ANALYSIS OF THE URBANISATION EFFECTS ON THE INCREASE OF FLOOD SUSCEPTIBILITY IN COASTAL AREAS

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Abstract
The unplanned urbanisation causes severe environmental, economic and social impacts to a region and its surroundings. Without providing adequate infrastructure, peri-urban areas might turn into dispersing and disorganised urban sprawls. The concept of sustainability already confirms the need of integrated urban and water resources management. For that, policymakers and planners need to be aware of the impacts caused by land use and land cover changes while urbanising a region. Remote sensing techniques and GIS frameworks provide tools to process and achieve data in a less expensive, time-efficient and accurate way. In addition, hydrological models simulate the effects of different land use change scenarios on the basin runoff or discharge. For such assessment, the runoff curve number method is widely used due to requiring a few parameters, such as land use and land cover classes and hydrological soil groups. However, for the determination of hydrological soil groups, the saturated hydraulic conductivity data is not always available in weathered soils like the ones located in Brazil. In the study, the method used for the hydrological soil group acquisition was based on the local physical and mineralogical properties, more suitable for the regional conditions and available data. This paper presents the final assessment results showing the most flood-susceptible areas of Juqueriquere River Basin due to land use and land cover changes predicted by the City Master Plan development.
Keywords:Land use and land cover changes, urbanisation, flood susceptibility, Curve Number, GIS.

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1. INTRODUCTION

Urban expansions are modifications to the rural/natural areas as a result of the population growth and infrastructure development (Palen 1975). It causes direct and indirect impacts to the area and its surroundings, such as vegetation destruction, floods and climate change (Grimm et al. 2008, Ramachandra et al. 2013, Boulomytis et al 2015). The dynamics of the urban-rural transition area is associated with the pressure it suffers from the urban development and the way it stimulates real estate speculation (Quevedo Neto & Lombardo 2006).

For the appropriate urban planning and development of an area, it is necessary to predetermine its potential land use and land cover (LULC) changes in a spatial-temporal scale (Patel & Rawat 2015, Ilchenko & Lisogor 2016). When the urbanisation process is unplanned, a dispersive growth in peri-urban areas may occur, which is usually called urban sprawl. It leads to a higher use of land without the necessary amenities, making it a disordered conglomeration (Sudhira et al. 2004, Ramachandra et al 2013).

Remote sensing techniques and GIS frameworks are extensively being used for urban assessment as they provide appropriate tools to store, process and analyse digital data from different sources in spatial-temporal bases (Boulomytis et al. 2015, Ilchenko & Lisogor 2016). Reliable data with diverse spatial, spectral and temporal resolutions are economically provided to the city planners to qualify and quantify impacts of LULC changes for city planners (Jensen & Cowen 1999, Ramachandra et al. 2013). Customised internet-based GIS systems have also become popular for the low budget expenses and friendly frameworks and sometimes, not having to be installed but just operated online (Masron et al. 2015).

Water resources management and urban planning are entirely correlated (Ioris et al. 2008, Wang et al. 2008). The sustainable development of a region depends on its integrated water management through suitable policy-making and planning strategies (Simonovic 1996, Boulomytis et al. 2015). These strategies are often not fruitful when there is a lack of reliable information about qualitative and quantitative aspects of water resources. Hydrological and hydraulic modelling are being used for data achievement and also for the prediction of different land use and climate change scenarios (Fohrer et al. 2001, Krysanova et al. 2005, Wang et al. 2008).

The Runoff Curve Number (CN) method has been widely used in hydrological models due to the very few parameters necessary for its determination (Arnold & Williams 1995). It estimates runoff from rainstorms with the association of Hydrologic Soil Groups (HSG) and LULC types, and varies from 1 to 100 (the most impervious condition).

The HSGs are classified from the lowest (type A) to the highest (type D) runoff potentiality. The CN is determined using the normal or average Antecedent Runoff Condition (ARC II) (previously referred as Antecedent Moisture Condition - AMC). It is based on the accumulated rainfall of the previous 5 days and can be converted to the dry (ARC I) or wet condition (ARC III) (United States Department of Agriculture - USDA 1986) as presented in Table 1.

TABLE 1 - RAINFALL GROUPS FOR ANTECEDENT RUNOFF CONDITION.

