

Article

Environmental Land Use Conflicts in a Macroscale River Basin: A Preliminary Study Based on the Ruggedness Number

Janaína Guidolini^{1,2,*}, Jean Ometto¹, Gustavo Arcoverde¹ and Angélica Giarolla^{1,2}

- ¹ Instituto Nacional de Pesquisas Espaciais, Centro de Ciência do Sistema Terrestre, São José dos Campos, SP 12227-010, Brazil; jean.ometto@inpe.br (J.O.); gustavo.arcoverde@inpe.br (G.A.); angelica.giarolla@inpe.br (A.G.)
- ² Grupo Política de Uso do Solo, Universidade Estadual Paulista (UNESP), s/n, Jaboticabal, SP 14884-900, Brazil
- * Correspondence: janaina.guidolini@inpe.br or janaguidolini@gmail.com; Tel.: +55-012-3208-7941

Received: 20 February 2020; Accepted: 7 April 2020; Published: 25 April 2020



Abstract: Inadequate land use planning is one of the main driving forces leading to the occurrence of erosion and environmental degradation. The negative impacts of poor planning influence soil physical quality and fertility, agricultural productivity, water quality and availability, biodiversity and other ecosystem services. In some areas, actual land use is not consistent with potential use. When this occurs, the area is termed as being in environmental land use conflict. Many studies have demonstrated the efficiency of the ruggedness number (RN) method for determining land use potential in watersheds. The RN method is simple and can be carried out using geographic information systems (GIS). However, the absence of potential land use or agricultural land suitability assessments is recurrent in territorial management plans or integrated water resources plans (IWRP), especially for macroscale river basins. Therefore, the aim of this preliminary study is to identify possible environmental land use conflicts at the Rio Grande Basin (BHRG), Brazil, using the Ruggedness Number. The results indicate high agricultural use potential and the predominance of appropriate or acceptable soil use at the BHRG. However, class 1, 2 and 3 environmental conflicts were identified in some Rio Grande sub-basins, suggesting greater environmental degradation risks. The findings clearly indicate that more exhaustive studies on environmental quality (soil capability, water, biodiversity) are required at the BHRG, especially in environmental land use conflict areas. We emphasize that this is an important preliminary study which may be carried out in any other macroscale hydrographic basin.

Keywords: soil conservation; land use conflict; river basin management; geographic information system

1. Introduction

Poorly planned land use is a major erosion accelerator and environmental degradation cause [1]. Poor planning impacts influence physical quality and soil fertility, agricultural productivity, water quality and availability, biodiversity and other ecosystem services [2]. Inadequate land planning and misuse leads to annual productivity losses, reaching approximately seven million hectares of agricultural land in various regions worldwide. In financial terms, these losses represent US\$70 per inhabitant, according to the United Nations Food and Agriculture Organization (FAO) [3].

In some areas, current land use is not consistent with soil potential use or soil capability. When this occurs, the area is termed as being in environmental land use conflict. The concept of environmental land use conflict encompasses two specific situations: (1) land use is above its capability or (2) soil is underestimated, leading to low productivity [1,4,5]. Land misuse is the precursor to environmental land



use conflicts. Therefore, understanding land capability is essential to plan and optimize its use with the implementation of joint soil conservation techniques [6]. It is understood that soil capacity, natural use or potential use is the planned and conscious use of soil, considering its natural characteristics. Furthermore, this does not accelerate or amplify erosive processes and maintains, with minimal losses, its physical, chemical and microbiological integrity characteristics [2,3]

The ideal work unit for land capability studies are watersheds, as natural processes can be associated to anthropic actions in these areas [6,7]. In order to optimize land use planning, various methods to determine soil capability have been developed [8–10], that evolved with the emergence of geographic information systems (GIS) Nevertheless, none of these models were designed to determine land use based on their soil capability [3]. One exception was the [11] model, based on the ruggedness number (RN).

The RN was introduced by [12] as a variable related to slope and drainage density in watersheds. The RN-based land use potential determination model establishes a relationship between soil capability, drainage density (Dd) and mean slope (Ms). The Ruggedness Number indicates the reality of sub-basin watersheds and offers a simple, quick contribution and precise planning, for better and more just economic exploitation, according to land aptitude. Soil capability in river basins and the Ruggedness Number are equivalent in over 95% of cases [13,14]. The higher the RN value, the greater the danger of erosion and environmental degradation [15]. In addition to providing a direct assessment of soil capability, the RN model effectively articulates with the conflict theory proposed by Ref. [1]. This theory assesses the environmental impacts generated by inappropriate land use. However, the RN-based model may display reduced effectiveness as a function of the size of the basin's contributing area. Due to heterogeneity, Ms and Dd may be insufficient to determine potential land use in large river basins [3]. In such cases, basin compartmentalization is recommended.

Many studies have demonstrated the efficiency of the RN method for determining soil capability in Brazilian watersheds [1–7,13–15] and other watersheds around the world [16–19]. However, the absence of potential land use or agricultural land suitability assessments is recurrent in territorial management plans and integrated water resources plans (IWRP). The situation is critical, as these plans include information on management actions, projects, works and priority investments that disregard local soil capability.

