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LOW COST POTENTIAL INFILTRATION ESTIMATION FOR WET TROPICAL WATERSHEDS FOR TERRITORIAL PLANNING SUPPORT

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Abstract: This study was developed at Caçula stream watershed of Ilha Solteira (Brazil) for potential infiltration estimation based on digital cartography. These methods aim at low-cost and quick analysis processes in order to support the territorial planning. The preliminary potential infiltration chart was produced using ArcHydro and pedological information of the study area. The curve-number method (Soil Conservation Service) was used to determine the potential infiltration combining information related to land-use and soil types in the watershed. We also used a methodology that assumes being possible to evaluate potential infiltration of a watershed combining average annual rainfall, land-use and watershed natural attributes (geomorphology, geology and pedology). Results show that ArcHydro is efficient for a preliminary characterization because it shows flow accumulation areas, allowing higher potential of degradation areas in terms of floods, mass movement and erosion. As land-use classes have significant weight in Soil Conservation Service method assessing potential infiltration, this method allow us to evaluate how land-use changes affect water dynamic in the watershed. The propose based on natural environment attributes enables to determine the homologous infiltration areas based on a higher number of natural characteristics of the area, and thereby obtain a result that is closer to the local conditions and, consequently for degradation surface processes identification.

Keywords: Potential infiltration; surface processes and degradation dynamics; territorial planning; São José dos Dourados UGRHI

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INTRODUCTION

Water infiltration process is an essential component in watersheds environmental dynamics and its function is related to a large number of natural environment attributes (like climate, soil, rocks, and relief) and land use/cover (Soares *et al.*, 2012).

In tropical wet climates, where soil exhibits thick homogeneous profiles, the relationship between soil properties and land use/cover are dominant in water infiltration changes and can govern significant environment degradation processes, as for instance erosion (Meeuwig, 1970; Neris *et al.*, 2012).

Changing in land use/cover patterns, such as urbanization, affect the hydrological processes once reduces natural permeability and causes soil structure disruption, restricting water infiltration, creating impervious areas, and promoting large runoff, flood and erosion, compromising water quality (Du *et al.*, 2012; Suriya & Mudga, 2012).

Establishing the relationship between land use/cover and water management of watersheds should support data to proper watershed planning, reducing degradation processes and allowing adjustments in land use policies for the sustainable development, minimizing peak flows and reducing water deficit in dry periods (Wang, 2001; Rufino *et al.*, 2009; Grindlay *et al.*, 2011; Gyawali *et al.*, 2013).

The study of processes causing environmental degradation in watersheds implies detailed surveys and analysis in order to ensure reliable natural environment characterization, which usually means costly and time consuming procedures. Culshaw & Price (2011) emphasize the advantages of a knowledge-based approach for development, recovery, and conservation of watersheds, highlighting that the benefits of this approach. This situation is more significant in wet tropical areas, where thick porous homogeneous soil profiles occurrence demands large financial resources for its characterization.

As an alternative approach for this situation, this paper proposes low cost and quick methods for potential infiltration estimation using ArcMap GIS (ESRI, 2010) ArcHydro toolbox for preliminary infiltration potential characterization; and the combination of curve-number method (USDA, 1972) with land use/cover and soil classes according to Soares *et al.* (2012), from natural environment data, land use/cover analysis, and rainfall data interaction. To test such procedures we select the Caçula Stream watershed.

Caçula watershed is located in Ilha Solteira (Brazil), in São Paulo State northwest region (**Fig. 1**), composing one of the small river basins which flow into Ilha Solteira Dam reservoir in São Paulo State Water Resources Management Unit #18 (SIGRH, 2012).

