Validation of a multicriteria methodology to evaluate the urban development impacts on the water resources

Validation d'une méthodologie multicritères pour évaluer les impacts du développement urbain sur les ressources en eau

Castro L. M. A.*, Baptista M. B.**, Barraud S. ***

* Agência Nacional de Águas
Setor Policial Sul, Área 5, Quadra 3, Bloco L - Brasilia - DF - 70.610-200 - Brazil - Tel 55-61-2109-5251
mitre@ana.gov.br

** Departamento de Engenharia Hidraulica e Recursos Hidricos da UFMG
Av Contorno, 842 – Belo Horizonte – MG – 30.110-060 – Brazil
marcio.baptista@ehr.ufmg.br

*** URGC Hydrologie Urbaine - INSA Lyon - Bâtiment J.C.A. Coulomb
34 avenue des Arts - 69621 Villeurbanne Cedex – France
sylvie.barraud@insa-lyon.fr

RESUME

Le développement urbain et ses équipements hydrauliques de gestion des eaux pluviales, des eaux usées et d'alimentation en eau potable peuvent induire des modifications importantes sur les cours d'eau. Cette publication présente la procédure utilisée pour valider et consolider la méthode multicritère proposée pour évaluer l'impact du développement urbain sur les ressources en eau. La procédure est basée sur des études de cas, sur la comparaison avec les méthodologies actuelles et sur les avis d'experts. La procédure de validation a montré que la procédure d'autorisation de rejet présentait des avantages indéniables et pouvait être utilisée de façon bénéfique par les institutions brésiliennes.

ABSTRACT

The urban development and its hydraulic structures, concerning stormwater, water supply, collection and wastewater systems, can cause important modifications on the water resources. The present paper presents the systematic used to validate and consolidate a proposed multicriteria methodology, based on indicators, to evaluate the sustainability of the urban development and its interferences with water resources. The applied systematic was based on case studies, comparison with actual methodologies and on a large specialist analysis. The validation process was found successful as it showed that can be applied in other indicators studies and its results were important to proceed the necessary adjusts on the indicators, to make them useful, subsidizing the current procedures of the state water management Brazilians institutions.

KEYWORDS

Indicators ; multicriteria methods ; urban drainage.

1 INTRODUCTION

The urban development, requiring the implementation of water supply, drainage and sanitation systems, can cause important modifications on the hydrologic cycle. The Figure 1, from Chocat (1997), presents the main impacts of the urbanization on the water resources.

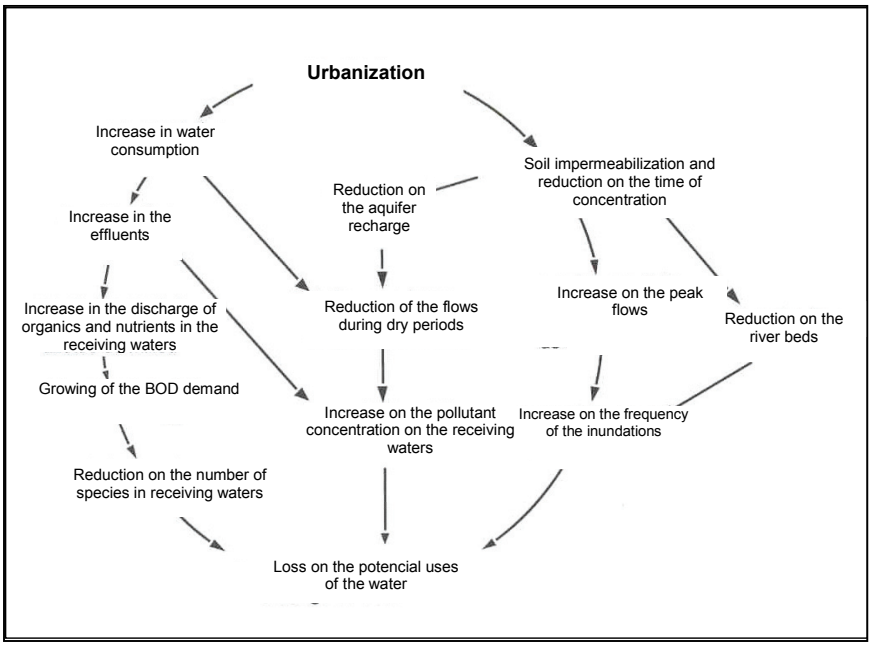

Figure 1 – Urban development impacts on water resources

According to US-EPA (1999), the main impacts of the urbanization on some hydrologic variables are due to the modifications on the impervious area, which changes the evapotranspiration, the runoff and the shallow and deep infiltration. These impacts are related to the watercourses quantity and regime in urban areas, as a result of the changes on the availability of water on the aquifers and on the river flows during rainstorms.

