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Physical Dynamics and the Influences of the Environment Built on Subbasins

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Abstract: The fields of engineering, architecture and urbanism ought to ponder on constructive changes to be employed in the environment. Environmental vulnerability usually reaches sites with greater abundance of water resources that are exposed to contaminable factors, which usually become residential expansion areas, and often extrapolate city boundaries. The general objective of this study is to assess physical characteristics of the subbasins of the Curtume and Água Preta streams, located in the Paraíba do Sul watershed in the municipality of Pindamonhangaba, in the state of São Paulo (SP), Brazil. The current situation regarding this environment, based on soil type and morphometric and physiographic attributes, is specifically sought to be identified. The results show the morphological and physiographic relationships with the hydrological data that determine the natural pattern of the site, associated with anthropic actions that characterize potentialities and vulnerabilities of the area, thus determining environmental dynamics. The results demonstrate that urban sprawl and residential constructions in subbasin conservation areas should occur in a planned and strategic manner, without advancing to water conservation areas.

Key words: Watershed, urban expansion, physical analysis, environmental conservation.

1. Introduction

Demographic growth and expansion of economic activities, associated with urbanization, are the causes of negative effects on natural resources [1, 2]. This occupation process generates urban densities, which expand to rural areas present on the outskirts of the city [3, 4].

The expansion of constructed environments extrapolates city boundaries and has negative impacts by causing greater contaminations in watersheds [5]. Conceptually, every land area is integrated into a watershed [6], thus forming an interdependent system [5, 6].

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Watersheds [7, 8] are influenced by climatic factors, vegetation, topography, geology, soil use and management. However, the dynamics of anthropic activities can contribute to the increase of fragility of the hydrographic system, which is responsible for natural balance [8, 9]. Therefore, it is important to carry out research studies that deal with management and monitoring of these environments and that are capable of considering planning and expansion of cities in an organized manner [8-10].

Hence, this study was carried out in Brazil, more specifically in a stretch of the Paraíba do Sul watershed. Its management is shared and integrated at the federal level by CEIVAP (Committee for the Integration of the Paraíba do Sul Watershed) and by the domain of the State, in some stretches of São Paulo (SP), Rio de Janeiro (RJ), and Minas Gerais

(MG) states.

When identifying physical characteristics of watersheds [10], one must consider the natural elements, which become extremely important for the assessment of hydrological behavior. This analysis consists of aspects related to drainage, relief and geology, which contain different environmental dynamics present in a given ecosystem [11].

However, the fields of engineering, architecture and urbanism [12] require studies and diagnoses which aim at understanding subbasins systematically that evaluate the forms of spreading built environments, based on soil use and its socioeconomic characteristics. These aspects are detected through scientific studies carried out in watersheds [11, 12].

In this regard, the structuring of environmental monitoring programs, carried out through measurements of hydrological, limnological, topographic and cartographic variables, can be assisted through the use of the GIS (Geographic Information System), and a better understanding of spatial characteristics in a determined study area [11, 13-16]. For that reason, it can be stated that one can contribute to environmental suitability of subbasins [17, 18].

By means of analyses of watersheds, the use of morphometric variables is highlighted, and it shows the possibility of understanding and defining environmental vulnerability [13, 18]. These comparisons and correlations comprise physical, biotic, hydrological and climatological characteristics that determine local patterns, in addition to the use and occupation caused by anthropogenic actions, which contribute to environmental vulnerability of subbasins and watersheds [18-20].

The general objective of this study is to evaluate physical characteristics of the subbasins of the Curtume and Água Preta streams, located in the Paraíba do Sul watershed, in the municipality of Pindamonhangaba, in the State of São Paulo, Brazil.

This study becomes of utmost importance when dealing with the fields of engineering, architecture and urbanism associated with physical and environmental use forms of subbasins [12]. As water resources are threatened by population increase, it is necessary to develop studies that suggest new public policies capable of guaranteeing environmental conservation, and defining forms and specific urban occupation areas [12, 20-24].