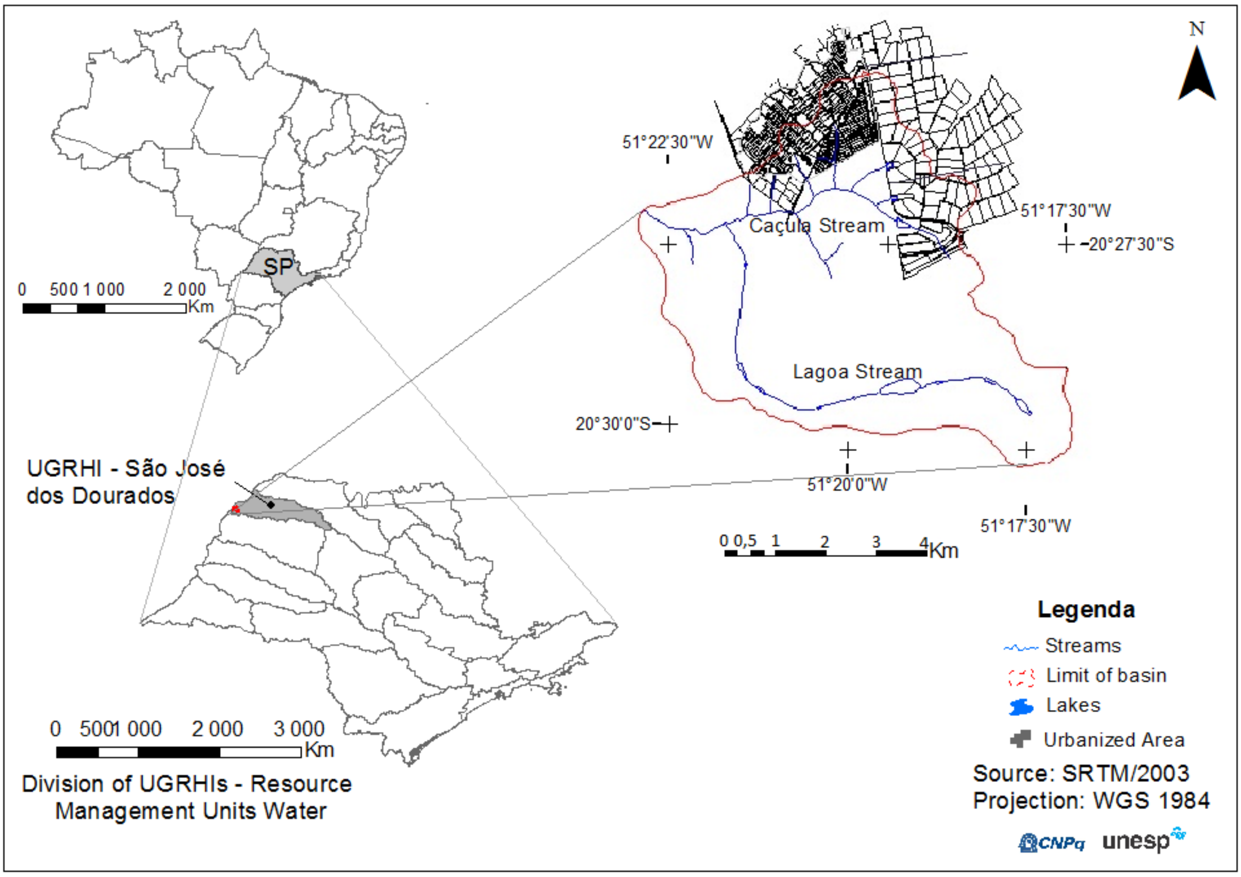

Fig. 1 Caçula Stream Watershed location (Santos, 2014).

Ilha Solteira urban expansion in Caçula Watershed and previously livestock activities substitution results soil degradation processes (erosion mostly). According to Tavares (2008), Ilha Solteira area predominant land use was livestock activities (almost 87% of the municipal area). Santos and Hernandez (2013) describes the recent expansion of ethanol industry and sugarcane cultivation as the main responsible by Caçula watershed new dynamics of the water conditions.

According to Santos and Hernandez (2013) the streams are practically devoid of riparian forest, and the main land cover is represented by agriculture and pastures. The presence of cattle in PPAs (Permanent Preservation Areas) inhibits the development of tree buds and nutrient cycling and accelerates soil degradation processes due to compaction, affecting water resources quality.

Studying a Caçula stream watershed tributary located in urban part of watershed, Gonzaga *et al.* (2010) identifies water quality degradation related to erosion in watershed hills and urban drainage system runoff. Authors also identifies riparian vegetation absence in Permanent Preservation Areas (PPAs), contributing to water quality degradation and which get worse with urban use increasing.

Ilha Solteira City Hall developed projects to improve environmental quality of this watershed including local erosion control projects like terracing and restoration of riparian vegetation (PMIS, 2012). However, its projects doesn’t present the expected results simply because haven’t consider properly natural environment attributes, like geological, geomorphological and hydrological conditions. Caçula Stream watershed area includes a significant part of Ilha Solteira urban area and urban expansion areas (highlighted area in **Fig. 1**)making this area most vulnerable to environmental problems.