In this context, the aim of this preliminary study is to identify possible environmental land use conflicts at the Rio Grande Basin (BHRG), Brazil, using the Ruggedness Number [11,20]. The methodology can be easily replicated to other macroscale river basins. The results presented in this research may support territorial planning and the elaboration of integrated water resources plans of river basins.

2. Materials and Methods

2.1. Study Area

BHRG is located in the southeastern region of Brazil and has a contribution area of approximately 145,000 km² divided between the state of Minas Gerais (60% of the total area of the basin) and the state of São Paulo (40% of the total area of the basin) (Figure 1) [21,22]. The basin is made up of 393 municipalities, totally or partially inserted in it, which corresponded to 4.5% of the Brazilian population in 2010. In addition, BHRG is of relevant importance for the Brazilian economy, representing 4.6% of the national GDP (Gross Domestic Product) [23].

The basin's rich and diverse biodiversity comes from the Cerrado and Atlantic Rainforest biomes. The climate is characterized by rainy summers and dry winters. Amplitude annual precipitation is of 632 mm, with average precipitation of 1423 mm, maximum of 1924 mm and minimum of 1292 mm [24].

Land erosion, diffuse pollution due to agricultural activities and deficiencies in environmental sanitation (sanitary sewage and solid waste) stand out as the main drivers of water use conflicts at BHRG.



Figure 1. River Grande Basin Location.

2.2. Data Processing

Data processing was performed through the Digital Elevation Model (DEM), using 90-meter Shuttle Radar Topography Mission (SRTM) scenes provided by the Consortium for Spatial Information (CGIAR-CSI), available at: http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp. The scenes used for the Rio Grande Basin were: 26_16, 26_17, 27_16, 27_17, 28_16 and 28_17. Originally, this DEM consists in a geographic coordinate system and Datum WGS84 (EPSG: 4326). Thus, the projection system was converted to UTM (Universal Transverse Mercator), Cartesian coordinate system, and Datum SIRGAS 2000 (Brazil Polyconic/EPSG: 5880).

The drainage network extraction and hierarchization were performed from the DEM and processed by Quantum GIS 2.18.20 from the r.watershed and Strahler order algorithms. The algorithms are found in the processing tool, inserted in the Quantum GIS 2.18.20 Geographic Resource Analysis Support System—Geographical Information System (GRASS-GIS).

The level 2 sub-basin hydrographic base prepared for the National Water Resources Plan (PNRH) and available at the ANA (National Water Agency) website (http://metadados.ana.gov.br/geonetwork/ srv/pt/main.home) were used. The BHRG is compartmentalized into 15 sub-basins (Figure 2). The Ottocodified Hydrographic Base (BHO) used by ANA is generated from the digital cartography of the country's hydrography and organized in order to generate hydrologically consistent information. For this purpose, BHO represents the hydrographic network in stretches between the confluence points of the water courses in a single-line manner. Each stretch is associated with a drainage surface called ottobacia, to which the Otto Pfafstetter basin coding is attributed. An essential characteristic of this representation is to be topologically consistent, that is, to correctly represent the hydrological river flow, through connected stretches and with a defined flow direction [24].



Figure 2. Rio Grande Hydrographic Basin compartmentalized into sub-basins.

2.3. Morphometric Characterization

Among the morphometric variables, the drainage density (Dd), the mean slope (Ms) and, finally, the ruggedness number (RN) were calculated according to the following equations:

$$Dd = \frac{\sum CT}{A}$$
(1)

$$Ms = 100 \times \left(\sum LCN \times \frac{\Delta h}{A}\right)$$
(2)

$$RN = Dd \times Ms \tag{3}$$

where:

Dd = Drainage density, $km \cdot km^{-2}$;

 Σ CT = Total length of watercourses, km;

A = Sub-basin Contribution Area, km²;

Ms = Mean slope, %;

 Δh = Equidistance between contours, km;

 Σ LCN = Total length of contour lines, km;

RN = Ruggedness number (dimensionless).

The Ms, associated with vegetation cover, type and land use, regulates runoff speed and influences erosive processes [11]. Ref. [25] rated slopes as follows: 0–3% (flat relief); 3–8% (gently undulating relief); 8–20% (wavy relief); 20–45% (strongly wavy relief); 45–75% (mountainous relief); >75% (strongly mountainous relief). Drainage density (Dd), on the other hand, represents the degree of topographic dissection in landscapes due to river action or expresses the number of channels available for flow and control exerted by geological structures [26,27]. Ref. [27] classified watersheds according to drainage density as follows: low density—Dd \leq 5 km·km⁻²; medium density—5 < Dd < 13 km·km⁻² and high density—Dd \geq 13 km·km⁻².