ARC	Total of 5-day accumulated rainfall (mm)	
	Growing Season	Dormant Season
I (dry)	< 35	< 12
II (average)	35 to 53	12 to 28
III (wet)	> 53	> 28

Where:

$$RCN(I) = \frac{4.2RCN(II)}{10 - 0.058RCN(II)} \qquad RCN(III) = \frac{23RCN(II)}{10 + 0.13RCN(II)}$$

The CN method was developed by the US Soil Conservation Service in the 50s (Soil Conservation Service – SCS 1964) based on the soil texture. However, it did not specify objective criteria, mainly the application outside the USA. The saturated hydraulic conductivity was then included in the revised edition (Natural Resources Conservation Service - NRCS 2007), making it a less subjective approach; but still, these data are expensive and time-consuming and because of this, they are not frequently available in many countries like Brazil. which have highly weathered soils (Sartori et al. 2009). Sartori et al. (2009) proposed a method based on the physical and mineralogical properties published in the Brazilian Soil Survey Manual (Brazilian Agricultural Research Corporation - EMBRAPA 2006) to create new HSGs. By the use of this approach after determining the HSGs (Sartori et al. 2009) and the LULC types, the CN values can be calculated or determined by the USDA (1986) tables.

This paper presents determinations of CN values for the comparison between the present and future LULC scenarios and predicts the impact caused by LULC changes towards the increase in flood susceptibility.

2. STUDY AREA

The study area is Juqueriquere River Basin, in the municipality of Caraguatatuba, located along the northern coastline of São Paulo, Brazil, lies between latitudes 23o 33’S and 23o 49’S and longitudes 45o 43’W and 45o 24’W (Figure 1).

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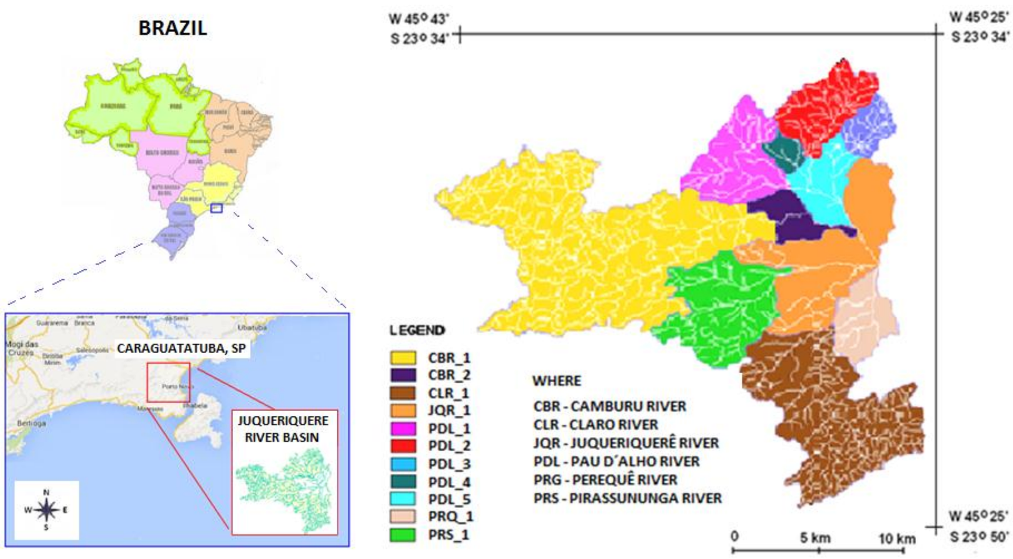

FIGURE 1 - STUDY AREA (SOURCE: ADAPTED FROM BOULOMYTIS ET AL. 2017).

The weather is tropical and rainy, with an undefined dry season and heavy rainfall in the summer (average annual temperature of 25o C and precipitation of 1784 mm). Between Serra do Mar Mountains and the ocean, it is influenced by high tide and at the same time, one of the rainiest areas of Brazil, contributing to the occurrences of frequent floods. When air reaches near the hill slopes, it also experiences a higher amount of orographic precipitation.

Juqueriquere River Basin exhibits the largest non-urbanised plains among the 34 basins. Its area and length are 419.36 km² and 135.25 km respectively, with the most representative discharge from all the basins, corresponding to 2,79 m³/s. It is also the only basin in the 7th Strahler order, with a minimum 3rd order restriction to flood and inundations and a morphometric susceptibility to floods (Souza 2005).

