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Incorporating Flood Vulnerability to the Water Poverty Index in the Juarez Municipality

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INCORPORATING FLOOD VULNERABILITY TO THE WATER POVERTY INDEX IN THE JUAREZ MUNICIPALITY

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ABSTRACT

The objective of this study is to incorporate the concept of flood risk vulnerability as a variable into the Water Poverty Index (WPI), developed by Lawrence *et al* (2002). The distribution and availability of water resources vary considerably from region to region due to geographical, hydrological and socioeconomic factors. The WPI integrates information from parameters applied to a country, these parameters include: water volume per capita of surface and groundwater resources; capacity of the country to accomplish its agricultural, industrial, and urban water demands; the potential for buying, managing and treating this resource; efficiency in domestic, agricultural and industrial water use without wasting it; and also an environmental factor which provides a measure for water sustainability by including water quality records, environmental regulation strategies, and number of species in danger of extinction. The aim is to evaluate the WPI for the municipality of Juarez, Chihuahua, Mexico. In this analysis the region is considered as a country and the numbers obtained for each of the parameters mentioned are those related to this particular study area. Each index and a diagnosis of the prevailing water resources situation with regard to flood hazard in the region are evaluated. The assessment of the flood control infrastructure and related contingency prevention measures to avoid flood damage in Ciudad Juarez is incorporated as part of the WPI. This allowed a better understanding of the overall effect of flood risk on this index.

I. INTRODUCTION

There are various criteria to evaluate the water sustainability of a region. Generally, the institutions responsible of the water management establish which scheme for the water administration is the best. Other sources, mainly academic, often criticize their implemented methodology and the institutions efficiency for the water management.

The present article has as the objective to analyze a criterion of evaluation of water management that overcomes all differences regarding the debate previously mentioned, with the

aim to implement the correct policies for water conservation and preservation in the region. To accomplish this objective, it is required to have a good diagnosis of the prevailing situation, this should include an index that offer a qualification about the availability, access, capacity, use, and environment related to the vital liquid.

In the center and north parts of Mexico, groundwater is very important because it is the main water supply source. The over extraction of water from the aquifers in the semiarid zones of this region has a number of consequences; water level depletions, reduction of the natural recharge, water quality and quantity degradation, as well as an increment in the pumping costs. Due to these consequences it is very important to know the hydraulic and hydrologic condition of a region (Porrúa and Chávez, 2004).

To have a sustainable water management, it is recommended to have a good water planning. It is important to create a water system that involves planning, management, monitoring and information. Groundwater sustainability in the semiarid zones is a difficult task to achieve, due to the excessive withdrawals and to the minimum aquifers recovery (Porrúa and Chávez, 2004).

The Water Poverty Index (WPI) has been formulated with the purpose of consider all of the aspects involved with water management in each country, bringing to light the worst and better situations that exist on a worldwide basis. Inside the WPI, there is a relation between poverty, social needs, environmental integrity, water availability and public health that allow to identify the main problems related to water, and to take the necessary measures to remedy the situation. On the other hand, the WPI parameter that indicates the water availability is not the one that determines the poverty level in a country, but the use efficiency for such resource (Sullivan, 2002). The WPI parameters are presented as follows:

Resources. It is based on the estimate of three important components: groundwater, surface water and the annual average precipitation. It should take into account the instability of the factors that directly affect the water quality and availability.

Access. It considers three important components: the population fraction with access to drinking water, population fraction with access to sanitation and population fraction of land irrigated with relation to the land under cultivation. These parameters intend to take into account the drinking water and the sanitation necessary for the relatively poor rural zones where water availability for irrigation is as indispensable as that for domestic and human consumption.

Capacity. There are four components to this parameter:

- Gross Domestic Product (GDP). Income per capita of the population adjusted to purchasing power.
- Mortality Rate (per 1000 live births). Health indicator related to the access to drinking water.
- Education Index. Adult's literacy and elementary, medium, and high education level inside the Human Development Index (HDI).

This parameter takes into account the socioeconomic variables that impact directly on the water access and quality, and distribute and adjust the access capacity and availability to drinking water.