The ruggedness number (RN) is an environmental parameter that directs potential soil use in terms of soil capability. From this parameter, potential land use can be classified as: (A) agriculture, (B) pasture, (C) forestry or (D) preservation. For class discrimination, the RN was calculated for the Rio Grande 15 sub-basins. After ordering the RN (from smallest to largest), the range, i.e., the difference between the highest and lowest RN values) and the class interval (I), resulting from the amplitude division/4 (referring to the four potential use classes) were calculated. As RN influences water erosion processes, the lowest value was associated with land with agricultural potential (class A) and the highest, with land suitable for preservation (class D) [1–3].

2.4. Determination of Environmental Land Use Conflict Areas

To determine environmental land use conflict areas, soil capabilities and actual land uses were first ranked, based on the ruggedness number (RN), in ascending order of their resemblance with agriculture (Table 1). Regarding land use classes (Figure 3 and Table S1), the following were considered as Class A: coffee, sugar cane, citrus, corn/soybean, central pivots and other crops. Pasture and Reforestation constituted Classes B and C, respectively. The Cerrado and Atlantic Rainforest formed Class D.

Table 1. Soil capability (ruggedness number (RN)) and actual land uses (X) ranking.

RN and X	Ranking
Agriculture (Class A)	1
Pasture (Class B)	2
Forestry (Class C)	3
Preservation (Class D)	4



```
Sources: Ref. [17,18,28].
```

Figure 3. Actual land use class distribution among Rio Grande sub-basins. Source: Adapted from the Brazilian National Water Agency—Ref. [23].

The criteria for environmental land use conflict determination are presented in Table 2. When a difference between actual land use and soil capacity is verified, an environmental land use conflict is present. This conflict has different levels. When actual land uses (X) are classified as soil capability (RN), A = 1—agriculture, B = 2—pasture, C = 3—forestry and D = 4—preservation, the conflict levels are assessed as follows:

- areas without conflict are characterized by X (A, B, C or D) ≤ 0, where the zero value does not represent conflict (an exact correspondence with natural use), while negative values represent areas where agriculture expansion is sustainable;
- conflict areas are characterized by $X (A, B, C \text{ or } D) > 0 \text{ e } X (A, B, C \text{ or } D) \le 3$.

Environmental Land Use Conflict Classes	RN – Actual Land Use					
Class 1	(Preservation) 4 – 3 (Forestry) (Forestry) 3 – 2 (Pasture) (Pasture) 2 – 1 (Agriculture)					
Class 2	(Preservation) 4 – 2 (Pasture) (Forestry) 3 – 1 (Agriculture)					
Class 3	(Preservation) 4 – 1 (Agriculture)					

Table 2. Criteria for determining environmental land use conflicts.

Source: Ref. [28].

In order to exemplify the environmental land use conflict determination criterion, we propose the following hypothesis: if soil capability, determined by RN, is 4/preservation, but currently the respective area is used for 1/agriculture, after ranking (Table 1) (4 - 1 = 3) identifies a class 3 environmental land use conflict (Table 2) [18,28].

3. Results and Discussion

To identify soil capability, the ruggedness number (RN) was calculated from the morphometric characteristics of the sub-basins. The results indicate that 73.3% of the sub-basins have potential for agricultural use, 13.3% display potential for pasture use and 12.4% of the sub-basins display the potential for reforestation or preservation. Soil has been used both correctly and/or acceptably in much of the BHRG, but conflicts of use are still noted.

Knowledge on land use along with the morphometric characterization of a watershed facilitates the assessment of possible ecosystem disturbances effect and contribute to the proper planning of anthropogenic exploitation [6]. Figure 3 and Table 3 indicate the actual land class distribution areas and morphometric characterization for the Rio Grande sub-basins, respectively.

	Ord	Α	Р	LMC	Lax	TL	TLLC *	Hmax	Hmin	Dd	Ms	RN
Sub1	3	8017.14	412.81	117.20	126.06	989.68	1,365,461.00	642	312	0.12	0.51	0.06
Sub2	4	7033.69	424.21	112.27	108.89	127.10	13,279,508.92	776	367	0.02	5.66	0.10
Sub3	4	9956.64	548.70	180.84	210.77	1198.98	18,397,600.03	762	371	0.12	5.54	0.67
Sub4	4	15,088.49	737.43	231.73	195.56	1879.99	32,391,461.88	1226	413	0.12	6.44	0.80
Sub5	4	5203.95	418.56	93.04	124.94	782.09	6,777,040.61	870	441	0.15	3.91	0.59
Sub6	4	9205.83	479.46	162.22	151.04	1448.16	40,627,430.84	1443	620	0.16	13.24	2.08
Sub7	3	6753.08	539.97	302.74	208.79	1620.00	17,332,246.04	1282	460	0.24	7.70	1.85
Sub8	3	10,351.18	623.38	355.89	198.50	3075.60	34,318,554.71	1559	482	0.30	9.95	2.96
Sub9	3	17,906.59	887.35	460.76	307.23	4115.60	56,881,875.18	1687	483	0.23	9.53	2.19
Sub10	4	16,209.60	840.17	285.19	195.01	1703.63	70,951,231.85	1478	729	0.11	13.13	1.38
Sub11	4	2427.81	258.24	107.06	77.40	1987.18	14,673,057.56	1796	858	0.82	18.13	14.84
Sub12	3	10,605.79	795.62	215.34	191.78	3614.31	50,946,273.42	1495	749	0.34	14.41	4.91
Sub13	4	8905.73	505.87	202.77	130.74	5493.06	49,287,576.49	2647	796	0.62	16.60	10.24
Sub14	3	6964.31	515.19	240.39	141.59	1266.04	46,198,627.29	2754	753	0.18	19.90	3.62
Sub15	4	9630.04	651.35	274.02	154.35	2231.30	69,476,708.56	2228	755	0.23	21.64	5.01