In this region, several mega projects have been implemented in the last decade concerning the petrol exploration, São Sebastiao Port Expansion and Tamoios driveway complex. Among the petrol exploration projects, the plant of UTGCA (Gas Treatment Unit of Caraguatatuba) has already been built constructed in the plains of Juqueriquere River Basin.

3. MATERIALS AND METHODS

For the determination of the CN parameter, each methodological step used is outlined in Figure 2, including the hydrologic soil group approach and the LULC data processing of the present and future scenarios, based on the City Master Plan of Caraguatatuba Municipality (Caraguatatuba City Council - CCC 2011).

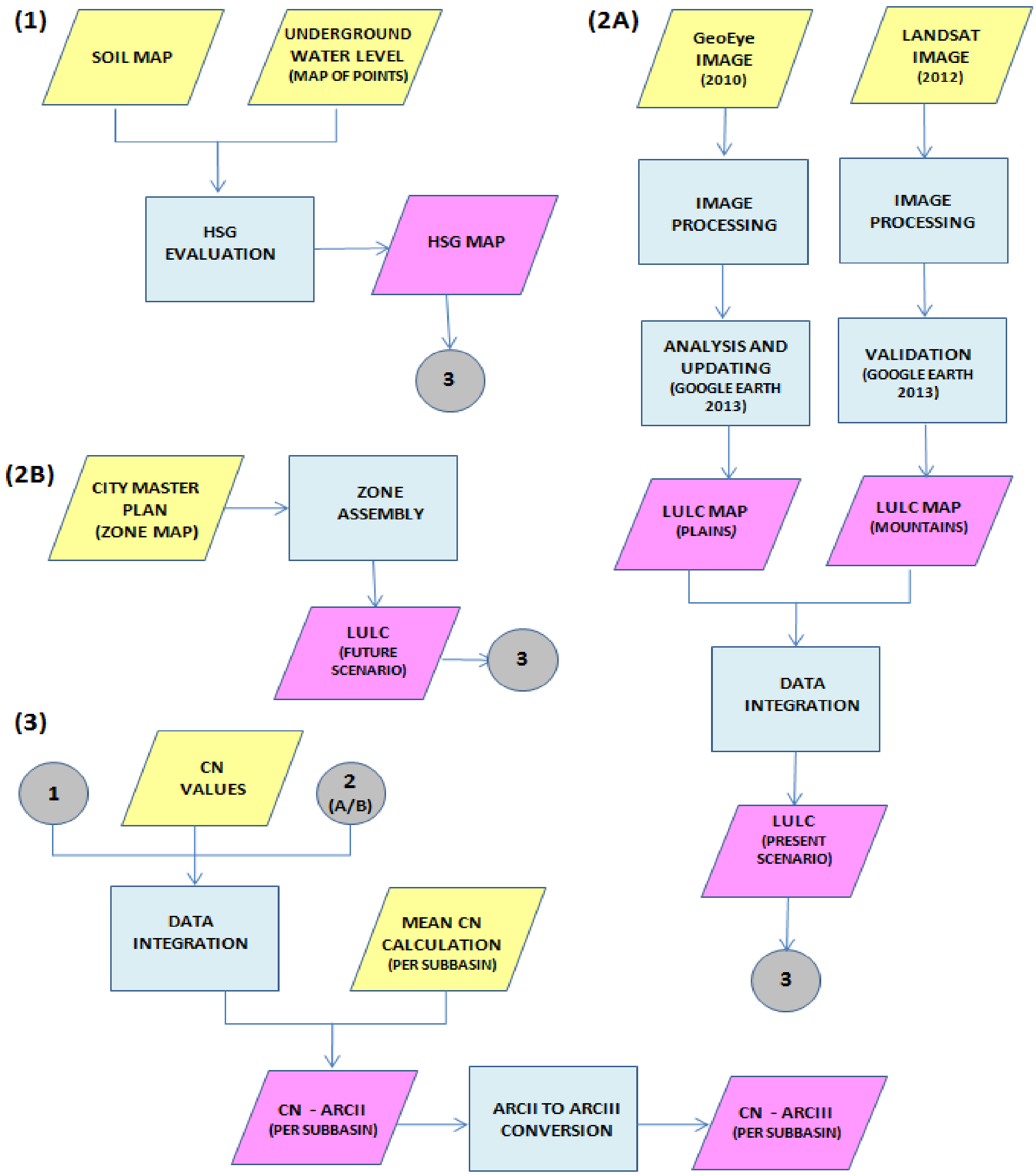

FIGURE 2 - FLOWCHART OF THE CN ATTRIBUTION FOR BOTH SCENARIOS.