METHODOLOGICAL PROCEDURES

Preliminary infiltration potential obtained from ArcHydro

The preliminary characterization of potential infiltration used ArcHydro (ESRI, 2009) a computer toolbox (available at http://support.esri.com) operating in ArcMap GIS (ESRI, 2010). ArcHydro was used to extract and treat data that describe drainage net for studied watershed.

A raster analysis was performed to determine flow direction, flow accumulation, drainage definition and watershed delimitation, allowing hydrological modeling. ArcHydro also allows watersheds geometric such area, length and steepness for the main water course.

Data was processed from Digital Elevation Model (DEM) from SRTM (Shuttle Radar Topographic Mission) data, resulting watershed surface drainage. Other results (flow direction, flow accumulation, watershed delineation and extraction of the drainage network) where obtained from DEM processing. The procedures where summed in Czekanski and McKinney (2006), adapted by Collischonn *et al.* (2009), and can be thus explained as follows.

Flow Direction was obtained from SRTM elevation cells values, considering the sinks (Fill Sinks) in DEM and flow direction was obtained for each cell based on 8 neighbor cells, assumed that water flows from one to neighbor according steepest ascending path rule (flow direction in smallest elevation neighbor cell), as shown in **Fig. 2**.

Flow accumulation was obtained from flow direction results and represents the number of cells that drain to each input flow direction DEM cell. In ArcHydro, flow accumulation was generated using the function *“Terrain*

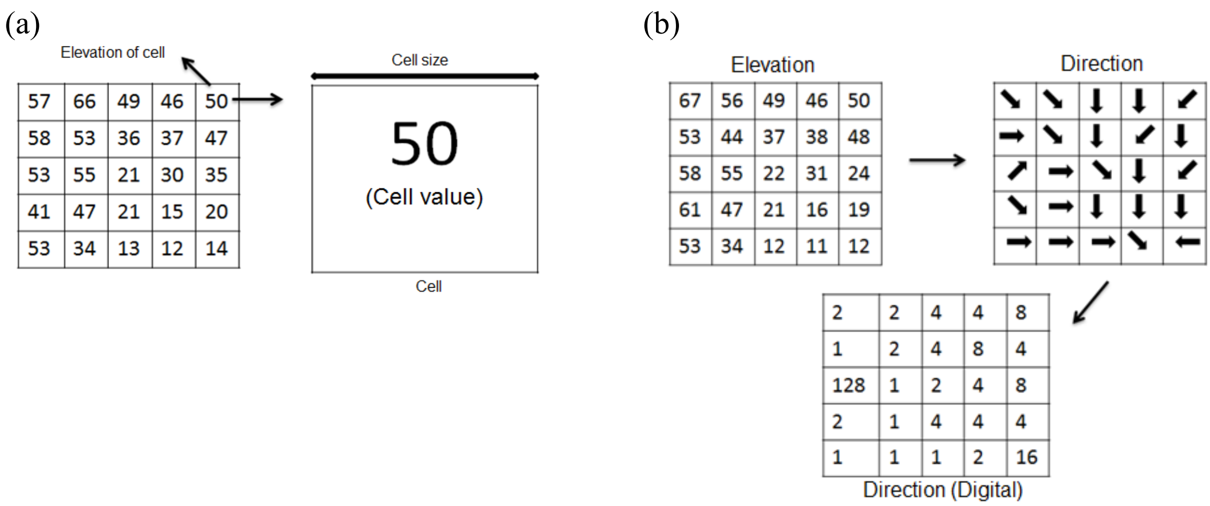

Fig. 2 Flow Direction obtaining: (a) Schematic DEM; (b) Flow directions grid (Czekanski and McKinney, 2006).