Table 3. Morphometric Rio Grande sub-basin characteristics.

Sub Basin; Ord—Order; A—Area (km²); P—Perimeter (km); LMC—Length of Main Channel (km); Lax—Length of Sub-basin Axial Axis (km); TL—Total Length of Watercourses (km); TLLC—Total Length of Level Curves (m); Hmax—Maximum Altitude (m); Hmin (Minimum Altitude); Dd—Drainage Density (km·km⁻²); Ms—Mean slope (%); RN—Ruggedness Number (dimensionless); * Equidistance between contours— $\Delta h = 30$ m.

The predominance of pasture and sugarcane is noted at the BHRG. In addition, sugarcane cultivation is notorious in flat to smooth undulating sub-basins, while pastures predominate in more rugged sub-basins. The altimetric amplitude (Hmax–Hmin) is high and the drainage density (Dd) was considered low in all sub-basins. The hierarchy of the river network (Ord) ranged from third to fourth order [29] and the mean slope (Ms) ranged from 0.51% (flat) to 21.64% (wavy) [25], between the sub-basins. It is important to highlight that the slope is a limiting factor concerning agricultural production and is related to the tolerable intensity of land use.

As mentioned earlier, low Dd values are associated with permeable rock and rainfall regions characterized by low rainfall rates [7]. Ref. [30] studied the relationship between drainage density and geomorphological and pedological factors in the Alto Rio Pardo area (São Paulo State/Minas Gerais State), and concluded that low Dd values (<1.5 km·km⁻²) are concentrated in oxisols in the peripheral depression, whose substrate is the sedimentary terrain of the Paraná Basin. Soils and permeable rocks on the soft topography terrain may have enabled the lowest runoff/infiltration ratio, resulting in low Dd values. When carrying out a morphometric characterization and the determination of the potential soil use for Uberaba River watersheds, Ref. [1] corroborated that oxisols display lower drainage efficiency.

The environmental degradation risk in river basins is represented by the RN, calculated from the product between Dd and Ms. This coefficient allows for the identification of potential land use. In the present study, an RN range of 14.78 and class interval (I) = 3.70 were verified. Thus, the thresholds for each potential land use class are presented in Table 4.

Table 4. RN class thresholds for Rio Grande sub-basins.

Soil Capability	RN Class Thresholds
Agriculture	0.06 to 3.76
Pasture	3.77 to 7.47
Forestry	7.48 to 11.18
Preservation	11.19 to 14.86

Most of the Rio Grande sub-basins display potential agricultural use (RN ranging from 0.06 to 3.76) (see Table 4), which is consistent with the slightly rugged relief and the predominance of latosols [7,30,31]. However, sub-basin 11 displays the potential use for preservation, while sub-basins 12 and 15 display capability for pasture use and sub-basin 13 displays capability for forestry. Ref. [1] obtained similar results for the Uberaba River watershed, reporting that 47.12% of the Uberaba River watershed area displays potential for agricultural use. It is important to note that the Uberaba River microbasins are inserted in the BHRG.

Cambisols predominate in areas suitable for reforestation or preservation. Figure 4 presents the potential land use for the assessed Rio Grande sub-basins and Table 5 displays the amounts of soil types by sub-basin. Cambisols occur in a variety of environments, but are usually associated with rugged (undulating to hilly) relief areas. In steep environments, shallower cambisols limit agricultural production due to high susceptibility to erosion and difficult agricultural mechanization. In contrast, oxisols, predominant at the RGHB, display high potential for agricultural use due to their good physical condition and softer reliefs. Oxisol limitations are related to poor fertility and moisture retention when the texture is coarse and the weather is drier [32].



Figure 4. Soil capability of Rio Grande sub-basins.

