Inventory and mapping of water services' needs as a tool to prioritize investments for water systems' development

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1. Abstract

An appropriate urban water service is a group of facilities for the supply of drinkable water and for the evacuation of water uses by a sewage system, which guarantee the health of the population in the urban area in terms of water quality. There are still many cities in developing countries that need strong investment in water facilities.

The purpose of this study is to describe and set the methodology to develop a tool that can identify and quantify the risks that the population suffer due to the lack of an adequate urban water service, in the districts of urban areas of developing countries, in order to generate maps with geospatial information which can help prioritize the investments needed.

When planning investments in water services, it is a need to prioritize according to population's vulnerability variables. Geospatial information databases and GIS (Geographical Information Systems)'s tools are very useful to identify which areas are more vulnerable, so need to be improved first.

We propose a method to typify urban areas by an indicator named "Water Investment Necessity" (WIN), which is proportional to the vulnerability of the population in the area (VUL) and inversely proportional to the quality of existing facilities (development of the existing water system: EWSD). We show an example of a map with this information, that could help identify where it is more urgent to act. Vulnerability is defined by different parameters, as the population density, infant mortality, illness rates, existing social facilities as hospitals or schools… These data could be found in different sources related to country databases. Existing Water System Development is more probable to need field-work and local-scale search.

With the example of a big city in a developing country, where the available starting information is quite rich, we set the base of a method that should be calibrated case by case, depending on local needs. With a similar approach, Canal de Isabel II uses GIS tools to plan investments, related to risks of floods or water scarcity.

Keywords:

Vulnerability, water facilities, investment, GIS tools

2. Introduction

It is a reality that there are still millions of people who suffer from the lack of water facilities; a large number of them live in big cities of developing countries. The lack of these facilities is known to be related to other factors, like high incidence of illnesses related to bad water quality.

It is a priority for the humanity to increase the access to water and sanitation systems, as it is exposed in Objective Number 6 of the Sustainable Development Goals of the United Nations. To increase the efficiency of the investments, so that they help the most vulnerable population, it is necessary to develop planification systems on a local scale. Geographic Information Systems (GIS) are definitely necessary to identify the most vulnerable areas where it is more urgent to act.

Fig. 1: people affected by the lack of water facilities

GIS offers us the opportunity to characterize the territory and correlate geographical information, so that we can infer some data from other if needed. In the poorest countries, where there is low availability of infrastructure data, the information of the scarcity of facilities can be related to other factors if we are able to compare it with places with similar characteristics. Besides, when complete information is available, we can use GIS to detect differences among different areas depending on the values of critical factors. We can prioritize the necessities according to these critical values, which is the subject of this study.

With a similar philosophy, Canal de Isabel II has developed a tool to identify flood-prone areas and the risk level over urban sector population, economical infrastructures (public and private road traffic, rail infrastructures and singular buildings) and the environmental sectors in the urban areas of Madrid's Community.

Flood risk can also be considered as a critical factor related to vulnerability because of the lack of a correct drainage system in cities of developing countries, depending on the case.

3. Objectives

The objective of the study has been the development of a system for the identification and quantification of the vulnerability of the population living in a certain district of an urban area, in order to obtain a tool that helps in decision-making for the prioritization and planning of new water infrastructures that must be carried out.

We get to the object by showing an example of an Index that can be used to help characterize the priority of investments, and the correlation among certain variables in a big city with a recent development, where there are enough data available. This correlation can be used in the study of cities with less information, in countries with a lower development.

4. Materials and Methods

To materialize the method proposed, we start from the information available of the city of Sao Paulo, in Brazil. This city has experienced a big and rational growth in the last decades, being an example as a city that successfully manages migration. The current "Strategic Master Plan" of 2014 has been awarded by ONU-Habitat, and it seeks to ensure a socially equilibrated city, inclusive and environmentally responsible, productive and, above all, with a good quality of live for its citizens.

It is, so, a good reference for cities in countries on process of development. Starting data in the city information system is quite rich; this has also been important for taking Sao Paulo as an example for this study.