Also the water course quality is affected by the urbanization, due to the wastewater and stormwater discharges. The stormwater flowing on urban areas can be, sometimes, seriously polluted as a result of vehicles circulation, industries pollution, animal dejects, solid waste, atmospheric pollution and pathogenic organisms.

According to Chocat (1997), these impacts can be related to chemical, biochemical and biological aspects, referring to the direct consequences or effects as the auto depuration and the consumption of dissolved oxygen.

Some researches showed on Ellis and Hvited-Jacobsen (1996), Barraud *et al.* (2004), Maglionico and Pollicino (2004), Malard *et al.* (2004), Chebbo et al. (1995) and Valiron and Tabucchi (1992) try to characterize the rainstorm pollution on the urban areas. Others, as can be shown in US-EPA (1999), Rossi (1998), Saget (1994), Gautier (1998) and Pagotto (1999) present the average concentration of pollutants on the stormwater in the United States, Switzerland and France. Most of the presented researches concluded that it is very difficult to preview the stormwater pollutant concentration with great certitude degree, but it can be said that:

- The annual loads coming from sanitary systems are, in general, greater than the ones that come from the rainstorms;
- The stormwater pollutant loads are greater than the ones coming from sanitary systems in hour scale, mainly relating to heavy metals and total solids.

The design of the drainage systems could also have important influence on the water quality, as the classic ones can transfer the problems downstream and the use of Best Management Practices (BMPs) can neutralize some urbanization impacts.

The alterations provoked by the urbanization on the water courses can be done in different scales in a way to be considered sustainable or not, depending on the problems taken to its quantity, quality and regime.

Based on this fact, the research presented by Castro *et al.* (2006) proposed indicators to evaluate the sustainability of the urban development implementation in relation to the alteration on the water course conditions. The indicators were aggregated by multicriteria methods Electre TRI and TOPSIS, to be used in a decision support system applied by water management state institutions.

The present paper presents the systematic applied to consolidate these indicators, done as a critical analysis based on case studies, specialists' consultation and comparison with actual methodologies.

2 SET OF INDICATORS

The first part of the research referred to the indicators proposal, that was done based on a bibliographical research related to the main possible alterations caused by different types of urban development and drainage systems (classical networks and BMPs) on water courses. The possible alterations were expressed in terms of impacts on the quantity, quality or regime of the water courses and the proposed indicators used hydraulic and hydrologic parameters, with mathematical expressions. The expected results take to values from 0 to 1, in a way to express clear results to the analyst. The complete expressions and parameters used on the indicators proposal are presented in Castro *et al.* (2006), but the Table 1 presents the main aspects that they aim to evaluate.

Alteration on the water courses	Main description
Quantitative aspects	Verification of the project infiltration volume in relation to the natural or actual situation (I_{qt1})
	Verification of the minimum outflow of the water course relating to the downstream consumption and ecological flow demands (I_{qt2})
	Verification of the previewed volume for reuse or recuperation of the rain (I_{qt3})
Water courses regime aspects	Verification of the outflow peaks in relation to natural or desirable ones (I_{r1})
	Verification of the outflow peaks in relation to the one that could cause inundation in some downstream area (I_{r2})
	Verification of the level of protection for the inundations in the area by the comparison of the return period according to the desirable one (I_{r3})
Qualitative aspects	Verification of the discharge standards for the wastewater (I_{qL1})
	Verification of the availability of dilution outflows for the wastewater discharge (I_{qL2})
	Verification of the discharge standards for the stormwater (I_{qL3})
	Verification of the availability of dilution outflows for the stormwater (I_{qL4})

Table 1 – Main aspects evaluated by the set of indicators

3 VALIDATION METHODOLOGY

After the indicators proposal, a systematic test method was applied to validate and consolidate the methodology. For that purpose, three types of test were carried out: one based on case studies, other based on comparison with actual empirical methodologies and the third based on specialist analysis.

3.1 Comparison with the actual methodologies

To validate the proposed methodology, the first test was based on its comparison with systems already in use in Brazil. In Brazil, each state has its institutions that are responsible to the water resources management at its water courses and a National Water Agency, that is responsible to the management of the federal water courses, that are the ones that cross two states or limits the borders of the two states.

In fact, some of the Brazilian water management state institutions don't have a specific methodology for this analysis as they don't analyze the urban development impacts on the water courses yet, even having the prevision in their legislation.