2. Materials and Methods

The Paraíba do Sul river belongs to the Atlantic-Southeast watershed district, and meets the Paraibuna and Paraitinga rivers, whose springs are located in the municipalities of Cunha and Areias, in the state of São Paulo (SP, Brazil) [25]. This watershed occupies approximately 56,665.00 km^2, distributed as follows: 13,599.60 km^2 in the State of São Paulo (SP); 20,966.05 km^2 in the State of Minas Gerais (MG); and 22,099.65 km^2 in the State of Rio de Janeiro (RJ) [26].

The Water Resources Management Unit (UGRHI-02), which is the object of study, consists of 34 municipalities belonging to the Paraíba do Sul watershed, and five other municipalities—Arujá, Guarulhos, Itaquaquecetuba, Mogi das Cruzes and Salesópolis, based on the Alto Tietê watershed (UGRHI-06), which shelters almost 5% of the population of São Paulo. Moreover, more than 90% of the inhabitants of this region live in urban areas [25, 26].

With an estimated population of 2,032,001 inhabitants and an urban area of 13,599.6 km^2 [26], the Paraíba do Sul watershed is characterized by the presence of peripheral dwellings that interconnect the greater part of the RMVP (Metropolitan Region of the State of São Paulo), and is part of the urban axis between Brazil cities of Rio de Janeiro (RJ) and São Paulo (SP).

The subbasins of the Curtume and Água Preta streams are located in the Water Resources Management Unit (UGRHI) 02, which covers an area of approximately 103.34 km^2, and is integrally part of the municipality of Pindamonhangaba, in the State of São Paulo [26]. The study area has an extension between 450,000 m and 462,000 m (West), and 7,468,000 m. and 7,448,000 m. (South) in the UTM (Universal Transverse Mercator) coordinate system, 23 UTC (Universal Transverse Mercator) South, WGS84 Datum [25, 26].

The subbasins of Curtume (SB1) and Água Preta (SB2) streams (Fig. 1) were selected to be the object of study due to the influence and regional importance that they exert over the territory. Through urban sprawl, forest remnants in the subbasins have increasingly been suppressed [25, 26].

In the study area, Yellow Latosol can be found in the north, Red Latosol, Yellow Latosol, and Red Clay Latosol are found in the central area, and Yellow Latosol in the south [27]. In the region of higher altitude (300 m and 700 m), springs of the subbasin of Curtume stream are found, and the presence of Acrisols was observed. Acrisols are described as poor and shallow soils, susceptible to erosion with low permeability and some restrictions of use, based on the Agricultural Potentiality Map of Soils of the National Atlas of Brazil [27].

The cartographic base of the present study was obtained through the conversion, digitalization, and production of maps and technical parts that use GIS, Terraview and ArcGis programs. Data on drainage network, road system with curves of equidistance level of 20 m [25] were collected from the topographic map of IBGE (Brazilian Institute of Geography and Statistics), folios SF-23-YB-VI-3 (Pindamonhangaba) and SF-23-YD-III-1 (São Luiz do Paraitinga). In addition to this reference, numerical equations were used to obtain the results [16, 28-31].