	Amounts of Soil Types in Rio Grande Sub-Basins									
Sub-basins -	Water	PVA	СХ	LVA	RL	RQ	NV	ΟΥ	PV	LV
Sub1	10.61	10.87							34.11	44.41
Sub2	6.25								21.06	72.70
Sub3	0.69	83.06								16.25
Sub4	5.43	9.37	0.35	10.91			0.03		3.83	70.08
Sub5		3.41		1.48						95.11
Sub6	3.16	0.86	5.21	18.33	17.12					55.32
Sub7	0.17	0.06		16.89		7.83				75.06
Sub8		32.12	0.72	12.19		8.11				46.85
Sub9		23.63	3.12	11.69				2.56	0.00	59.01
Sub10	9.26	16.42	20.55	5.13	0.27					48.38
Sub11		18.19	70.02							11.79
Sub12		9.33	36.06	33.15						21.46
Sub13	1.29	0.75	93.04	0.00						4.92
Sub14			25.67	24.09						50.24
Sub15	_	4.40	5.04	37.91						52.65

Table 5. Amounts (%) of soil types in Rio Grande sub-basins.

PVA—Red-Yellow Argisol; CX—Cambisol; LVA—Red-Yellow Latosol; RL—Litolic Neosol; RQ—Quartzarenic Neosol; NV—Red Nitosol; OY—Organic Soil; PV—Red Argisol; LV—Red Latosol. Source: Adapted from the Brazilian National Water Agency Ref. [23].

Inadequate land use planning causes environmental land use conflicts [6], which may occur in two situations: (1) the current land use contradicts the recommendation obtained from the RN and overestimates soil capability or (2) soil use is underestimated, displaying low productivity [1]. In the present study, "acceptable use" areas are considered as those preserved with natural vegetation, areas with agricultural potential used for pasture and/or reforestation, areas with potential for pasture used for forestry and water. In addition, "conflict" comprises built areas (Table 6).

A stual I and I las	Soil Capability or Potential Land Use							
Actual Land Use –	Agriculture	Pasture	Forestry	Preservation				
Agriculture	Appropriate	Conflict 1	Conflict 2	Conflict 3				
Pasture	Acceptable	Appropriate	Conflict 1	Conflict 2				
Forestry	Acceptable	Acceptable	Appropriate	Conflict 1				
Preservation	Acceptable	Acceptable	Acceptable	Appropriate				
Built areas	Conflict	Conflict	Conflict	Conflict				
Water	Acceptable	Acceptable	Acceptable	Acceptable				

Table 6. Actual land use versus soil capability.

Table 6 shows the appropriate and acceptable land uses and environmental land use conflicts in the Rio Grande sub-basins. In most sub-basins, appropriate and acceptable land use are predominant. However, sub-basin 11 is noteworthy as the sub-basin presenting the highest risk of environmental degradation at the BHRG (RN = 14.84—highest value), presenting class 1, 2 and 3 conflicts. Sub-basin 13 (RN = 10.24) presented class 1 and 2 conflicts and sub-basins 12 (RN = 4.91) and sub-basin 15 (RN = 5.01) presented class 1 and 2 conflicts, respectively. Suggesting that the soil is being used in an appropriate or acceptable way does not mean exemption from care in maintaining its physical, chemical and microbiological properties. The use of conservation techniques will imply the soil maintenance capability (Table S1).

A worrying observation about land use at BHRG is the low proportion of preserved natural vegetation, especially in areas presenting a flat or smooth undulating relief. This suggests a possible deficit in permanent preservation and legal reserve areas due to agricultural expansion in the basin. The relevance of natural vegetation for maintaining water quality and availability and in soil conservation is well known. Thus, we consider natural vegetation preservation as paramount, and their presence at BHRG is acceptable (and recommended) regardless of RN values.

There exists general recommendations and non-categorical actions for each class of environmental land use conflict. In class 1 conflict areas, severe or permanent risks/limitations are noted when land is used for annual crop and pasture cultivation. Thus, the joint implementation of soil conservation techniques, especially displaying both a vegetative and mechanical character, is essential. In class 2 conflict areas, forestry or preservation are recommended, as class 2 conflict areas are unsuitable for intensive agriculture. Finally, for class 3 conflict areas, preservation is recommended, as these areas are unsuitable for agriculture or grazing. It is noteworthy that recommendations are not followed in some Rio Grande sub-basins [17,18,28].

Sub-basin 11, in particular, should be preserved. However, over 90% of its area is used for agriculture, pasture, forestry or building and less than 10% is preserved. With a predominance of cambisols (70% of the total area) and an undulating relief, its susceptibility to erosion is high [32]. Cambisols also predominate in sub-basin 13, with potential use for forestry, where class 1 and 2 conflicts were observed, the relief is undulating and less than 17% of the total area is preserved.

Soil loss through erosion is the main impact caused by environmental land use conflicts. Consequently, decreased agricultural productivity and soil organic matter, nutrient leaching, deterioration of surface and groundwater quality and decreased biodiversity, as well as other damages to the provided ecosystem services are observed [2,3].

Currently, few countries in the world have established technical and legal criteria for land use, occupation and conservation. The "polluter pays principle" is an exception in force in Brazil that warns of the legal and social responsibility of soil conservation [33]. According to this principle, the landowner must mitigate or even remediate environmental impacts as a result of unsustainable practices [3]. Permanent Preservation Areas (PPAs), pursuant to articles 4, 5 and 6 of Law No. 12,651/12 (New Forest Code), are defined as: "protected areas, covered or not by native vegetation, with the environmental function of preserving water resources, landscape, geological stability and biodiversity,

facilitating the gene flow of fauna and flora, protecting the soil and ensuring the well-being of human populations" [34].