Table 1. CN values for rural areas (related to soil classes A to D)

Land Use	Surface	A	B	C	D
Plowed Soil	With rectilinear ruts	77	86	91	94
	In straight rows	70	80	87	90
Regular Plantations	At levels curves	67	77	83	87
	Terracing level	64	76	84	88
	In straight rows	64	76	84	88
Plantations of Cereals	At levels curves	62	74	82	85
	Terracing level	60	71	79	82
	In straight rows	62	75	83	87
Plantations of vegetables or grown	At levels curves	60	72	81	84
	Terracing level	57	70	78	89
	Poor	68	79	86	89
	Normal	49	69	79	94
	Good	39	61	74	80
Pasture along contour lines	Poor	47	67	81	88
	Normal	25	59	75	83
	Good	6	35	70	79
Permanent Camps	Normal	30	58	71	78
	Sparse, low transpiration	45	66	77	83
	Normal	36	60	73	79
	Dense, high transpiration	25	55	70	77
Farms dirt roads	Normal	56	75	86	91
	Bad	72	82	87	89
	Hard surface	74	84	90	92
Forest	Very sparse, low transpiration	56	75	86	91
	Sparse	46	68	78	84
	Dense, high transpiration	26	52	62	69
	Normal	36	60	70	76

Preprocessing/Flow". Thus, at the end of the processing the flow accumulation values are obtained for each cell. Higher value represents cells with high flow accumulation concentration, i.e. possible drainage channels.

Once flow direction and flow accumulation automated were obtained from DEM, drainage network can be obtained applying a threshold to flow accumulation. This threshold classifies all flow accumulation cells as zero (below threshold) or 1 (greater than threshold). The appropriate threshold matches the flow accumulation value that represents an average drainage channel, and using *"Stream Network"*, the drainage network can be defined.

The delimitation of the watershed is performed using *"Watershed Processing / Batch Subwatershed Delineation"* function, once user defines the point that represents main channel outfall of the basin, as the origin of watershed delineation.

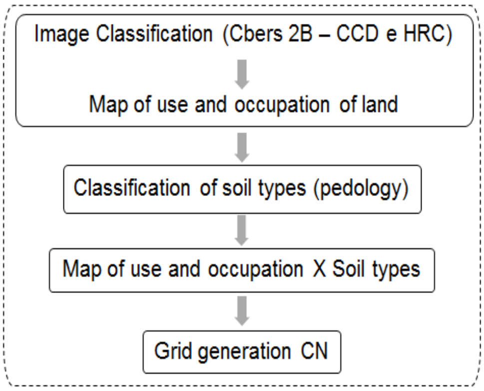

Fig. 3 Processes to obtain the CN (SANTOS, 2014).

Table 2. CN values for urban and suburban watersheds (related to soil classes A to D)

Land Use Description		Soil Type A	B	C	D
Open spaces					
• Thickets or grass covers 75% or more of the area		39	61	74	80
• Thickets cover 50% to 75% of the area		49	69	79	77
Commercial areas (85% impervious)		89	92	94	95
Industrial districts (72% impervious)		81	88	91	93
Residential areas					
Lot size (m²)	Impervious area (%)				
<500	65	77	85	90	92
1000	38	61	75	83	87
1300	30	57	72	81	86
2000	25	54	70	80	85
4000	20	51	68	79	84
Parks and parking lots, roofs, viaducts		98	98	98	98
Streets and roads					
• Asphalt and storm drainage		98	98	98	98
• Cobbled		76	85	89	91
• Ground		72	82	87	89

Infiltration potential from Soil Conservation Service (SCS) method

Potential infiltration map based on the curve-number method describes potential surface runoff and potential infiltration based on land-use / occupation and soil existing in the area, using the CN parameter (USDA-SCS, 1972).

CN parameter varies from very permeable cover (value 0) to a completely waterproof cover (value 100), and its determination from digital processing demands cross-referencing land-use and soil information. **Tables 1–2** present typical CN values for urban and rural areas, according to soil classes in **Table 3**. **Figure 3** shows digital operations in obtaining the CN.

Table 3. Soil hydrologic groups (soil properties and management conditions)

Group	Soil types and conditions of use
A	Sandy soils with low content of clay, less than 8%, with no rock or clay layers, and even densified to a depth of 1.5 m. The humus content is very low not reaching 1%.
B	Less deep sandy soils than Group A, and less content of clay, but still less than 15%. No rocks and clay layers up to 1.5 m, often more densified subsurface layer than surface layer.
C	Loamy soils, total clay from 20 to 30%, impenetrable clay or rocks layer less to 1.2 m deep. In purple soils, these limits may be 40% and 1.5m. About 60 cm deep layer more densified than Group B, but far from impenetrable conditions.
D	Clay soils (30 - 40% clay) with 50 cm deep densified layer. Sandy soils as Group B presenting almost impenetrable clay layer, or pebbles horizons.