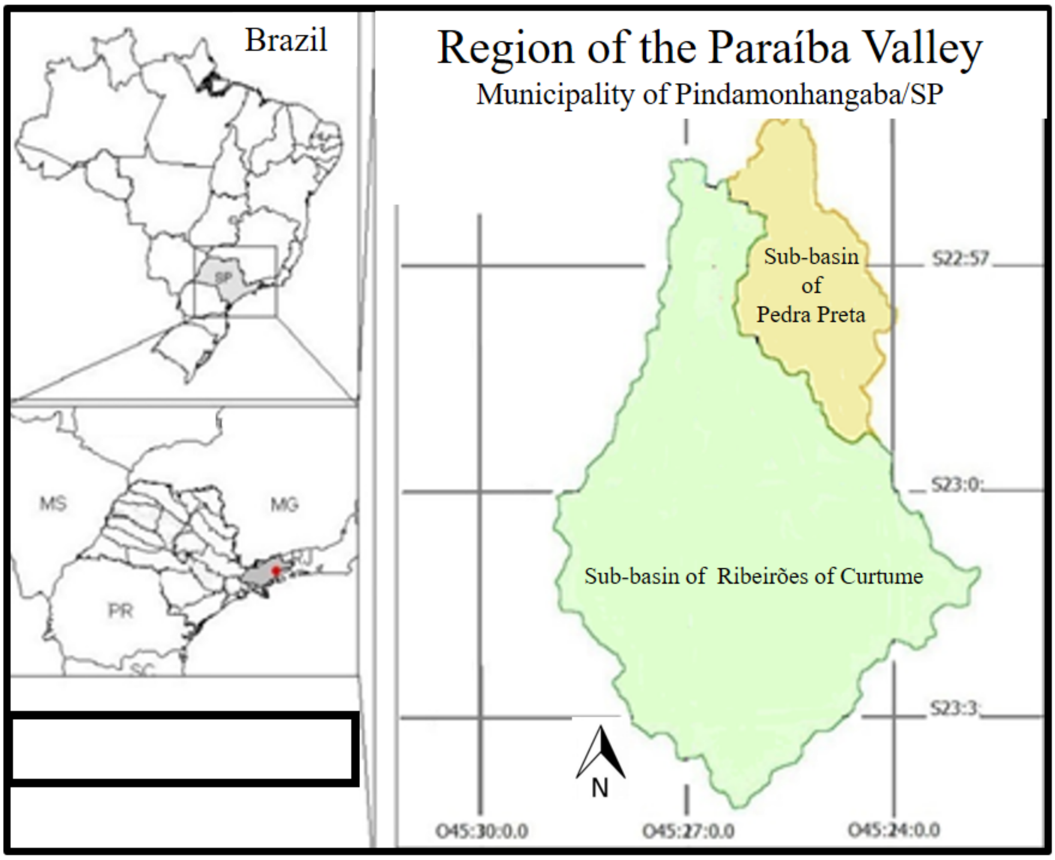

Fig. 1 Study unity, Pindamonhangaba/SP, 2017.

The ordering of channels from the entire morphometric data collection was performed by breaking down the network into discrete segment numbers, followed by the methodology described of first, second and third ordering of channels [16, 28-31].

GIS was used to obtain physical characteristics of the two subbasins. It then defined the area, perimeter, axial length of the subbasin and the main river [15, 16]. It was possible [31, 32] to identify the total extension of the drainage network, and the maximum and minimum altitudes, which served to determine morphometric and physiographic attributes on urban space.

3. Results and Discussion

Anthropic action has contributed to significant changes in subbasins, thus influencing infiltration and surface water runoff [21-24].

The municipality of Pindamonhangaba covers an area of 730.17 km^2, and is composed of subbasins of the Curtume (SB1) and Água Preta (SB2) streams, which occupy 14.15% of this territory, with a total area of 103.34 km^2 [25].

SB1 has an area of 86.69 km^2, and the length of the main river is 18.25 km. The drainage density (*Dd*) is 1,688 km^2.

However, SB2 covers a surface area of 16.65 km^2, and a perimeter of 21.18 km. In its territorial extension, water network is composed of 19.21 km of rivers, with drainage density (*Dd*) of 1,153km/km^2 [25].

The quantitative measure of network complexity of drainage systems is characterized as of 5th order for SB1, and of 3rd order for SB2.