Considering the low amounts of natural vegetation preserved at the BHRG, especially in sub-basins suitable for agricultural production, we can infer that PPA boundaries are not in line with the legislation (which provides for at least 30 m in width). In addition, Ref. [33] concluded that 30 m wide PPA strips are insufficient for maintaining water quality.

The strength of this study is the advancement of knowledge related to potential land use at the BHRG, as this is the first study that covers the whole basin. Determining the potential use for the Rio Grande sub-basins and identifying conflicting areas can support action planning, territorial management and integrated water management.

However, the major limitation of this study is the reduction in the effectiveness of the RN methodology with increasing catchment areas. Due to increased heterogeneity, Dd and Ms values may be insufficient to discriminate land use potential in large basins [3].

In this preliminary study, the RN method was deemed efficient, especially because it discriminates potential uses, despite the low drainage density found in all sub-basins. When testing the method for the BHRG, without compartmentalizing the data in sub-basins, an RN of 0.92 was obtained. Low RN values suggest potential agricultural use [11], the result would be less consistent with reality, although most assessed sub-basins display the potential for agriculture use.

The results indicate the enormous agricultural potential at the BHRG. However, it is important to highlight that socioeconomic development must be linked to environmental quality. This requires integrating water resources management with other public administration sectors that also affect water quality and availability [21]. Land management, closely related to land use and occupation, must be adapted in accordance to environmental, social and development policies. Sustainability is the best approach to this end.

Future studies, including sustainability research, may use watershed-scale environmental land use conflicts as an indicator for soil degradation risks. To improve the effectiveness of the applied methodology, we suggest the refinement of the RN method by crossing soil, mean slope and roughness coefficient data [6] or integrating relief variables (RN), relief shape (dissection) and soil properties (magnetic susceptibility) [3], for example, to compare other data to our study. In addition, it is possible to compartmentalize sub-basins into smaller areas (microbasins) in GIS and develop required exhaustive studies on environmental quality (soil capability, water, biodiversity) at the BHRG, especially in environmental land use conflict areas.

In summary, our results suggest high agricultural potential at the BHRG and suggest the presence of class 1, 2 and 3 environmental land use conflicts. The low amounts of natural vegetation in the sub-basins indicate vegetation suppression due to agricultural expansion. In Brazil, environmental quality maintenance requires monitoring compliance with environmental laws and the effectiveness of the Polluter Pays Principle.

4. Conclusions

This preliminary study reports on the potential land use in the Rio Grande sub-basins and identified environmental land use conflicts area based on the morphometric variables Dd (drainage density), Ms (mean slope), and the Ruggedness Number.

Dd was low for all sub-basins (<0.5 km \cdot km⁻²). The Ms, on the other hand, ranged from 0.51% (flat) to 21.64% (wavy). Regarding type of soils, latosols (in flatter reliefs) and cambisols (in more rugged reliefs) were the most noteworthy.

Overall, Rio Grande sub-basins display a high capability for agricultural use (73.3%). Sub-basins 12 and 15 showed capability for pasture use. Sub-basins 11 and 13 showed capability use for preservation and reforestation, respectively.

Class 1, 2 and 3 environmental land use conflicts were noted throughout the Rio Grande Basin. Sub-basins 11 and 13 were the most noteworthy in this regard, at 90.24% and 82.80% of conflicting areas in relation to the total sub-basin area, respectively.

Reporting that the soil is being used in an appropriate or acceptable way does not suggest the dispensability of using joint conservation techniques to maintain soil capacity.

The low proportion of natural vegetation in the sub-basins indicate vegetation suppression due to agricultural expansion. Thus, enforcement of compliance with environmental laws and the effectiveness of the Polluter Pays Principle becomes paramount.

The RN was effective in suggesting soil capability and environmental land use conflict areas in Rio Grande sub-basins. However, the effectiveness of this methodology may decrease if the contribution area of the sub-basin increases.

Given the relevance of the issue assessed herein, environmental land use conflicts can be used as soil degradation risk indicators in river basin sustainability surveys.

This preliminary study contributes to the advancement of knowledge related to environmental land use conflict at the BHRG, as it is the first study that covers the entire basin. Studying soil capability and identifying environmental land use conflict areas can support territorial management and integrated watershed management. We emphasize that this is an important preliminary study which may be carried out in any other macroscale hydrographic basin.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4441/12/5/1222/s1, Table S1: Identification of environmental conflicts in Rio Grande sub-basins.

Author Contributions: J.G. contributed with investigation, conceptualization, methodology, and writing the original draft; G.A. contributed to review and editing; J.O. and A.G. contributed to supervision. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Conselho Nacional de Desenvolvimento Científico e Tecnológico, grant number 14125/2015-0.

Acknowledgments: The authors would like to thank Rachel Ann Hauser Davis for copyedit the manuscript. The project "Towards the International Nitrogen Management System (Towards INMS)" financed the publication charge.