We analyze the correlation among the data available and we propose an equation to classify the different areas. Finally, a global Water Investment Necessity (WIN) map at the municipal level is obtained as a result. This map already constitutes a decision support tool; in this way, actions can be planned based on objective criteria.

Equation:

The relation among vulnerability, development and investment necessity can be expressed by a simple equation:

$$WIN = VUL / EWSD$$

where:

WIN=Water Investment Necessity, with values from 1 to 5, the higher the WIN value is, the higher the necessity of investment

VUL=Vulnerability, with values from 1 to 5, the higher the Vulnerability is, the higher the value

EWSD= Existing Water System Development, with values from 1 to 5, the more developed the system is, the higher the value

The methodologies to assign values to variables are varied and turn out to be more or less complex, depending on the number of parameters that it is decided to incorporate in the calculation, their weighting and treatment. In the present work, the risk for the population due to the lack of a proper water system is represented directly by the vulnerability variable. We propose a relation between vulnerability and infant mortality that should be characterized case by case.

Variables:

Vulnerability:

In order to assess vulnerability from the point of view of the most affected sector of the population, related to the lack of water facilities, the variable directly related to the vulnerability is proposed to be infant mortality. We establish five representative ranges to which a value of 1 to 5 is assigned (the highest the infant mortality, the highest value for the vulnerability). Other factors can be used to help classify the areas with the highest infant mortality in very vulnerable cities, such as population density or geomorphological variables that represent special difficulties for the access to water.

Table 1: Degree of vulnerability for population due to lack of piping water system

Value	Vulnerability
5	Extremely high
4	Very high
3	High
2	Moderate
1	Soft

In case the vulnerability would be directly related to the lack of a proper drainage system, we could assess vulnerability from the point of view of the population density, as exposed in Canal de Isabel II's method for characterization of flood risks caused by urban drainage network overflows. The idea of this method is that the higher the population density, the greater the vulnerability, since more human goods will be affected. Therefore, five representative ranges are established to which a value and a minorizing coefficient are assigned. Thus, the higher the population density, the value of the range will be the maximum (=5) and the coefficient in this case will be equal to 1 since the vulnerability of the population will be the maximum. However, in rural areas where the density is less than 10 inhabitants/ha, the value of the range will be the minimum (=0) and the coefficient will also be 0, since in this case the population can hardly be considered an asset vulnerable to drought. flooding due to its non-existence. The vulnerability ranged in the table below is used in a more complex equation to characterize the risk associate to floods.

Table 2. Population vulnerability to floods in urban areas.

Density (inhab/Ha)	Value	Minorizing coefficient
D >= 150	5	1,0
100 <= D <150	3	0,9
50 <= D < 100	2	0,6
10 <= D < 50	1	0,2
D < 10	0	0,0

Existing Water System Development:

Existing Water System Development (EWSD) is more probable to need field-work and local-scale search. We propose a classification consisting in identifying the existence of a network for drinking water and a sewage system, making the difference on the fact of it being at the scale of particular houses.

We propose a classification this way:

Table 3: Existing Water System Development value

Value	Degree of development
5	High scope of water and sewage system house to house
4	Moderate scope of water and sewage system house to house
3	Poor scope of water and sewage system house to house
2	Water and sewer system available for groups of houses
1	There area groups of houses with no access to water

In the case study of Sao Paulo, in the sources consulted there is a specific variable that shows the percentage of houses with piped access to drinking water and the private sanitation system. Therefore, this is the variable than can be directly used to establish the representative ranges with values from 1 to 5.

Case Study:

For the city of Sao Paulo the information for the different districts can be obtained from the public geoportal of Prefeitura de Sao Paulo ("Mapa Digital de Cidade de Sao Paulo").