Fig. 2 shows the calculated geometric attributes

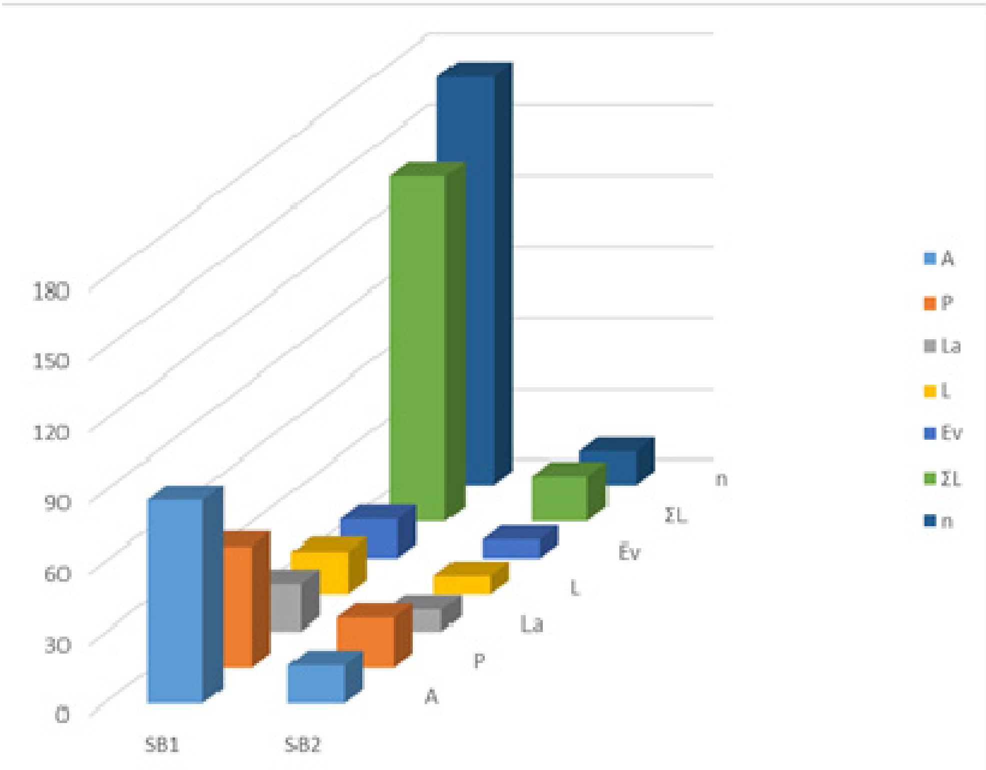

Fig. 2 Geometric attributes: *A*—basin area (km^2); *P*—perimeter (km); *La*—axial length of the basin (km); *L*—main channel length (km); *Ev*—vector length of the main channel (km); Σ*L*—total drainage network length (km); *n*—total number of channels of subbasins of the Curtume and Água Preta streams, Pindamonhangaba/SP.

for SB1 and SB2. These dimensions can be obtained [30, 31] by considering the length of the main channel (river) and the axial length of subbasins.

When considering geometric attributes, subbasins are influenced by sediment load, lithological compartmentalization, geologic structure and channel slope. The abovementioned [19, 20] is defined by the number of river bends, thus turning this index into a controlling factor of surface RV (runoff velocity).

In the present study, a similarity in index value between the two subbasins was found. This similarity was probably found due to the elongated format, which led the authors of this study to stating that both subbasins are favorable to the flow and present a lower risk of flooding to the population. What can compromise the existing dwellings at the site [23, 24] is the increase of future housing constructions at preservation areas of subbasins [21-24].

However, the gradient (*G*) of the main channel is given by the relationship between altimetric range (ΔH) and vector length (*Ev*) of the main channel. It has been found that the values for drainage density (*Dd*) are lower when corresponding to the total of 7.5 km/km^2 [31, 32].

The development of this drainage system provides efficiency, as it expresses the relationship between the sum of the lengths of all channels of the network and the total basin area [18-20, 30]. In this length [30], all channels, whether perennial, intermittent or temporary, are considered.

Based on these results, it can be infered that the study area has low drainage capacity despite the difference in its relief, where SB1 presents sloping relief close to the springs. This leads to a greater dispersion of sediments in areas of lower altitude, thus causing the spreading of the main river.

However, SB2 presents lower altitude range, which results in lower surface runoff velocity, associated with lower rainfall catchment area. The situation is aggravated by population advance in areas of environmental conservation [24].

