Landscape Imperviousness Index: An Indicator of Water Conservation in Urban Areas

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Abstract

The process of urban growth, one of the key features of modern reality, has led to the gradual increase of environmental impacts, especially on the water resources. The strategies used to understand, deal with and reverse this situation have been intensified, with the urban environmental indicators playing an important role. The Landscape Imperviousness Index (TI) presented in this paper, may be considered an excellent indicator of environmental impact related to urban planning and its integration to water resources. The immediate consequence of having this index simultaneously included in the urban legislation and in that of water resources, means recognizing the importance of the urban watershed as a unit for planning and management. This indicator contributes not only to the study of anthropogenic actions on the water resources and the environment, but also, to the issues of water quality and conservation in urban areas, as demonstrated in this study. Besides that, the TI is often used as a parameter in water models for the simulation and forecast of floods in urban basins. This index also includes in its composition several other parameters related to environmental impacts such as air pollution, a rise in temperature, the green areas per inhabitant ratio and lack of infrastructure services. The study of the historical development of TI in a given area, here represented by the water basin of Jacarepaguá lowland, an area in expansion in the city of Rio de Janeiro, can, not only provide us with measurable evidence of the increase of the environmental impact and the degradation of the water resources, but also with qualitative aspects about the agents and their relations in the process of occupation of urban areas. It is believed that the historical analysis and the TI definition can contribute to the adoption of more immediate and pressing measures, as well as the formulation of future strategies for urban sustainability. This index can also be used for public information and, since it is directly related to the physical conditions of the water basin, it becomes a useful tool, easily identified.

Introduction

The process of urban growth has been marked by serious environmental impacts often associated with decline in the living standards. In the Brazilian case, the rapid urban growth and the swelling of several areas in the mega cities have, among other reasons, been associated with a lack of state planning and policies that could effectively respond to this dynamics, thus creating several social, economic and environmental problems. This model of land and water management (Kleiman & Kauffmann, 2006) has failed to deal with the problem of floods, which also result from the urban population growth and the increasing imperviousness of the soil in the catchment basins. This issue has been frequently mentioned in the urban legislation and in several studies including that of Hall (1984), which have warned that, an increase in the imperviousness of the watersheds has a direct effect on groundwater (aquifers) storage and on urban drainage, significantly changing the runoffs, and contributing to the increase in the frequency of floods. The advantage of using the Land Imperviousness Index (TI), first demonstrated in Kauffmann (2003), lies in the fact that among other reasons, this index can include a series of important parameters to limit and control urban growth, aiming at its sustainability. These parameters are population and housing density, availability of green areas, water quality and the existence of urban infrastructure services.

The use of this indicator (TI) as a parameter applied to the watershed, the basis for the planning and management of water resources, may represent a new approach and an important strategy to directly linking the management of water resources to urban planning (Kauffmann & Pimentel da Silva, 2005; Pimentel da Silva et al., 2005; Kleiman & Kauffmann, 2006). Especially if included in the urban legislation, the (TI) indicator can minimize the flexibility caused by the distortions of some key parameters for the control and projection of urban growth. It can also be integrated to hydrologic modelling systems that simulate the effects of imperviousness on streamflow.

Methodology

Aiming at assessing the importance of using the TI as a parameter to measure sustainability and as an indicator for water conservation in urban areas, it was adopted in this study the same criteria applied in Kauffmann (2003). This methodology comprises the use of ***Equations 1 and 2***, and classification standards to assess catchments water quality (***Table 1***) presented by Schueler (1994, apud Sleavin et al., 2000), resulting in TI(b). In ***Equation 1***, the imperviousness index is related to permeable area, availability of green areas per inhabitant (Ferrari, 1979 and Ferreira dos Santos, 1988) and to population density, resulting in TI(c). ***Equation 2*** relates the imperviousness index to urban legislation parameters, resulting in TI(a and d). ***Table 2*** presents parameters definitions used on the imperviousness index formulation.

Then, comparing the actual catchment's imperviousness rate to the values of TI(a), TI(b), TI(c) and TI(d), the catchment present condition can be assessed and, eventually, scenarios can be simulated and limits set for future catchment's imperviousness/occupation rates.