Conflicts of Interest: The authors declare no conflict of interest.

References

- 1. Valle Júnior, R.F.; Galbiatti, J.A.; Pissarra, T.C.T. Diagnosis of conflict of land use and occupancy of river basin Uberaba. *Glob. Sci. Technol.* **2013**, *6*, 40–52.
- Valera, C.A.; Valle Júnior, R.F.; Varandas, S.G.P.; Sanches Fernandes, L.F.; Pacheco, F.A.L. The role of environmental land use conflicts in soil fertility: A study on the Uberaba River basin, Brazil. *Sci. Total Environ.* 2016, *562*, 463–473. [CrossRef]
- 3. Costa, R.C.A.; Pereira, G.T.; Pissarra, T.C.T.; Siqueira, D.S.; Fernandes, L.F.S.; Vasconcelos, V.; Fernandes, L.A.; Pacheco, F.A.L. Land capability of multiple-landform watersheds with environmental land use conflict. *Land Use Policy* **2019**, *81*, 689–704. [CrossRef]
- Siqueira, H.E.; Guidolini, J.F.; Antunes, D.H.; Oliveira, F.P.; Valle Júnior, R.F. Diagnóstico da qualidade da água em área de conflito de uso do solo na microbacia Mangabeira, Uberaba-MG. *Enciclopédia Biosf.* 2012, *8*, 1164–1178.
- Pacheco, F.A.L.; Sanches Fernandes, L.F.; Valle Júnior, R.F.; Valera, C.A.; Pissarra, T.C.T. Land degradation: Multiple environmental consequences and routes to neutrality. *Curr. Opin. Environ. Sci. Health* 2018, *5*, 79–86. [CrossRef]
- 6. Oliveira, L.F.C.; Calil, P.M.; Rodrigues, C.; Kliemann, H.J.; Oliveira, V.A. Potencial do uso dos solos da bacia hidrográfica do alto rio Meia Ponte, Goiás. *Ambient Água*. **2013**, *8*, 222–238.
- 7. Lima, W. *Hidrologia Florestal Aplicada ao Manejo de Bacias Hidrográficas*, 2nd ed.; Departamento de Engenharia Florestal, ESALQ-USP: Piracicaba, Brazil, 2008; p. 242.
- 8. Feick, R.D.; Hall, G.B. Balancing consensus and conflict with a GIS-based multi-participant, multi-criteria decision support tool. *GeoJournal* 2002, *53*, 391–406. [CrossRef]