By analyzing the frequency of drainage network (*Dr*), texture ratio (*T*), hydrodynamic density (*Dh*) and drainage density (*Dd*) [16, 28-31] shown in Fig. 3, it can be observed that SB1 presents higher values due to a more accentuated relief caused by the flow and

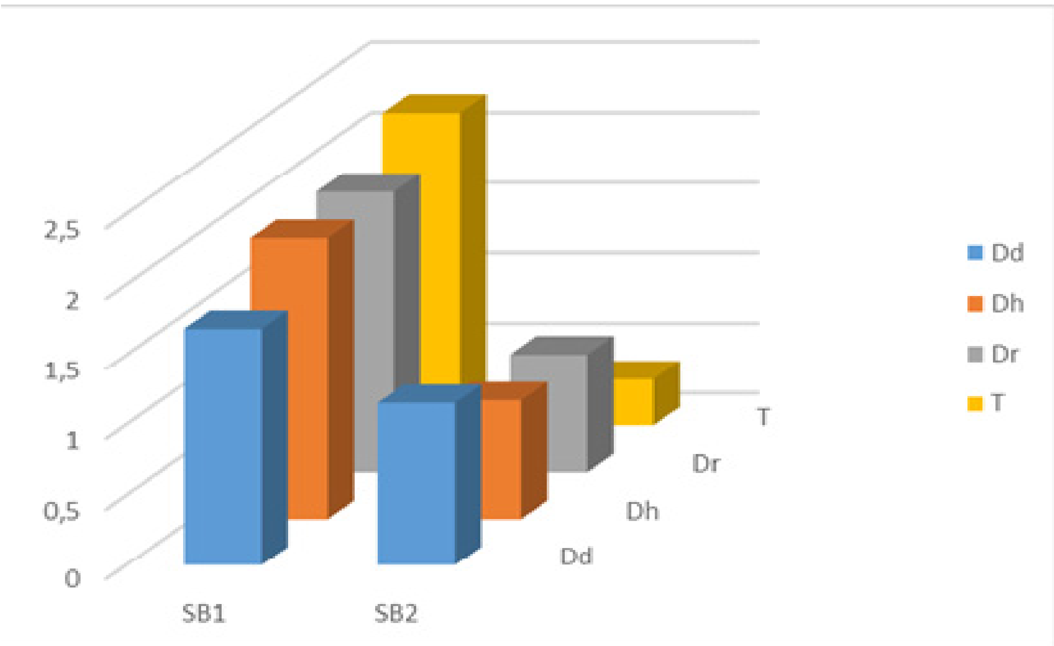

Fig. 3 Relative values calculated for the characteristic parameters of the drainage network: *Dd*—drainage density (km/km^2); *Dr*—frequency of drainage network (channels/km^2); *T*—texture layer (channels/km^2); *Dh*—hydrographic density (channels/km^2) of the subbasins of the Curtume and Água Preta streams, Pindamonhangaba/SP.

deepening of valleys and slopes.

Drainage values found were 1,688 km/km^2 for SB1 and 1,153 km/km^2 for SB2. In this relationship [24], SB1 is considered vulnerable to anthropogenic action.

It is pointed out the need for integrative practices that aim to reduce the loss of soil, nutrients and water flow, as well as to considerably interfere in the dynamics of environmental components. A possible solution could be the control of horizontal urban sprawl at the conservation areas of subbasins [12, 22].

This significant differentiation in drainage pattern observed between the subbasins resulted in comparisons of the types of soil and relief [26]. Predominant soil types are associated with areas of lower slope and propensity to greater water infiltration in Latosols [27].

For the type of soil present in more accentuated relief, conditions favorable to surface runoff were observed in SB1.

When considering the relationship between drainage network and dimensions of subbasins, there is a positive trend in all characteristics of SB1, which present higher values of number of watercourses and total length of the network. The results obtained were 1.9976 channels/km^2, considering SB1 a good hydrographic density, and being different from SB2, which presented 0.8408 channels/km^2, with less than 1 channel/km^2.