The hydrologic soil group was classified according to the criteria proposed by Sartori (2010) (Figure 2, part 1), taking into consideration the soil classification of the study area (EMBRAPA 2006) shown in Figure 3.

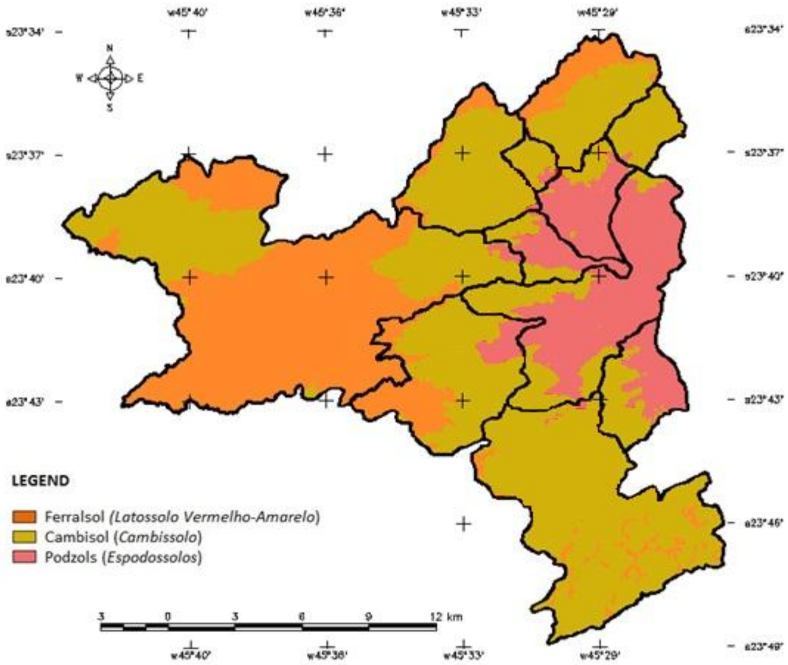

FIGURE 3 - SOIL CLASSIFICATION MAP OF THE STUDY AREA.

Some geotechnical survey sampling data of water table levels (Brazilian Petrol - PETROBRAS 2007, Waterloo Brazil Environmental Consulting - WBEC 2009) were also used for the consideration of inference on the HSG (Sartori et al. 2009). The samples were located at the UTGCA, between the Camburu and the Pau d'Alho rivers, and along the stretch of the tunnel which will be constructed between the UTGCA and the Sao Sebastiao Port.

All the map crossing procedures were done at the GIS software SPRING v. 5.1.8 (Camara et al. 1996) for the acquisition of the hydrologic soil group thematic map.

For the present LULC assessment, we used the following imagery: 1) the high-resolution GeoEye image (datum UTM/SAD69, zone 23S, achieved on 30/04/2010) for the urban and semi-urban plains; 2) the Landsat 7 ETM+ image (orbit 218, point 76, achieved on 01/10/2012) for the mountainous areas. This procedure was necessary as the high-resolution image covered only part of the study area.

The GeoEye image was segmented and classified using the GIS software SPRING v. 5.1.8 (Camara et al. 1996). We used the growing regions technique for the image segmentation with a similarity level of 5 pixels and the minimum area comprised 30 pixels. At least 20 samples were selected for each class in the training step and later analysed. After the extraction of regions, the image was classified by the use of Bhattacharyya distance (Bhattacharyya 1943), widely applied for pattern recognition, within an acceptance threshold of 95%. A thematic map was generated featuring the 2010 LULC of the urban and semi-urban areas (plains).

For the generation of the 2013 LULC thematic map, all classes obtained at the 2010 map were updated. This procedure was done using the Google Earth imagery and visual interpretation. We overlaid the Google Earth image with the 2010 LULC map in a regular grid of 200 m, to facilitate the visual scanning and the assessment of LULC changes between 2010 and 2013.While updating the land use classification, the ARC of both 2010 and the 2013 images were compared and evaluated for the proper visual interpretation of the area.