The next needed step is to obtain S parameter, which represents the maximum storage capacity of the soil (mm), and can be obtained using the CN values by applying **Eq. (1)**.

$$CN = \frac{1000}{10 + \frac{S}{25,4}} \qquad (1)$$

Surface runoff determination required determining the monthly average rainfall over the watershed. Using monthly average precipitation in a 20-year time series data from UNESP weather station of Ilha Solteira (171 mm/month) in **Eq. (2)** we obtain runoff and potential infiltration, once relationship between runoff values and the monthly average rainfall is defined from **Eq. (3)**.

$$Q = \frac{(P - 0,2)^2}{P + 0,8S}, P > 0,2S \qquad (2)$$

where: Q = direct runoff (mm); P = total accumulated precipitation (mm); S = maximum storage capacity of the soil (mm):

$$I = P - E \qquad (3)$$

where: I = infiltration (mm/month); P = monthly rainfall average (mm/month); and E = surface runoff (mm/month). The data were processed with the ArcGis 10.0, such as the calculations involved in this process. **Table 4** shows the CN values obtained from these processes application.

Infiltration potential from Soares *et al.* (2012) method

Soares *et al.* (2012) proposes a methodology to map potential infiltration based on the assumption that its evaluation can be obtained from natural environment attributes and land-use information. Thus, potential infiltration was classified from average annual rainfall, land-use, geomorphological, geological and pedological information, with algebra map operation as showed in **Fig. 4**.

Considering Caçula stream watershed small dimensions (56.3 km^2) and precipitation data from weather station in the area, precipitation was considered homogeneous in the watershed. Pedological, geological,

Table 4. CN values obtained for Caçula stream watershed

Class	CN		S (mm/month)		Runoff (mm/ month)		Infiltration (mm/ month)	
	Group B PVA	Group C LV	Group B PVA	Group C LV	Group B PVA	Group C LV	Group B PVA	Group C LV
Agriculture	76	84	76	52	104,72	121,32	66,28	49,68
Water	100	100	0	0	171	171	0	0
Asphalt	98	98	5	5	165,14	165,14	5,86	5,86
Forest and natural vegetation	68	78	119	72	81,4	107,28	89,6	63,72
Pasture	67	75	125	60	78,66	115,44	92,34	55,56
Preparation for planting and exposed soil	67	81	63	38	113,33	132,57	57,67	38,43
Roofing	98	98	5	5	165,14	165,14	5,86	5,86

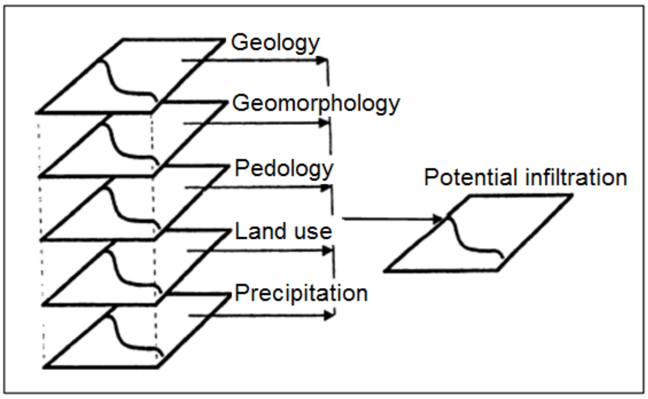

Fig. 4 Integration of attributes to generate the potential infiltration chart (Soares *et al.*, 2012)

and geomorphological data were obtained from previous studies in the area (CINDIRU, 1995; Lollo, 1998; Cruz, 2008; Tavares, 2008).

Land-use was classified from composed CBERS satellite images (CCD and HRC images fusion) treatment and classification, composing a synthetic image with 2,7m spatial resolution using a supervised process (Maximum Likelihood) in seven land-use classes: agriculture, asphalt, forest and natural vegetation, pasture, preparation for planting and exposed soil, roofing, and lakes. **Figure 5** presents Caçula watershed pedological, geological, geomorphological, and land-use maps.