- 9. Koontz, T.M. We Finished the Plan, So Now What? Impacts of Collaborative Stakeholder Participation on Land Use Policy. *Policy Stud. J.* 2005, 33, 459–481. [CrossRef]
- 10. Zhang, Y.J.; Li, A.J.; Fung, T. Using GIS and Multi-criteria Decision Analysis for Conflict Resolution in Land Use Planning. *Procedia Environ. Sci.* **2012**, *13*, 2264–2273. [CrossRef]
- 11. Rocha, J.S.M.; Kurtz, S.M.J.M. *Manual de Manejo Integrado de Bacias Hidrográficas*, 1st ed.; Editora da UFSM: Santa Maria, Brazil, 2001; p. 282.
- 12. Strahler, A.N. Hypsometric (area-altitude) analysis of erosional topography. *Geol Soc. Am. Bull.* **1952**, *63*, 1117–1142. [CrossRef]
- Baracuhy, J.G.V.; Kurtz, S.M.J.M.; Kurtz, F.C.; Duarte, S.M.A.; Lima, V.L.A.; Rocha, J.S.M.; Dantas Neto, J. Deterioração físico-conservacionista da microbacia hidrográfica do riacho Paus Brancos, Campina Grande, PB. *Rev. Bras. Eng Agríc Ambient.* 2003, 7, 159–164. [CrossRef]
- 14. Sampaio, M.V.; Santos, M.F.; Rocha, J.S.M.; Paula, M.D.; Mendes, A.V. Deterioração Físico—Conservacionista da Sub—Bacia Hidrográfica do Rio Ibicuí—Mirim—RS. *Cienc Agrotec.* **2010**, *34*, 300–306. [CrossRef]
- 15. Rodrigues, V.S.; Valle Júnior, R.F.; Sanches Fernandes, L.F.; Pacheco, F.A.L. The assessment of water erosion using Partial Least Squares-Path Modeling: A study in a legally protected area with environmental land use conflicts. *Sci. Total Environ.* **2019**, *691*, 1225–1241. [CrossRef]
- 16. Pacheco, F.A.L.; Varandas, S.G.P.; Sanches Fernandes, L.S.; Valle Júnior, R.F. Soil losses in rural watersheds with environmental land use conflicts. *Sci. Total Environ.* **2014**, *485–486*, 110–120. [CrossRef]
- 17. Valle Júnior, R.F.; Varandas, S.G.P.; Sanches Fernandes, L.S.; Pacheco, F.A.L. Environmental land use conflicts: A threat to soil conservation. *Land Policy* **2014**, *41*, 172–185. [CrossRef]
- Valle Júnior, R.F.; Varandas, S.G.P.; Pacheco, F.A.L.; Pereira, V.R.; Santos, C.F.; Cortes, M.R.V.; Sanches Fernandes, L.S. Impacts of land use conflicts on riverine ecosystems. *Land Policy* 2015, 43, 48–62. [CrossRef]
- 19. Pacheco, F.A.L.; Sanches Fernandes, L.S. Environmental land use conflicts in catchments: A major cause of amplified nitrate in river water. *Sci. Total Environ.* **2016**, *548–549*, 173–188. [CrossRef]
- Valle Júnior, R.F.; Abdala, V.L.; Val, B.H.P.; Carmo, D.A.; Souza, M.A.C. Diagnóstico do uso potencial do solo e conflitos ambiental na microbacia hidrográfica do rio Veríssimo, Veríssimo-MG. *Enciclopédia Biosf.* 2011, 7, 1–10.
- Guidolini, J.F.; Giarolla, A.; Toledo, P.M.; Valera, C.A.; Ometto, J.P.H.B. Water Sustainability at the River Grande Basin, Brazil: An Approach Based on the Barometer of Sustainability. *Int. J. Environ. Res. Public Health* 2018, 15, 2582. [CrossRef]
- 22. Legal Basis for Water Resources Management in Brazil: Case Study of the Rio Grande Basin. Available online: https://publications.waset.org/10008902/legal-basis-for-water-resources-management-in-brazil-case-study-of-the-rio-grande-basin (accessed on 28 January 2020).
- 23. Agência Nacional de Águas (Brazilian National Water Agency)—ANA. *Produto Parcial (PP02): Diagnóstico da bacia hidrográfica do Rio Grande;* Agência Nacional de Águas (Brazilian National Water Agency)—ANA: Brasília, Brazil, 2016; p. 553.
- 24. Agência Nacional de Águas (Brazilian National Water Agency)—ANA. *Qualidade da Água Da bacia do Rio Grande;* Agência Nacional de Águas (Brazilian National Water Agency)—ANA: Brasília, Brazil, 2013; p. 58.
- 25. Empresa Brasileira de Pesquisa Agropecuária—Embrapa. *Súmula da X Reunião Técnica de Levantamento de Solos;* Empresa Brasileira de Pesquisa Agropecuária—Embrapa: Brasília, Brazil, 1979; p. 83.
- 26. Silva, V.A.; Oliveira, L.T.; Estevam, J.P.S.; Siqueira, H.E.; Valle Júnior, R.F. Análise morfométrica e definição do potencial de uso do solo da microbacia do córrego Neca, em Uberaba-MG. *Fazu Em Rev.* **2013**, *10*, 13–16.
- 27. Christofoletti, A. Geomorfologia, 2nd ed.; Edgar Blucher: São Paulo, Brazil, 1980; p. 190.
- 28. Valle Júnior, R.F. Diagnóstico de áreas de risco de erosão e conflitos de uso dos solos na bacia do rio Uberaba. Ph.D. Thesis, Universidade Estadual Paulista, Jaboticabal, SP, Brazil, 2008.
- 29. Strahler, A.N. Quantitative analisys of watershed geomorphology. *Trans. Am. Geophys. Union* **1957**, *38*, 913–920. [CrossRef]
- 30. Hiruma, S.T.; Ponçano, W.L. Densidade de drenagem e sua relação com fatores geomorfopedológicos na área do Alto Rio Pardo, SP e MG. *Rev. Inst. Geológico.* **1994**, *15*, 49–57.
- 31. Horton, R.E. Erosional development of streams and their drainage basins, hydrophyrical approach to quantitative morphology. *J. Jpn. For. Soc.* **1955**, *37*, 257–262.
- 32. Empresa Brasileira de Pesquisa Agropecuária—Embrapa. *Sistema Brasileiro de Classificação de Solos;* Empresa Brasileira de Pesquisa Agropecuária—Embrapa: Brasilia, Brazil, 2018; p. 355.

- 33. Valera, C.A.; Pissarra, T.C.T.; Martins Filho, M.V.; Valle Júnior, R.F.; Sanches Fernandes, L.F.; Pacheco, F.A.L. A legal framework with scientific basis for applying the 'polluter pays principle' to soil conservation in rural watersheds in Brazil. *Land Use Policy* **2017**, *66*, 61–71. [CrossRef]
- 34. Valera, C.A.; Pissarra, T.C.T.; Martins Filho, M.V.; Valle Júnior, R.F.; Oliveira, C.F.; Moura, J.P.; Sanches Fernandes, L.F.; Pacheco, F.A.L. The Buffer Capacity of Riparian Vegetation to Control Water Quality in Anthropogenic Catchments from a Legally Protected Area: A Critical View over the Brazilian New Forest Code. *Water* **2019**, *11*, 549. [CrossRef]



© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).