For the segmentation of the Landsat 7 ETM+ image, the similarity level was 5 pixels and the minimum area comprised 100 pixels, due to the homogeneity of the land cover in the conservation areas of Serra do Mar Mountains.

The statistical analysis for both the GeoEye and the Landsat 7 ETM+ imagery classification was done based on a confusion matrix and the kappa index (Congalton & Green 2009).

Finally, the achieved thematic maps were integrated using a standard mosaic GIS procedure, comprising both mountainous regions and plains (semi-urban areas).

For the future scenario (Figure 2, part 1B), the City Master Plan of Caraguatatuba Municipality (CCC 2011) was imported, registered and digitalized using vector editing tools at the GIS software SPRING v. 5.1.8 (Camara et al. 1996). The LULC features of each zone were analysed and assembled for the further attribution of the CN values.

For the attribution of the CN values (USDA 1986), the procedure was similar to both the current and the future scenarios (Figure 2, part 3). The map of the hydrologic soil group was integrated into the maps of LULC and discretised subbasins. The mean CN values were calculated and weighed according to the percentage of each LULC type in the subbasin area. The CN value was first evaluated taking into account the ARC II but was later converted to the wet condition (ARCIII) based on the accumulated rainfall of the previous 5 days. This third step was processed by the GIS software ArcGis v.10 (Environmental Systems Research Institute - ESRI 2011).

Finally, the CN value achieved in each subbasin was compared between the present and the future scenarios in order to evaluate the effects of the urbanisation process on the increase in flood susceptibility of the study area.

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4. RESULTS AND DISCUSSIONS

4.1. Hydrologic Soil Group Classification

The hydrologic soil group classification was based on (Sartori et al. 2009) approach, taking into consideration the weathered soils of Brazil and also their main hydraulic properties, such as the saturated hydraulic conductivity, which is not always available. The criteria proposed by (Sartori et al. 2009) is mainly based on soil texture, the presence of iron oxide, the level of the water table and restrictive layer.

The sampling data extends from the JQR_1 to the PRQ_1 subbasins along the tunnel site (PETROBRAS 2007) and are also located in the PDL_5 subbasin, at the UTGCA (WBEC 2009).

Along the tunnel site, there are 24 sample locations (ST-06 to ST-30). The water table levels found in the floodplains varied from 30 cm (ST-08) to 125 cm (ST-06).

At the UTGCA, 20 sample results were provided and the water table levels varied from 30 cm (PM-02) and 400 cm (PM-18). According to WBEC (2009), at the UTGCA, the area had been landfilled with layers comprising similar soils to the original ones. This probably occurred due to the mineral extraction alongside the Camburu River that used to be in the same location, and recently it occurs near 1 km upstream.

The pedological information (EMBRAPA 2006) and geotechnical survey sampling data of the water table levels (PETROBRAS 2007, WBEC 2009) provided the relevant physical properties for the hydrological group acquisition, described in Table 2.

TABLE 2 - PHYSICAL PROPERTIES FOR THE HSG ACQUISITION.

Soil	Relevant physical properties of the study area soil	HSG
Ferralsol	Moderate restrictive layer between 50 and 100 cm; medium clayey or very clayey texture; highly weathered soil; medium to low presence of iron oxide.	B
Cambisol	No restrictive layer; medium or clayey texture with incipient Horizon B.	B
Podzol	Water table lower than 100cm for a short period of the year or permanently; saturated for a few days during the rainy season.	D

Nevertheless, the survey samples showed that the water table levels were shallower than 50 cm in the floodplains, providing the necessary data for the hydrological soil group acquisition of the Podzols, according to (Sartori et al. 2009).

4.2. Imagery classification for the present LULC scenario

For the present scenario, the LULC comprised the following thematic classes: water, agriculture, forest, pasture, bare soil, urban. The classes were designated taking into consideration their further CN attribution.

For updating the GeoEye image (achieved on 22/02/2010), the Google Earth imagery was composed of two scenes (achieved on 08/01/2013 and 03/03/2013), with the antecedent runoff conditions shown in Table 3.