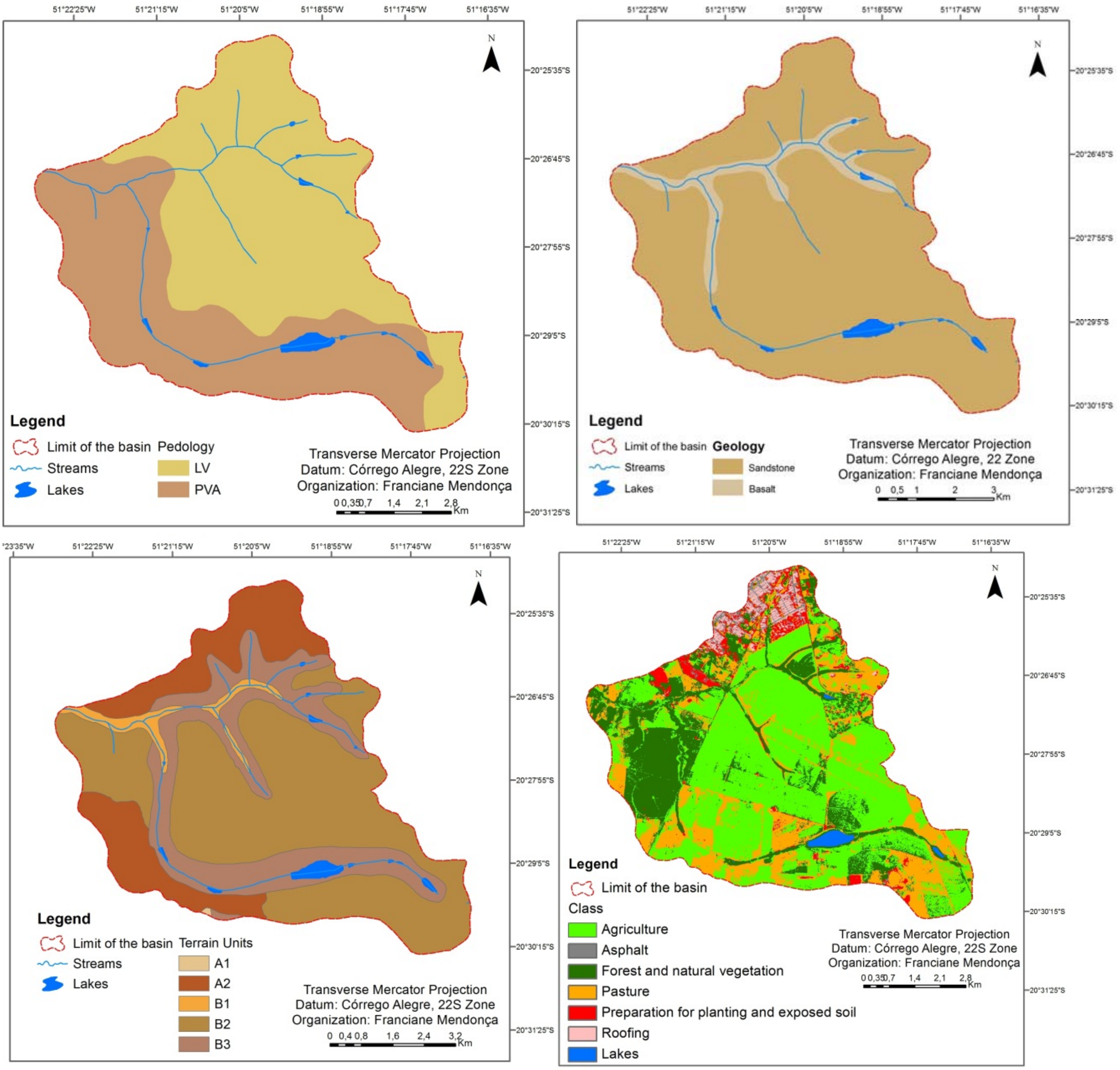

Fig. 5 Attributes used for Soares *et al.* (2012) method: (a) Pedological, (b) Geological, (c) Land units (relief), and (d) Land-use.

Table 5. Attributes classification for potential infiltration in Soares *et al.* (2012) method

Attributes	**←←←← Infiltration potential**					
Geology	Sandstone - porous structure, bigger permeability. 4		Basalt - compact structure, high cohesion, small permeability. 2			
Geomorphology	convex flat hills (B2) 5	convex wavy hills (A2) 5	smooth valleys (B3) 2	steep small valleys (A1) 2	broad valleys (B1) 1	
Pedology	PVA - well-drained and deep profiles, more permeable. 4		LV - usually deep, homogeneous, restricted permeability and slow water infiltration. 2			
Land use	Forest and natural vegetation 5	Agriculture 4	Pasture 3	Preparation for planting and exposed soil 2	Asphalt 1	Roofing 1
Precipitation	Homogeneous in Caçula watershed					

The soil classes identified in the study area consist of LV soils - Red-yellow Latosol and PVA - Red-yellow Argisol (Embrapa, 2006). The geological unit's presents in Caçula watershed are tholeiitic basalts from Serra Geral Formation and fine to coarse sandstones from Santa Anastácio Formation. Relief units are composed by round to flat hills and varied valleys, with bigger or lesser steepness and extension according parental lithology classes.