For the ones that have a methodology, it was verified that they are much diversified and could be sometimes only applied for their state in a specific situation. This could take to results when equal projects could be authorized in some region and not in another, in function of the fragility and diversity of the methodologies. This was an important advantage showed by the proposed indicators, which can be used in a similar way in all the country, just varying some legal parameters, specific for each state.

Referring to the indicators proposed for the quantity analysis, it was observed that the state institutions only verify actually the minimum outflow of the water courses relating to the necessary consumption. The other aspects on the proposed indicators are not analyzed and so important questions are left aside.

Considering the aspects related to the water courses regime alteration, none of the Brazilian state institutions have technical criteria defined in legislation or applied in a usual way in their current procedures. Each of the interferences in water resources is analyzed in a different way with different criteria. So, this comparison took to the important advantage of the proposed methodology, when it standardizes the procedures and criteria, so that the impacts of different urban developments can be compared in order to define the projects that can be considered sustainable.

According to the analyzes done in the actual procedures, most of the state institutions don't analyze water quality aspects and the ones that do analyze, only take into account discharge of domestic waste water, but not the quality of the stormwater discharge in relation to the dilution availability in the water courses. So, the possibility and the expressions that permit the consideration of stormwater pollution aspects can be considered the greatest advance relating to the analysis of the quality alterations provoked by the urban development on the water courses.

In resume, this comparison was important to show the advantages and advances brought by the proposal in relation to the actual methodologies. It was relevant to conclude that the proposed methodology has indicators that verify aspects not considered by the state institutions in their actual analyze and that all the actual current procedures are included in the indicators. Another important advance was the possibility to verify the urban development based on all of its impacts in a global analyze, which was possible due to the use of indicators and multicriteria methods.

3.2 Specialist Analysis

The second test consisted on the evaluation of the indicators by a group of specialists. First of all it was necessary to identify the main actors of the decision

process that could interfere on the indicators set and its relative importance. The main actors in Brazil could be technicians, from state institutions or from municipal systems, responsible for the technical analysis of projects, the consultants, responsible for the conception of the systems, researchers, working on the subject, the representatives in basin committees and, finally, the population. These people and their role on the decision process were evaluated and it was verified that the researchers and the technicians from state institutions are the ones who participate actively on the proposal of indicators.

So, the proposed indicators were evaluated by these specialists. A questionnaire was sent to 10 researchers from different universities and 11 technicians, members of brazilian state water resources institutions in order to evaluate the proposed indicators, with the following objectives:

- Verification of the pertinence of the proposed indicators in relation to the main alterations provoked by the urban development on the water courses;
- Verification of the absence of a relevant aspect between the proposed indicators;
- Analyze of the relative importance of the indicators, defining their weights on the process.

During the next 45 days, there were obtained results from 5 researchers and 10 technicians, with a global response of almost 72% of the questionnaires.

In relation to the defined weights, important differences were verified between the responses, mainly that the researchers gave more importance to aspects related to the water courses regime alterations and the technicians to the water quantity alterations. That could be possibly explained because the state institutions actually have criteria only to analyze the differences in quantity aspects and the researchers that answered the questionnaires concentrate their studies on the urban drainage interferences on the water courses regime, mainly from the BMPs. The defined average weighs are those presented on the Table 2.

Criteria	Indicator	Average Researchers (%)	Average technicians (%)	Average all specialists (%)
Quantity alterations	I_{qt1}	8,60	12,44	11,07
	I_{qt2}	8,40	12,00	10,71
	I_{qt3}	10,40	11,11	10,86
Regime alterations	I_{r1}	13,40	10,44	11,50
	I_{r2}	15,80	10,89	12,64
	I_{r3}	10,80	8,67	9,43
Qualidade alterations	I_{qL1}	10,80	9,11	9,71
	I_{qL2}	6,50	12,22	10,18
	I_{qL3}	8,80	5,67	6,79
	I_{qL4}	6,50	7,44	7,11

Table 1 – Average weights defined by the specialist analysis

Most of the specialists presented comments relating to the absence or pertinence of the considered aspects. Treating the indicators' pertinence, all of them affirmed that the indicators deal with aspects related to the proposed objective of the research, but they are concerned about the lack of information on the quality of the stormwater and

its influence on the water courses in Brazil. According to them, the lack of this information could take to difficulties to calculate the indicators I_{qL3} and I_{qL4}.

The specialists also presented some aspects that they thought to be absent on the indicators proposal. Some of their comments could be included in the indicators calculus but others were mainly related to socio-economical themes, which are not previewed to be verified in this methodology.

This part of the consolidation process was important to consider the vision of other specialists and their comprehension of the proposed indicators and methodology.