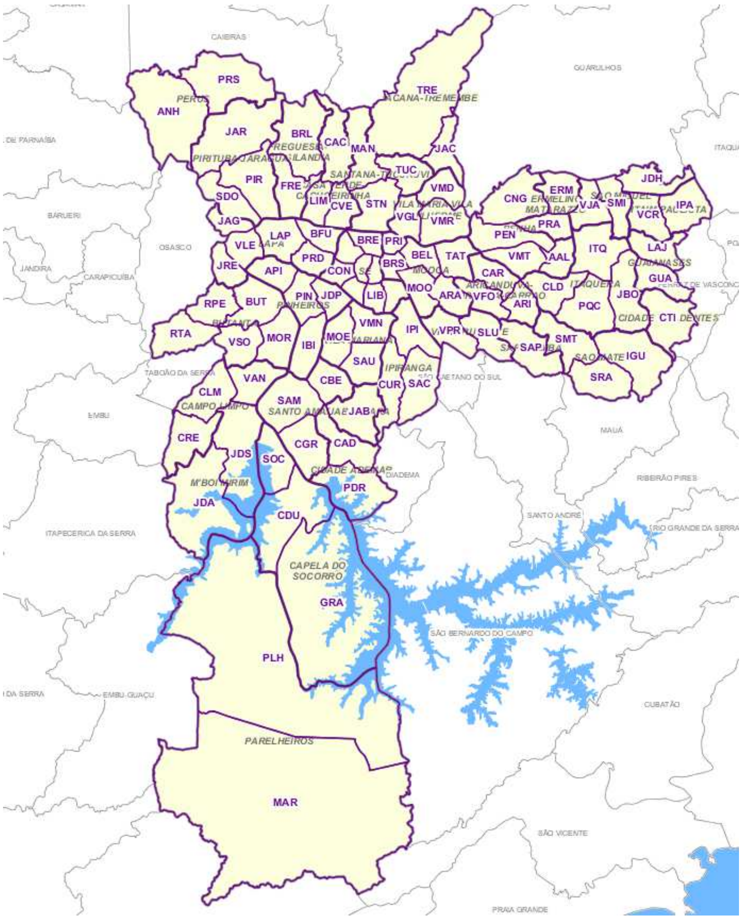


Fig. 2: districts of the city of Sao Paulo (96)

The variables used in this case are the following, available at the geoportal in the layer that characterize the districts: MORT5 and TBANAGUA.

MORT5: Mortality at five years. This variable is obtained from the maps available. We propose a geometrical interval method to stablish 5 ranges. This method provides a similar number of values in each range.