Table 1 - Catchment Impact Classes and Imperviousness Index (adapted from Schueler apud Sleavin et al., 2000) – TI (b)

Catchment Degradation	Imperviousness Index
Eroded Catchments	10-15%
Impacted Catchments	16-25%
Degraded Catchments	> 25%

$$TP = \sum_{i=1}^{i=n} TZ_i\,(AV_i \, . \, D_i) \quad \text{and} \quad TI\,(c) = 1 - TP \qquad \text{Eq. 1}$$

$$TI\,(a \text{ and } d) = \sum_{i=1}^{i=n} TZ_i\,\{(TI_{lotes\,i} \, . \, C_i) + TI_{vias\,i}\} \qquad \text{Eq. 2}$$

Table 2 - Parameters Definition used in Equations 1 and 2

Parameters	Description
TP	Sum of permeable area rate (green)
TZ_i	Parcel area rate, calculated from total catchment area (AT) and parcelling class or sector areas (AZ_i): $TZ_i = AZ_i / AT$
AV_i	Minimum recommended green area per inhabitant (area/hab)
D_i	Recommended population density (hab/area)
N	Total number of catchments or planning area parcelling types or classes
TI	Sum of impermeable area rates
$TI_{lotes\ i}$	Lot area imperviousness index, which might be considered equal to the lot area occupation index (TO_i) if not established on Legislation
C_i	C_i is urban legislation allowed building area rate, equals the sum of rate for lot building ($C_{lotes\ i}$) and for public building (schools, nurseries, health care centers etc) ($C_{e\ i}$), estimated from: $C_i = C_{lotes\ i} + C_{e\ i}$
$C_{lotes\ i}$	Corresponding to the rate of total area for building site for lots and estimated according to the building site for public use (PU_i) which is specified in urban legislation: $C_{lotes\ i} = 1 - PU_i$
$C_{e\ i}$	Rate corresponding to public area of building site for urban public construction. Given by $C_{e\ i} = PU_i - TI_{vias\ i}$
$TI_{vias\ i}$	Index for streets (estimated based on lot's index). Its calculation is based on PU_i and $C_{e\ i}$: $TI_{vias} = PU_i - C_{e\ i}$
$TP_{lotes\ i}$	Permeable Lot rate

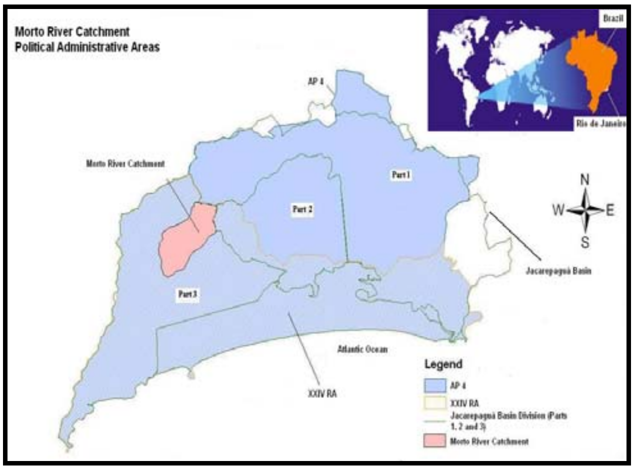
Follows results of applying this methodology to Morto river catchment, situated in Jacarepaguá, an area of urban growth in the city of Rio de Janeiro, Brazil.

Results

The area under study, the Morto river catchment, is situated in Lot 3 of Jacarepaguá basin, in the district of Vargem Grande, Administrative Area of Barra da Tijuca (XXIV RA), Planning Area 4, an area in expansion in the city of Rio de Janeiro.

Figure 1 shows the location of the Morto River catchment in relation to the drainage area of Jacarepaguá, Administrative Areas and in Brazil. At present, catchment has a low urban occupation rate and remainig areas of lush vegetation, which stresses the importance of applying this methodolgy to assess the urban sustainabilty of the area. The zoning and parcelling of the Morto river catchment, regulated by the Municipal

Ordinance nº 322[1] (please see the zoning of the Morto River catchment in ***Figure 2***) *,* Decree 3.046[2] and the Project for Urban Development of Vargem Grande and Vargem Pequena areas ("PEU das Vargens"[3]), was then applied to the area under study and the corresponding imperviousness index, for each assumption ((TI(a), TI(b), TI(c) and TI(d)) is presented in ***Table 3***.