3.3 Case study 1 – condominium « Vale dos Cristais »

The Condominium "Vale dos Cristais" is located in the Metropolitan Region of Belo Horizonte, the capital of the state of Minas Gerais, Brazil. Its area is about 587 ha in a mountainous region of argillaceous soils. It is situated upstream of the city of Nova Lima, which is already frequently flooded and so the drainage project needed serious restrictions to control downstream peak flows.

This case study was chosen as the area was in natural state before urbanization and as it was necessary to use BMPs in the project, developed by CONSOL (2004), not to increase the flood problems downstream. To validate the methodology all the indicators of the project were evaluated and the multricriteria procedures applied and compared.

The results of the indicators that analyzed the quantity aspects were important to the conclusion that there was availability of outflows to the necessary consumption and to the ecologic ones and that the previewed infiltration systems maintained a greater volume than the natural one. The project didn't previewed directly recuperation of rainstorm waters, which could be verified by the third indicator.

The regime alterations were efficiently verified with the indicators that showed that the peak outflows of the condominium were minor than the natural ones, which was important not to increment the inundation process in the city of Nova Lima, located downstream. The protection of the condominium area against inundations was also possible to verify, according to the design return period of its stormwater structures.

Treating the water quality alterations, the indicators were efficient to show that the availability in the water courses in the region was not sufficient to the dilution of the residuary waters. Relating to the rainstorm water quality, it was verified that the two indicators couldn't be obtained because the predictions of their parameters had not good quality.

In resume, the application of the methodology, gave relevant results in the evaluation of the project and indicated some aspects which interference in the water courses could not be found sustainable and must be reviewed.

For this case study, the same indicators were calculated by three technicians in order i) to test the robustness of the method, ii) to compare and verify difficulties in the comprehension and definition of the parameters used in the procedure. The three technicians found the indicators accessible and their analyzes and results didn't present important differences, showing robustness of the set of indicators and the methodology.

3.4 Case study 2 – urbanized region in « Goiânia »

The second case study was an urbanized region in the city of Goiania, capital of the state of Goias, in Brazil. It is a 17 ha area mostly occupied by buildings. This area was already submitted to frequent flooding caused by the imperviousness of the soils.

The choice of this area was due to the fact that, contrary to the "Vale dos Cristais", this zone was already highly urbanized before the project. Moreover three alternative

projects were proposed to solve the inundation problems by Milograna (2001): one using classic systems, the second using detention basins in each lot and the third using detention basins in public areas. It was thus interesting to compare the different alternative projects and the relevance of the methodology as a decision support system for the three alternatives developed.

For this case study, all the indicators relating to the alteration of quantitative and regime aspects could be calculated and showed important results to the decision of the analyst. As the area was already urbanized, with inundation problems due to the impervious areas and the classic drainage systems, the indicators were relevant to show that the infiltration of greater volumes could take to a better situation. This was particularly seen with the conjunction of the indicators that evaluated the infiltration volumes and the downstream outflows previewed.

The results obtained were also important to show the lack of the sensibility on some indicators, between different alternatives. These indicators must have its expressions changed.

The indicators that verified water courses quality aspects related to residuary effluents were important as they presented results that showed that, for all the project alternatives, there were not available dilution outflows. This was important to indicate to the analyst the main aspect where the project had to be reviewed.

Similar to the case study 1, the stormwater quality could not be assessed with a nice degree of certitude, showing some indicators that had to have the expression and parameters changed.

The comparison as a decision support system was also done with the methodologies proposed by Castro and Baptista (2004) and Moura (2004), based on hydraulic, sanitary, environmental, social and economical indicators to evaluate urban drainage systems in developing countries. The main result of this comparison was that the proposed methodology is possible to be aggregated to other systems, including different sets of indicators with diverse characteristics, in order to realize a global analysis of the urban development.

4 CONCLUSIONS

This paper presents the validation and consolidation process used to validate proposed indicators and methodology to evaluate project alternatives. The text presents the justification and the main aspects verified by indicators and the methodology proposed to evaluate the sustainability of the urban development according to its interferences on the quantity, quality and regime of the water courses.

The most important aspect of the validation process is that it was important to let to the necessary modifications on the indicators and the methodology. After all the executed tests, the validation process has led to minor modifications on some indicators and the methodology proposed seems to give encouraging and quite useful results.

Another relevant aspect from the adopted systematic is that it's adaptable and accessible to be used in any study that intends to validate and consolidate proposed indicators and an evaluation methodology.

The consolidation and the adjusts made reaffirmed the methodology to be adapted and efficient for the use in usual procedures of the institutions, due to their calculus feasibility and interesting prescriptions to analyze and help authorizing discharges and other interferences coming from urban development.

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