A value is assigned to each element, within a 1 (very low) to 5 (very high) concerning its infiltration potential, according to its influence on the infiltration process. The sum and classification of attributes combining was developed in ArcGis 10.0 considering the weights for each class of attribute, as shown in **Table 5**

RESULTS AND DISCUSSION

Preliminary potential infiltration chart

The accumulated flow chart generated from the ArcHydro shows the runoff flow accumulation without consider hydrologic data. Flow accumulation indicates saturation areas, where the relief conditions tend concentrate flows during precipitation resulting higher potential infiltration. The integration of this flow accumulation map with the pedological map of the study area, allows relating this information to the potential infiltration, generating the preliminary infiltration map (**Fig. 6**).

Preliminary potential infiltration map shows the influence of PVA soil class increasing potential infiltration in the basin. This result is a consequence of PVA physical characteristics (deep or very deep profile, well drained, medium texture and high to very high total porosity), which combined with highest concentration of flow accumulation in south area of Caçula watershed, results high potential infiltration in this area.

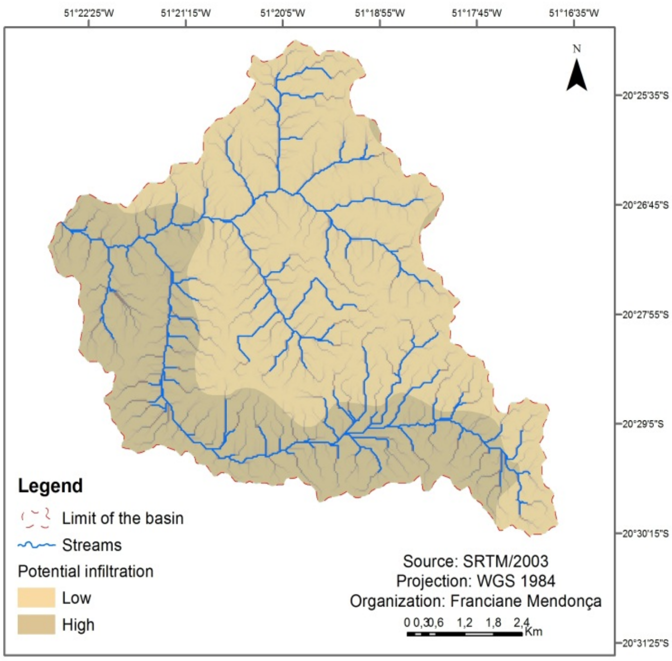

Fig. 6 Preliminary potential infiltration chart.

Potential infiltration chart from SCS method

This potential infiltration map (**Fig. 7**) allows estimating maximum soil-water potential infiltration of the watershed from Curve Number parameter. Result indicates strong influence of soil classes in obtained infiltration potential.

In this potential infiltration chart, the results express land-use classification associated soil profiles in the area. Areas with asphalt and roof classes (typical urban areas) CN values were high, and related to greater runoff rate (varying from 132.58 to 171 mm/month), and the lowest infiltration values (0 to 5.86 mm/month).

Instead, areas with predominant vegetation presents the lowest CN values (lower runoff rates, i.e. 81.41 to 121.32 mm/month), thereafter, higher potential infiltration values (66.29 to 92.34 mm/month). As land-use has great influence in runoff and infiltration dynamics in the watershed, SCS method enrich this attribute. Thus monitor land-use changes with time and using SCS method can be an excellent strategy for preventing environmental degradation like erosion and silting, while also preventing the occupation of areas which are prone to flooding.

Potential infiltration chart from Soares method

The potential infiltration map resulted from Soares *et al.* (2012) method application (**Fig. 8**) express areas with homologous physical characteristics influencing the infiltration process. The procedures for implementing this methodology assume that it is possible to identify and assess the infiltration potential in a watershed through the interaction of data related to rainfall, physical environment elements and land-use and occupation data.