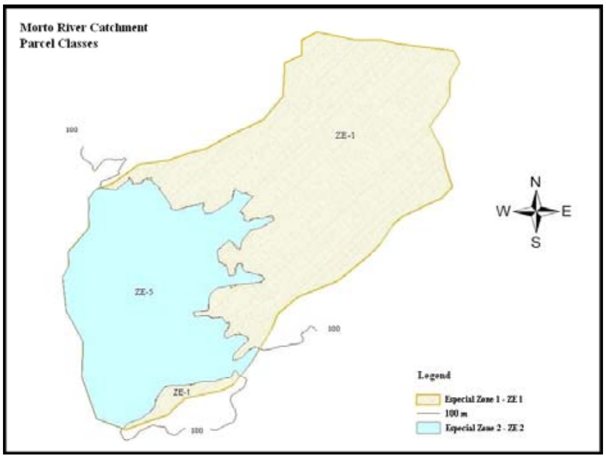


Figure 1 - Morto River Catchment, Jacarepaguá, City of Rio de Janeiro, Brazil

Figure 2 - Morto River Catchment . Legislation Zoning - ZE 1 and ZE 5

Table 3 - Morto River Catchment Landscape Imperviousness Index Parameterization

Reference / Index	Plano Piloto Legislation Adopting TI_{lotes} = TO (a)	Water Quality TI_{total} = 25% (b)	Green Area per Inhabitant (c)	Vargens PEU Legislation (d)
TI_{lotes}	10 %	53.69 %	58.91 %	50% (sector C), 40% (sector E) and 20% (sector H)
TI_{total}	12.96 %	25 %	26.44 %	18,74%

The catchment landscape imperviousness index (TI) estimated for the Morto river catchment shown in ***Table 3*** and the present landscape imperviousness estimated from 1999 air photos survey (equals 2.5%, calculated considering as impermeable the sum of projected roof areas, roads and sidewalks), were applied as the impermeable area parameter for IPH II hydrological model (Germano et al., 1998 and Tucci and Campana, 1993). In ***Figure 3****,* these simulations are presented. As expected, as catchment imperviousness index rises, so do both stream peak flow and time to peak. Therefore, as catchment impervious surface increases, so does the risk of urban flooding, demonstrating the importance of TI indicator also for urban flooding management.

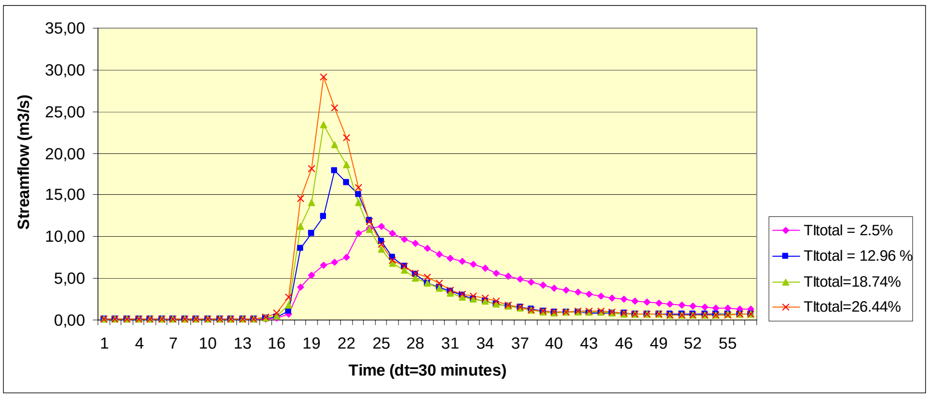


Figure 3 - Stream Flow Simulations for Different Catchment Landscape Imperviousness Index (TI)

[1] Municipal Ordinance from March, 3rd 1976, regulates the zoning of the area establishing ZE 1 and ZE 5.
[2] Municipal Ordinance from April, 4th 1982 details the Zoning of Jacarepaguá Basin and is here related to ZE 5 of the basin.
[3] PLC nº 72/2004 also refers to ZE 5 of the Morto River catchment and revises existing ordinance.