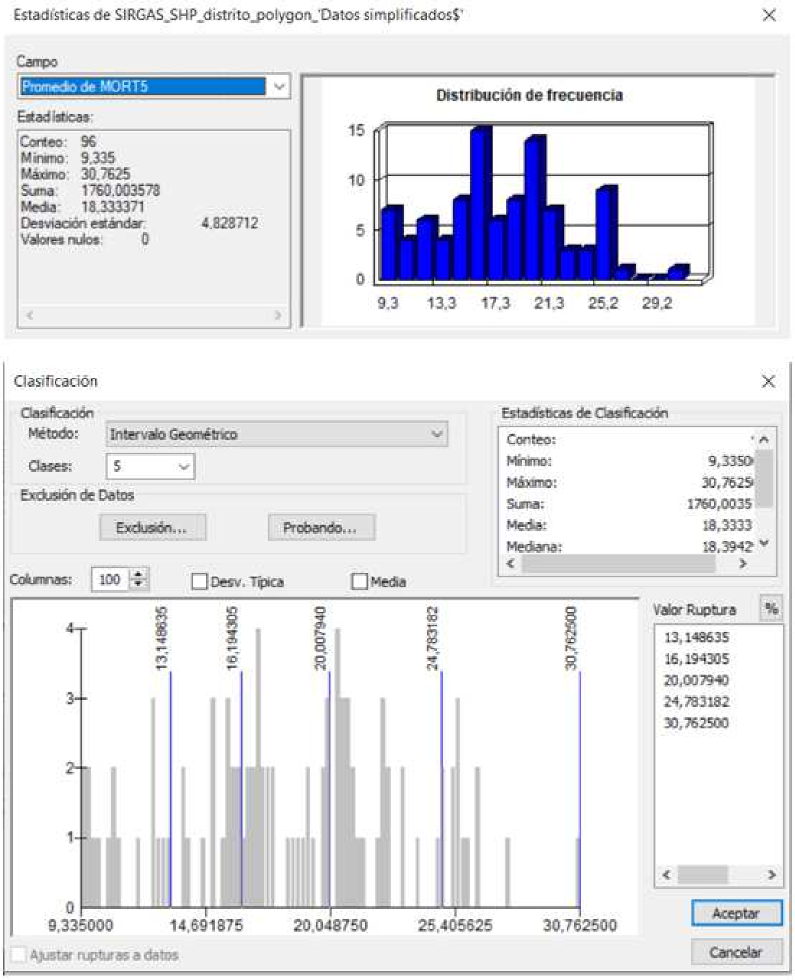
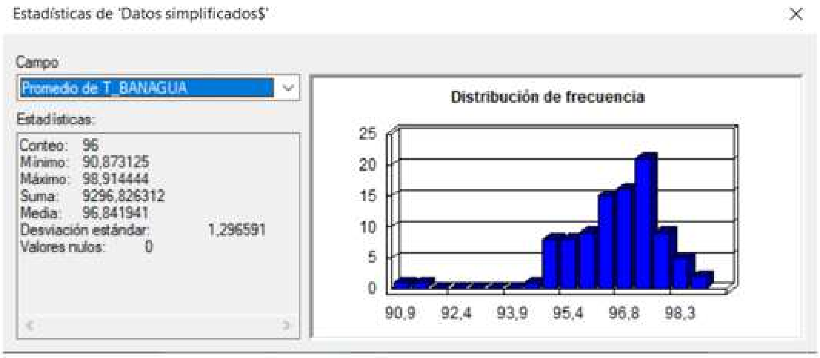


Fig. 3: values and ranges for the variable that represents the number of children died before 5 years out of 1000

Each of these ranges can be assigned with a value from 1 to 5.

TBANAGUA: percentage of homes out of the total that have networks and a bathroom. This variable can be used directly as an indicator of the degree of the Water System Existing Development.



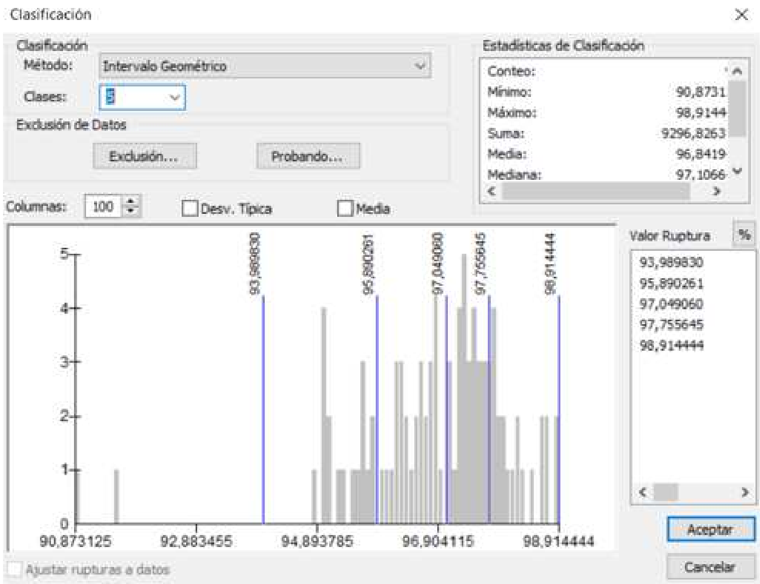


Fig. 4: values and ranges for the variable that represents the percentage of homes with piping water and a bathroom

Each of these ranges can be assigned with a value from 1 to 5.