TABLE 3 - ARC OF THE STUDY AREA WHEN THE IMAGERY WAS ACHIEVED

- Imagery	Acquisition Date	Accumulated Rainfall (5 Days)	ARC
GeoEye	22/02/2010	40	II
Google Earth (scene 1)	08/01/2013	33	I
Google Earth (scene 2)	03/03/2013	0	I

Due to a higher precipitation volume in the previous 5 days, some water ponds could be detected at the high-resolution GeoEye image, but could not be detected in the Google Earth images. As they were located in frequently flooded areas (Boulomytis et al. 2017), the water class was not modified after the visual interpretation evaluation process.

At the mineral extraction sites, the bare soils vary daily, so the classification remained the same and was not modified when compared with the Google Earth images.

The urban class was attributed to all the bare soil, agriculture and pasture classes that were classified as urban on the 2013 Google Earth images. Some bare soils in the 2010 images were classified as pasture in the 2013 Google images, as vegetation had been recovered in specific areas.

The average accuracy of the imagery classification was 82.50% and the kappa index was 0.78 (Table 4).

TABLE 4 - CONFUSION MATRIX AND KAPPA INDEX FOR THE ACCURACY EVALUATION.

Classes (LULC Map)		Classes (Reference Map)							Kappa Index
		WAT	AGR	FOR	PTR	BSL	URB	Total	
Water	WAT	3	0	0	0	0	0	3	1.0000
Agriculture	AGR	0	6	0	1	1	0	8	0.7345
Forest	FOR	3	0	27	1	0	0	31	0.8280
Pasture	PTR	0	1	2	27	2	1	33	0.7576
Bare Soil	BSL	2	0	1	1	26	1	31	0.7825
Urban	URB	2	0	0	0	2	10	14	0.6825
Total		10	7	30	30	31	12	120	0.7763

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According to Landis and Koch (1977), the quality of the classification process is considered very good when the kappa value is between 0.60 and 0.80 range. The LULC map for the present scenario is shown in Figure 4.

4.3 City Master Plan evaluation for the future LULC scenario

For the future scenario, we evaluated the City Master Plan of Caraguatatuba Municipality (CCC 2011) and assembled its zones into different clusters taking into account their association with the classes of the present scenario LULC map and the further attribution of the CN value (Figure 5).

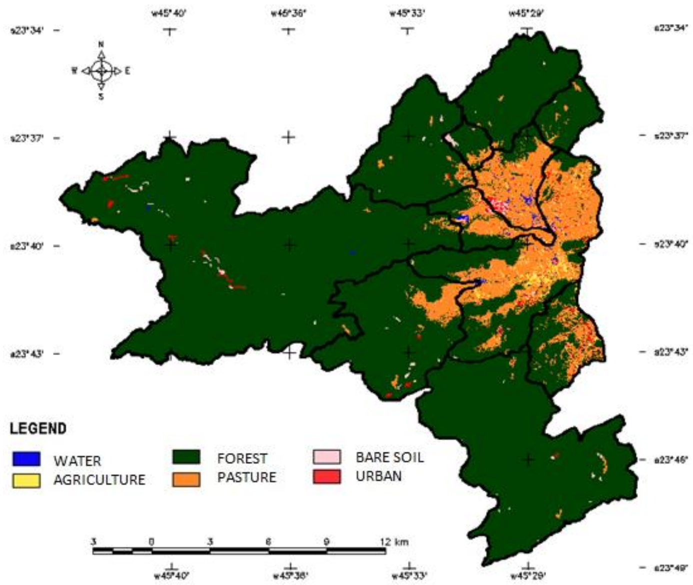

FIGURE 4 - LULC CLASSIFICATION MAP OF THE PRESENT SCENARIO.