Conclusion

Based on the example given, it can be noted the importance of TI, not only to confirm the use of the Basin as a planning unit, since TI is closely related to basin total area, but also to study the effects of increasing basin's impervious surface on water resource systems. This study emphasizes the need for thorough research into the effects of imperviousness on the hydrologic system and the importance of having mechanisms to control urban occupation included in the legislation on urban and water resources. To this purpose, it endorses the use of TI as an interesting urban-environmental indicator and as a parameter to assess sustainability and water conservation in urban areas. Additionally, the use of TI can incorporate the analysis of new quantitative and qualitative aspects, thus enabling the new added parameters to detect situations on the sustainability continuum. In TI calculation, the parameter related to the availability of infrastructure services in the catchment, may include the rate for streets weighed by factors that reduce the imperviousness index of streets due to the use of pavement surfaces that are more or less permeable to the infiltration of stormwater. In the same way, the different situations concerning urban drainage, both of private lots or public streets and areas, may be represented by a parameter that is adjusted by indexes expressing quantitative and qualitative aspects, including among others techniques to reduce outflow and to sotre stormwater. Also, the parameter on the availability of green areas may incorporate alternative solutions such as green roofs, suspended gardens, among others, that provide thermal, visual and emotional comfort.

The TI indicator besides having in its calculation the above mentioned attributes, may also support planning decisions and actions by means of the historical analysis, relating the physical reality (the catchment) that is the target of the project to the projected results, the legislation and its objective application. It can also detect the dynamics of sustainability development and how it can be achieved, bringing to light the contradictions in the interests of the agents involved, thus supporting and giving the tools for a better understanding of this historic and collective process.

References

Ferrari, C. (1979) *Course on Integrated Municipal Planning. Town Planning* (second edn). Pioneira, São Paulo, Brazil (*in Portuguese*).
Ferreira dos Santos, C. N. (1988) *The City as a Playing Card Game*. Niterói, EDUFF – Editora Universitária de São Paulo, Projeto Editores Associados Ltda, Brazil (*in Portuguese*).
Germano, A., Tucci, C. E. M. & Silveira, A. L. L. (1998) Estimating IPH II parameters for some urban Brazilian catchments*. Brazilian J. Water Resour.* (RBRH) 3(4), 103–120. (*in Portuguese*).
Hall, M. J. (1984) *Urban Hydrology.* Elsevier Ltd, Belfast, Ireland.
Kauffmann, M. O. (2003) Urban expansion and life quality: proposal for development of sustainability indicators applied to urban legislation. Masters Dissertation, Environmental Engineering, FEN/UERJ, Rio de Janeiro, Brazil (*in Portuguese*).
Kauffmann, M. O. & Pimentel da Silva, L. (2005). Land Imperviousness Index: A Resource to Implement the Watershed as a Unit for Urban Planning Integrated to Water Resources Management. In: ANPUR XI National Conference . Salvador, BA, Brazil (*in Portuguese*).
Kleiman, M. & Kauffmann, M. O. (2006). Impacts of a Model of Land and Water Management in Paraíba do Sul Shared River Basin: The Committee for Integration of Paraíba do Sul River Basin – CEIVAP – São Paulo, Rio de Janeiro, Minas Gerais, Brazil. In: 5º Iberian Congress of Water Planning and Management, Faro, Portugal. Zaragoza: Fundación Nueva Cultura del Água (*in Portuguese*).
Pimentel da Silva, L; Kauffmann, M. O. & Rosa, E.U. (2005). Urban Growth and Life Quality: Application of Indicators in Integrated Water and Urban Planning. In: Seventh IAHS Scientific Assembly-Sustainable Water Management Solutions for Large Cities. Foz do Iguaçu, PR, Brazil.
Schueler, T. R. (1994) *The Importance of Imperviousness. Watershed Prot. Tech*. 1(3), 100–111.
Sleavin, W. J., Civco, D. L., Prisole, S. & Giannotti, L. (2000) Measuring impervious surfaces for non-point source pollution modeling. In: *Proceedings of the ASPRS Annual Conference* (May 2000, Washington DC), 11p. (*in http://resac.uconn.edu/publications/tech_papers/pdf_paper/asprs2000wdsl.pdf*).

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