5. Results

The results in this study are obtained in the form of GIS maps by applying the criteria of Vulnerability and Existing Water System Development described. The assignment has been made by using the available variables. Values are obtained for the subdistricts in which the city is divided.

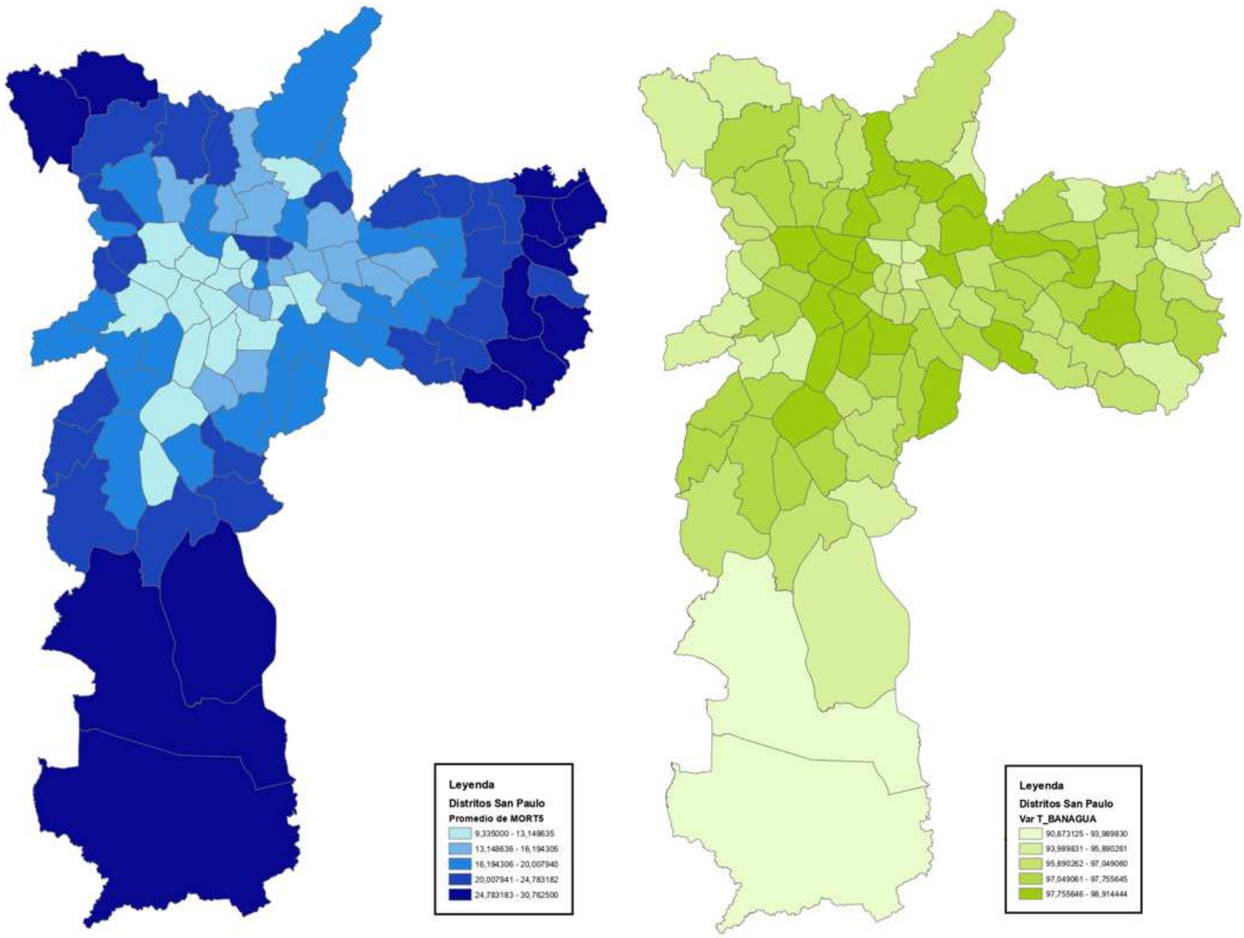
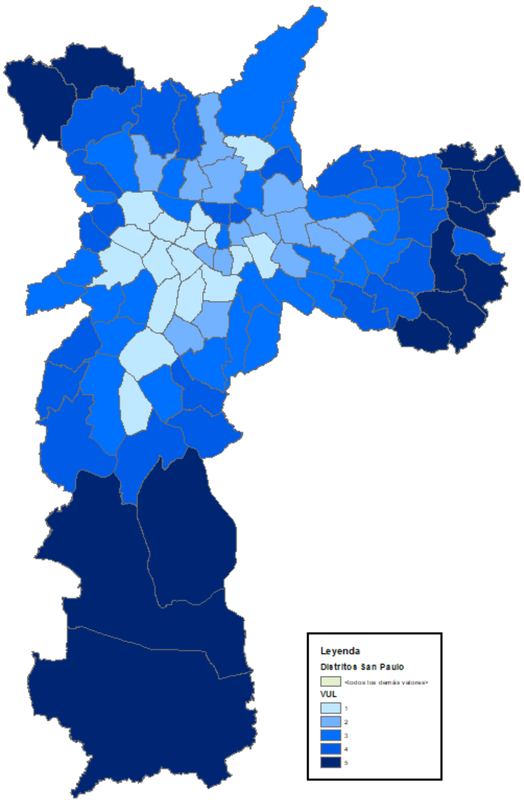