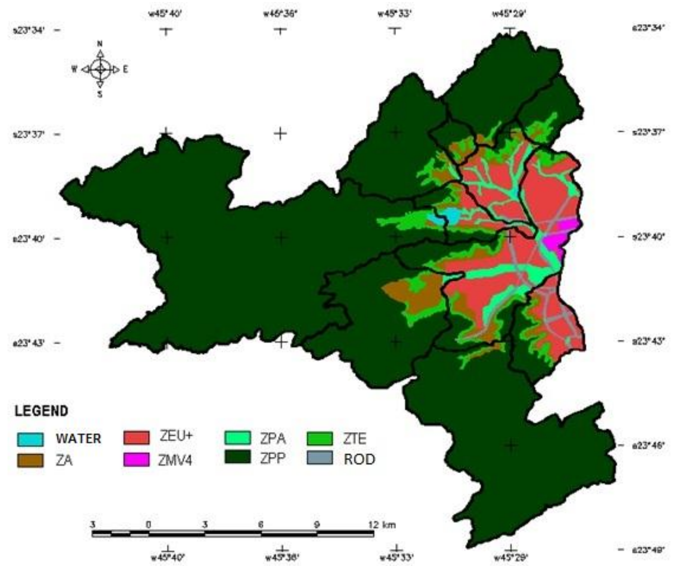

FIGURE 5 - LULC CLASSIFICATION MAP OF THE FUTURE SCENARIO.

The criteria established for this zone assembly was based on the USDA (1986) CN LULC patterns and the zone functionality predicted by the CCC (2011). The steps and sequence of this approach are listed as follows.

- At the Permanent Protection Zone (ZPP), there will be less LULC change, as it is located at Serra do Mar State Park and protected by law. Nothing has been mentioned at the CCC (2011) about urbanising this area. Thus, in this zone, it was assigned the same CN of the present scenario as forest class.
- At the Touristic Ecological Zone (ZTE), the most critical land use was taken into account. It is regarding the residential zone (RU3) or the flat condominium (RMH2) with parcels of land of 5,000 m², and 20% of them with construction sites or impervious areas. This percentage was used for the attribution of CN.
- At the Buffer Zone (ZA), the most critical condition was the straight row crops (agriculture class), increasing runoff and erosion towards the river.
- At the Environmental Protection Zone (ZPP), the woods might be protected from grazing, and the soil covered by litter and brush.
- The Logistic and Industrial Zone (ZLI), Urban Support Zone (ZSU), Industrial Strategy for the Proper Use of Petrol and Gas (ZIEPG), Mix Vertical Zone (ZMV-9) and Urban Expansion Zone (ZEU) were assembled to the ZEU+ cluster. The most critical scenario took into account the land use of industries and large companies. The calculated CN was based on the impervious area of 80%, which is predicted by the CCC (2011).
- At the Mix Vertical Zone (ZMVA) the most critical condition is 70% of the area being impervious.
- The ROD class was attributed to all driveways as prescribed by the CCC (2011).

4.4. CN value attribution

The CN values were attributed for both B and D HSGs of all classes, at the present and future scenarios (Table 5). The average CN was calculated for each subbasin. They were originally obtained for the ARC II and converted to the ARC III, for further studies (i.e. hydrological modelling) using the most critical condition for flooding (Table 6).

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TABLE 5 - ATTRIBUTED CN VALUES FOR THE PRESENT AND FUTURE LULC SCENARIOS.

Present Scenario LULCClasses	CN		Future Scenario LULC Classes	CN	
	HSG B	HSG D		HSG B	HSG D
			AGU	98	98
AGU	98	98	ZA	81	91
AGR	78	89	ZEU +	87	93
FLR	55	77	ZMV4	78	88
PTG	69	84	ZPA	73	86
SLE	82	89	ZPP	55	77
URB	86	94	ZTE	68	84
			ROD	98	98

TABLE 6 - AVERAGE CN VALUES OF EACH SUBBASIN IN THE PRESENT AND FUTURE LULC SCENARIOS.

Subbasin	ARC II		ARC III	
	Present LULC Scenario	Future LULC Scenario	Present LULC Scenario	Future LULC Scenario
CBR_1	55.41	55.46	74.08	74.11
CBR_2	72.92	78.63	86.10	89.43
JQR_1	75.02	83.26	87.35	91.96
PDL_1	55.89	56.82	74.45	75.16
PDL_2	55.16	55.67	73.89	74.28
PDL_3	56.00	58.21	74.54	76.21
PDL_4	60.76	64.67	78.08	80.80
PDL_5	79.02	86.12	89.65	93.45
PRQ_1	70.23	79.09	84.44	89.69
PRS_1	58.13	59.98	76.15	77.51
RCL_1	55.26	55.33	73.96	74.02

The CN values increased in all the subbasins for the future scenario, except CBR_1 and RCL_1, where there will be no urbanisation process according to the CCC (2011) (Figure 6).