The character and extension of channels (drainage pattern) affect the availability of sediments as well as the rate of formation of defluvium [16]. These characteristics are controlled or influenced by the geologic structure [14, 16, 28-31].

In these two subbasins [30, 31], the classification of fluvial courses is rectilinear. Thus, SB2, the nominal slope, presented surface runoff with lower velocity on the ground, and lower rainfall catchment area. However, the SB1 counterpart presents larger catchment area and greater altimetric range, which results in larger drainage areas.

In relation to slope, it was observed that SB2 presents categories which are distributed between flat and slightly undulating topographies. For SB1, the categories of steep and strongly undulating topographies were found.

The results obtained in SB1 contributed to the preparation of suggestions of actions related to environmental protection. That is, through appropriate soil use, it is possible to develop conservation ecosystem practices for SB1 and SB2.

In this sense, it is suggested non-authorization for human actions to be applied in properties with agricultural production, residential subdivisions and industrial enterprises.

Fig. 4 shows morphometric descriptors for SB1 and SB2. These physical and specific parameters qualify the system dynamics of these two studied subbasins.

These characteristics of form and their interrelationships can quantify water availability, through attributes such as drainage hierarchy, measured by the compaction coefficient (*Kc*), the form factor (*Kf*) and the roundness index (*Ic*).

In subbasins SB1 and SB2, the formation composed of internal drains that do not have direct ocean runoff can be observed. Therefore, this generates potential flood spikes or susceptibility for the population that lives near flood risk areas.

The form factor (*Kf*) is the relationship between the mean width and the axial length of the subbasin. Thus, it can be considered that the lower it is its value, the more area the subbasin will have, resulting in higher flow and compaction coefficient (*Kc*).

In relation to the roundness index (*Ic*), which comprises area and perimeter, it is believed that the further away from the 1.0 value, the lower the risk of large floods. It should be noted that forms close to the rectangle assume the following reference values: $Kc > 1.25$; $Kf < 0.5$; $Ic < 0.5$, so for subbasins under study, they can be considered elongated [16, 28-31]. Therefore, the results found for SB1 and SB2 were as follows: Kf = 0.2165 and 0.2055; Ic = 0.4145 and