Fig. 5: representation of children mortality (left) and existing water services (right) in 5 ranges

GIS tools allow us to represent in a map the different values of variables and easily detect the correlation among them. In the example of Sao Paulo, the values of vulnerability and water system development can be directly obtained by the database information available. In any other cases, where there is not such information, we can infer useful variables from the existing information, seeing the existing correlation among other variables that can be made as in the example.



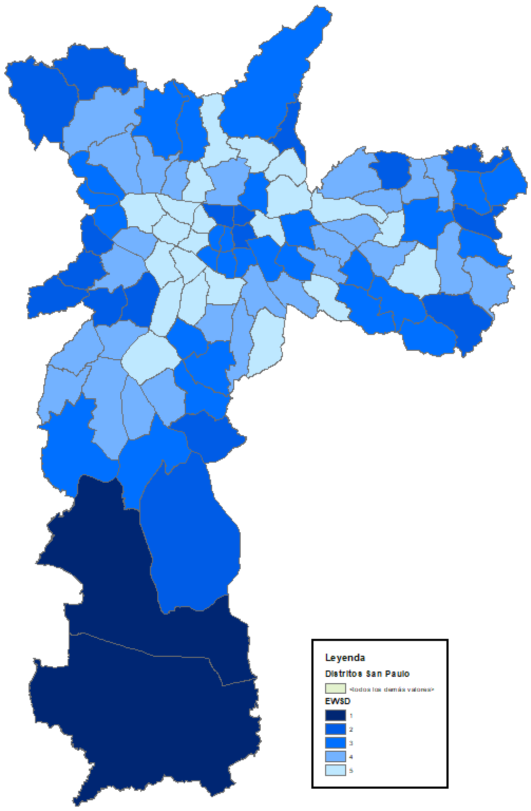


Fig. 6: Index of vulnerability attending to infant mortality

Fig. 7: Index for development of water facilities

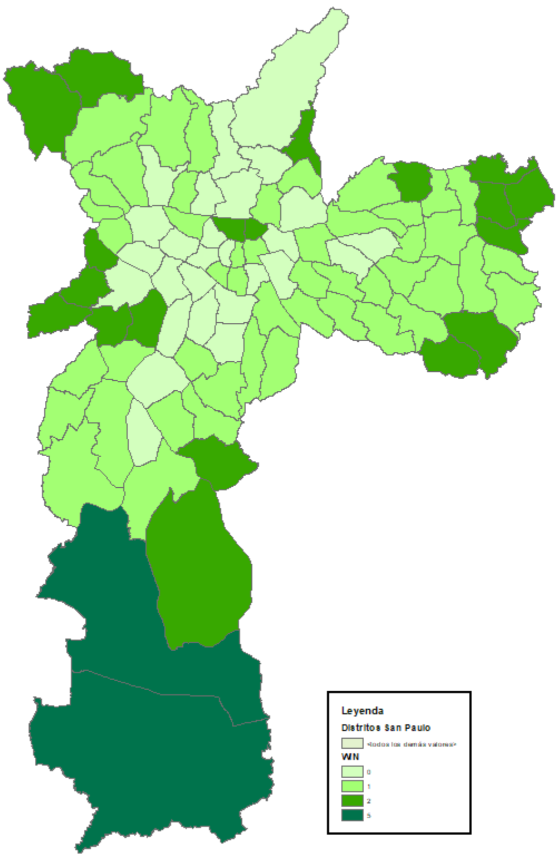


Fig. 8: WIN index: Water Investment Necessity (values rounded down to integer)

The representation of the information available in this example lets us easily appreciate how the high scarcity of water facilities is directly related to infant mortality (the two big districts at the south). Percentages of homes with piping water and bathrooms below 94 % (EWSD<2) also correlate with high infant mortality in most of the cases. The correlation with infant mortality is not so direct with percentages of homes with piping water and bathrooms over 95,4%. The districts with more need of investments are, in most cases, related to their peripheral condition in the urban area.

6. Conclusions

The simple WIN index shown in this case as an example gives a quick approach to the usefulness of GIS tools for planning investments in water facilities. It is necessary to support the decision-making plans with geographical information, to ensure that these plans really improve life conditions for the most vulnerable part of the population in developing countries.

The characterization of urban areas could be improved taking into consideration variables available as peripheral condition, population density, age of the network…, apart from the infant mortality used in this study. Vulnerability for the population could also be improved considering the risk of flooding, as explained in the Methods' paragraph in this study, in a similar way as Canal de Isabel II has characterized urban areas in the Community of Madrid.