The obtained results clearly reflect the used natural attributes and land-use classification. High potential infiltration areas are mainly concentrated in the southern region of the watershed due to PVA soil presence combined with more flat land units (A2, B2 and B3) which favors infiltration. These areas also have large sections covered by perennial and temporary agriculture and forests and natural vegetation, land-use classes that favor infiltration process.

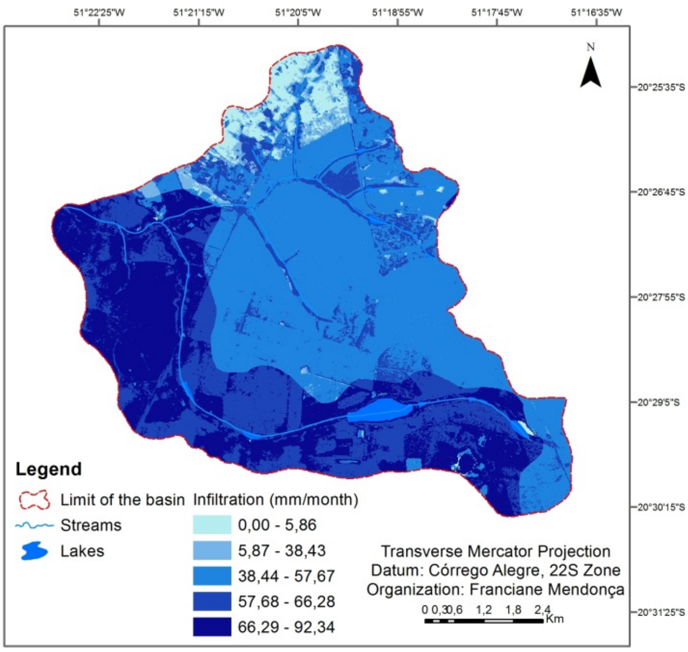

Fig. 7 Potential infiltration chart from SCS.

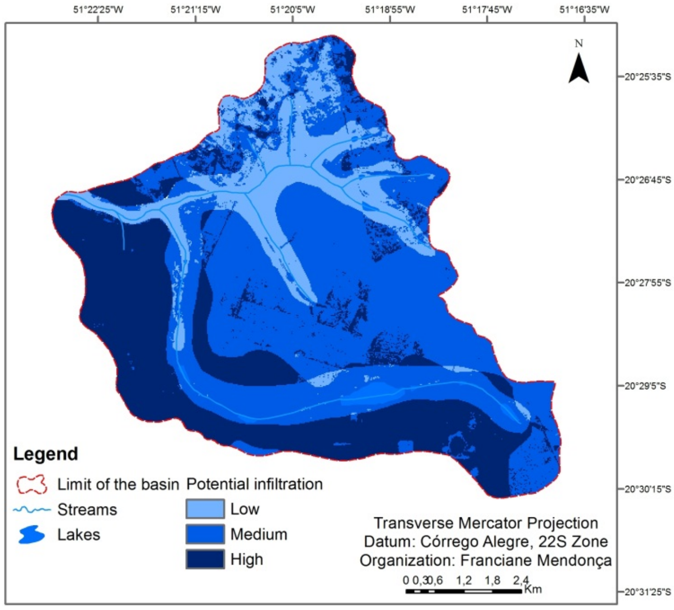

Fig. 8 Potential infiltration chart according Soares *et al.* (2012).

Bottom valley results low potential infiltration due to geologic conditions (basalt) and thin soil profiles. Low potential infiltration areas also occur in the northern part of the watershed, which has the urbanized area, with emphasis on roofs and asphalt.

CONCLUSIONS

Due to its efficient representation of flow accumulation areas, ArcHydro a good option for a preliminary characterization, once allows higher potential of environmental degradation areas related to floods erosion.

Soil Conservation Service method assessing potential infiltration can be very useful in discussing how land-use changes affect water dynamic in the watershed, since land-use classes have significant weight in its process.

As Soares *et al.* (2012) uses watershed natural attributes associated with precipitation and land-use, it can be very efficient in represent more realistic local results and provides the advantage of allows the effect of natural attributes changes in the water dynamics in the watershed, compared with SCS method. Thus, this method can be very useful in more detailed studies focusing intervention choices.

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