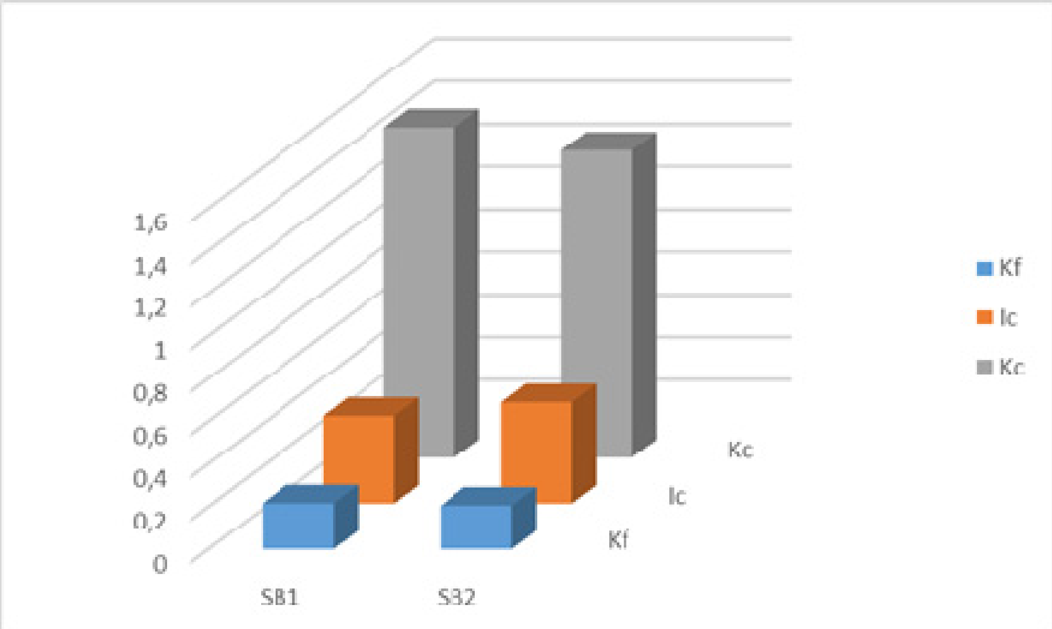

Fig. 4 Morphometric descriptors: *Kf*—form factor; *Ic*—roundness index; *Kc*—estimated compaction coefficient for subbasins of the Curtume and Água Preta streams, Pindamonhangaba/SP.

0.4745; *Kc* = 1.5495 and 1.441.

The higher the drainage density, the greater it will be its surface runoff capacity. Subbasins with rectangular shape, in case of long-term rainfalls, tend to cause floodings, and some housing areas become more susceptible [16, 28].

Regarding maintenance coefficient, it was observed that SB2 presented 867,302 m^2 in detriment to 592,41 m^2 for SB1. This maintenance coefficient [28-31] represents the minimum area required for maintenance of one meter of the outlet, which in the extension of subbasin forms drainage channels with preferential flows and concentrates.

Therefore, vulnerability of the subbasin of the Curtume stream is highlighted when relating maintenance coefficient to altimetric range. In this case, it reached 335 m, together with the considerable increase in flow velocity and the values of sinuosity index, with lower rainfall concentration time, thus making it extremely susceptible to water erosion.

Another analysis carried out relates to relation relief (*Rr*), roughness indexes (*Ir*), and geometric similarity (*Rm*) of subbasins [28-31]. When considering the SB2 area, it was found that the lower the altitude areas have, the more susceptible they are to floodings [16, 28-31]. Therefore, the relief ratio was higher than SB1, with a value of 13.96 (10^{-3}), while for SB2 the value found was 36.00 (10^{-3}).

Regarding roughness index, the values found were 565.48 (SB1) and 65.72 (SB2). This index [29-32] represents the relationship between altimetric range and the subbasin area.

4. Conclusions

The subbasin of the Curtume stream presented geomorphological indices that verified the need for construction and application of a controlled management plan. Therefore, the increase of dwellings in areas of conservation of water resources can be avoided.

In some areas, relief has excessive slopes and they trigger greater speed of rainwater flow and, therefore, aggravating, influencing and accelerating erosion processes, and loss of soil nutrients. These degradations can be aggravated by urban sprawl on the areas of environmental conservation [15, 16].

The subbasin of the Ribeirão do Água Preta stream has unfavorable conditions to anthropic occupations, as they may compromise the conservation of natural resources. This area of conservation of subbasins becomes increasingly an object of urban sprawl, with lack of urban planning, specially in squatter camps, and therefore characterizing them as atypical dwellings in that area.

When verifying the intensified degradation of the two subbasins, the need for integrated practices that solve different conflicts of interest—social, economical and political—is evident.

Currently, human action can be considered as a transforming agent of the environment [21-24], capable of interfering with processes that alter relief, hydrography and vegetation cover. This comprehensive understanding of subbasins leads the researchers to customizing demands for environmental management, in order to minimize negative impacts, and to favor conservation of natural resources still existing in the areas under study.

Analyses carried out can contribute to lower repair, remediation and mitigation costs of possible damage caused during occupations that notably [22-24] began in risk areas, in an irregular and disordered manner.

The importance of integrated studies in subbasins that comprise the Paraíba do Sul watershed is undeniable, given its strategic importance for local and regional development. However, it is noteworthy to mention that if urbanization continues to increase in conservation areas, the environment will become increasingly insalubrious, which is unacceptable in architectural projects.

It is suggested that the fields of engineering, architecture and urbanism [12] develop studies that involve subbasins and their conservation areas, and their relationships with the increase of dwellings on the outskirts of the city. Therefore, it is feasible to reflect on and suggest more suitable forms to expand cities horizontally [12].

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