a Permanent Protection Areas (APP) or Legal Reserve (RL), a kind of special areas established in the Brazilian Forest Code.

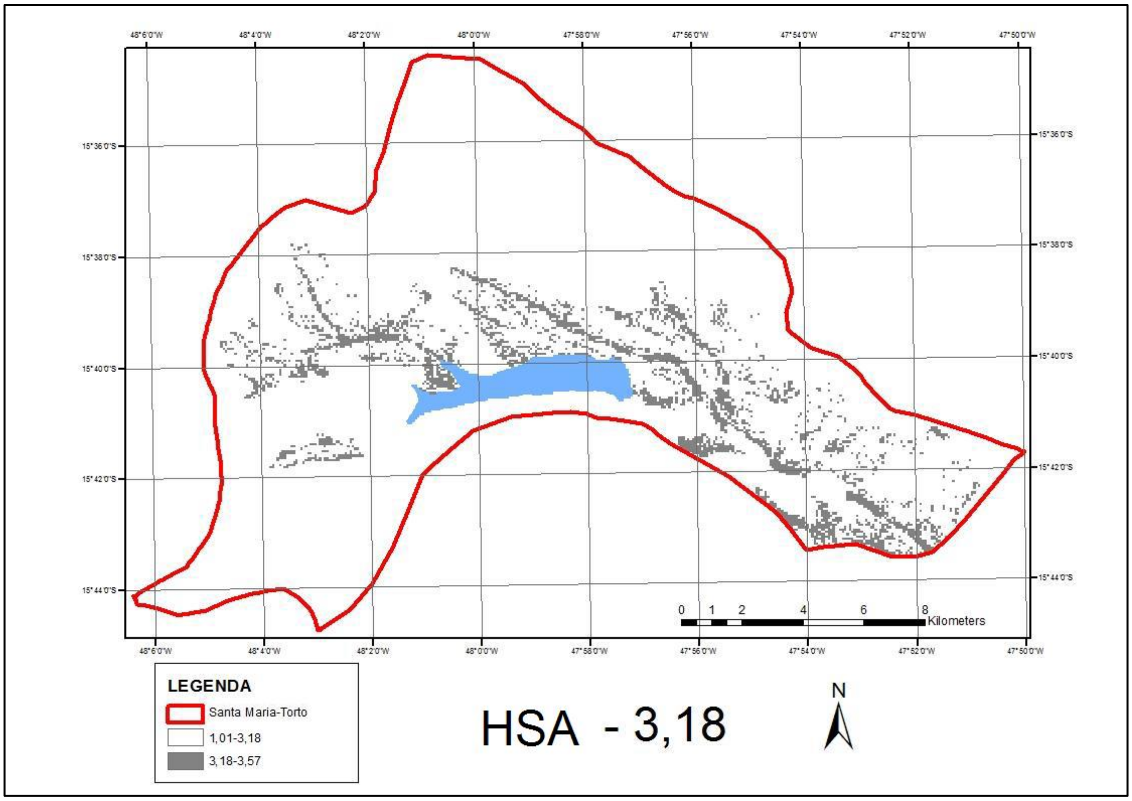

Figure 7. Hydrologically Sensitive Areas (HSA).

Additionally, the erosions near the reservoir is another worrying factor, which have also been identified as HSA, thus requiring urgent mitigation measures aiming at the environmental quality of the sub-basin. The HAS located in the exposed soil could be also a quality water supply problem. Another worrying factor is the presence of HSA in urban areas, thus becoming an environmental concern, as it is a potential diffuser of pollutants by the transportation of rainwater, and therefore management measures are also recommended.

CONCLUSION

Based on the results, it is possible to conclude that the methodology produces a satisfactory indicator of hydrologically sensitive areas (HSA). In this way, the results are of great relevance for the environmental management of the Santa Maria-Torto sub-basin. It is also possible to implement this methodology to obtain environmental protection and management measures that can be applied to different areas and aiming to promote the conservation of the local environment and the water supply reservoir. However, it is important to emphasize that this specific case study should be complemented with other research in the sub-basin, to result in a complete and efficient prognosis.

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