The increase of the CN value in each subbasin implies that less water will infiltrate through the land surface, and subsequently more runoff over the surface (Hsu et al. 2000, Shuster et al. 2005). At the study area, the most significant changes are predicted to occur on the floodplains at the following subbasins: CBR_2, JQR_1, PDL-5 and PRQ_1.

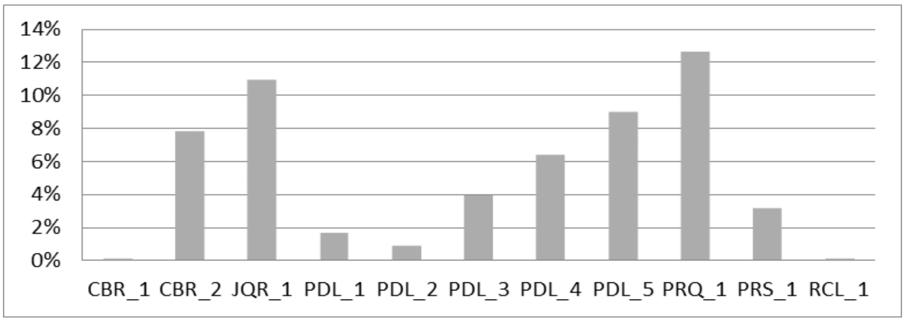

FIGURE 6 -CN VARIATION BETWEEN THE PRESENT AND THE FUTURE LULC SCENARIOS.

For the PRQ_1 subbasin, the CN value shows the largest percent increase of 12.6% under the future scenario. It was predicted that this subbasin will host several significant industrial developments. An expansion of the ZPA area could be done to increase the vegetation cover and thus, infiltration, reducing the potential increase in CN value. Additionally, alternative permeable paving materials could be used for an efficient drainage of the industrial and urban areas (Ball & Rankin 2010, Imran et al. 2013). When traditional paving is used, the CN value is 98 for the HSG of D class (USDA 1986), which is the case for the PRQ_1 subbasin.

In the JQR_1subbasin, the percent increase of the predicted CN value is 11.0%. The same land use entities of PRQ_1 subbasin are assigned to the JQR_1subbasin but on a larger scale. JQR_1 is the largest subbasin, comprising the most susceptible area to floods. Nonetheless, the drainage design should include permeable paving materials to the roads, parking lots and patios.

The UTGCA is located at the PDL_5 subbasin. In the future, the area will also be used for the industrial strategy of petrol and gas, similar to the CBR_2 subbasin, with an additional potentiality for the logistic development. Even though there are two water courses draining this area, Pau d'Alho and Camburu Rivers, the slope is mild. Runoff over the land brings sediments to the rivers. Significant amounts of sediments deposit on the river bed, reducing the effective flow area and eventually causing floods in the rainy season. This is a frequent problem in the JQR_1 subbasin, downstream of Claro River, between Pirassununga and upstream of Claro Rivers. Thus, this area needs control measures towards effective drainage and flood protection systems (Barros et al. 2008, Neal et al. 2012).

5. CONCLUSIONS

A composition of high and medium spatial resolution imagery resulted in a very good classification and acquisition of the present land use scenario map. Part of the validation process used free online imagery, proving that remote internet-based GIS systems may provide reliable results, where not all the data are available.

Sartori et al. (2009) approach was also found to be suitable for the acquisition of the HGSs, as it took into account the local and available physical and mineralogical properties. Without using this approach it would not possible to present appropriate results, mainly in the floodplains, where water table levels had a crucial role in the decision-making process.

The CN method could forecast the most critical floodplains affected by the future land use changes scenario. However, as an average CN value was calculated per subbasin, it was not possible to predict particularly impacted areas inside these clusters. Thus, for more expressive impact agents, such as the driveway construction or large company parking and paving, it is recommended that subbasins are further subdivided into smaller clusters, according to the specific land use type of the agent itself.

The traditional runoff CN method could not reflect more expressive variations in the most impacted subbasins where there was saturated land when comparing the present and future land use scenarios. Hence, other criteria should also be used in association with the CN value, to provide more realistic hydrological simulations.

Nonetheless, as the Juqueriquere River basin is already susceptible to floods, it is mandatory to plan the urbanisation process of the plains in integration with the proper water resources management, to ascertain a sustainable development and avoid environmental, economic and social vulnerability of the region.

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