In countries in process of development, if reliable information about water facilities or vulnerability of the population is not available: correlations among certain variables can be done by using data from comparable cities with a richer GIS. The example of Sao Paulo, a city that has experienced a big growth in the last decades, responsible with the improvement of the quality of life of its inhabitants, is a good reference for other populated urban areas.

We set the base of a method to generate maps which could help in decision-making for the prioritization and planning of water facilities. The maps should be calibrated case by case, depending on local needs. With a similar approach, Canal de Isabel II uses GIS tools to plan investments, related to risks of floods or water scarcity.

Future studies would define more complex indexes, that could help prioritize the best solutions for improving water facilities adjusted to the local scale.

References

A. Pinilla, A. Lastra and M. Ortega. Canal de Isabel II (2022). “Characterization of Flood Risks Caused by Urban Drainage Network Overflows in 136 Municipalities of the Madrid Region”.

Nania-Escobar, L.S. (1999) Numerical and experimental methodology for danger analysis of urban runoff in a street network. *Universitat Politècnica de Catalunya. Barcelona, Spain*, ISBN: 978-84-690-5623-3

“Sao Paulo, an example of a city that fights against xenophobia”. United Nations. Economic and Social Affairs Department. https://www.un.org/es/desa/cpd51-sustainable-cities

Geoportal of the city of Sao Paulo: https://geosampa.prefeitura.sp.gov.br/PaginasPublicas/_SBC.aspx

Daniel Jato-Espino, Nora Sillanpaa, Susanne M. Charlesworth, Ignacio Andrés-Doménech (2016). “Coupling GIS with Stormwater Modelling for the Location Prioritization and Hydrological Simulation of Permeable Pavements in Urban Catchments”. https://www.mdpi.com/2073-4441/8/10/451

“United Nations Sustainable Development Goals”: https://www.un.org/sustainabledevelopment/es/water-and-sanitation

https://wesr.unep.org/article/wesr-geospatial-data-and-services

https://www.cideu.org/miembro/sao-paulo/