Use. It includes the following three important components:

- Domestic water use (%). It considers 50 L per person for day for developing countries. There may be countries that are below of this minimum quantity and others that are found to be above.
- Industrial water use (%). Here the proportion of the GDP originating from the industry is divided by the proportion of water used by the same economic sector.
- Agricultural water use (%). Here the proportion of the GDP originating from the agriculture is divided by the proportion of water used by the same economic sector.

Environment. This parameter concentrates several environmental components that reflect the water management and provision, including the Environmental Sustainability Index (ESI) that considers the quality, stress and degree in which the water is found in the environment. It is calculated based on the average obtained from the five elements that compose it, presented as follow:

- Water quality index, which considers the following parameters:
    - Dissolved salt concentration
    - Sulphates concentration [SO_4]
    - Total dissolved solids concentration [SDT]
    - Total hardness concentration [$CaCO_3$]
    - Electrical Conductivity (CE)
- Water stress index, based on:
    - Fertilizer consumption per hectare of arable land
    - Pesticide used per hectare of arable land
    - Industrial organic contaminants (irrigation/fresh/drinkable) by water available.
    - Percentage of the territory under severe water stress.
- Regulation and management capacity index, considering the following aspects:
    - Environmental regulatory under scarcity
    - Environmental regulatory under innovation
    - Percentage of land area under protection status
- Index of informational capacity based on information development about sustainability, environmental strategies and planning and data form the public sources.
- Index of biodiversity. It is based on the percentage of species in danger of extinction.

I.1 Objectives

The objective of this study is the application of the WPI methodology developed by Lawrence, Meigh and Sullivan (2002) in the Municipality of Juarez, Chihuahua, México, with the purpose of knowing the degree of sustainability of the water resources development of the region. A secondary objective is to integrate the Climate Vulnerability Index (CVI) to evaluate the flood vulnerability of the municipality.

II. METHODOLOGY

II.1 Construction of the Water Poverty Index

In the construction of the WPI the policy measures related to water availability are considered. There is a large number of people that suffer from water shortages and that they do not have the buying power to get the sufficient water for satisfying their basic needs, carrying out from time to time exhaustive physical efforts to get it sometimes from inadequate and unsafe water supply sources (Lawrence, Meigh and Sullivan, 2002).

Local studies that evaluate some of the main characteristics of water availability and management were considered. To obtain the values of each of the parameters, the following procedure was carried out:

- Search. Several institutions that contributed with the pertinent data for the index construction were identified. The National Institute of Statistics, Geography and Informatics (INEGI), the Observatory of the College of Border Northern (COLEF), The Water Utilities and Sanitation (JMAS), the Geographical Information System for Water Planning in El Paso del Norte region (Water Task Force), and The National Water Commission (NWC).
- Classification. The obtained information was classified based on the five components of the WPI
- Analysis. The data were analyzed in order to standardize them and to be able to make the comparisons and the corresponding calculations for each of the components that integrate the WPI.

Regarding water availability, it is necessary to consider the account of surface water, as well as groundwater and precipitation. The access parameter is not only related to drinking water, but also to water for irrigation. The capacity parameter measures the way to meet, buy, and manage the water supply. The use refers to domestic, agricultural, industrial and commercial use. The environmental factors are measured with relation to the impact that affects the resource availability (droughts, floods, etc.).

Some of the derived indicators are based on the Human Development Index (HDI), which considers three important parameters:

- Live span from the birth date. This is built taking into account the fraction of the difference between the real value by country with a minimum of 25 years and a maximum of 85. In this way, for the Municipality of Juarez with a life span of 75.5 years, will have an index of (75.5-25)/(85-25) = 0.84
- Educational Achievement. Index of adult literacy to basic medium, and higher education.
- Gross Domestic Product (GDP).

The HDI measures the economic and social progress that goes further than the measure of the national income and other indicators that are used to compare countries such as the National Index of Consumer Prices of (INPC), based on the Index of the Mexican basic food basket, and the GDP, among others. The advantage to have only one index is to provide just one parameter to illustrate where the country is found on a worldwide basis.

The Water Poverty Index, is determined by equation (1)

$$\text{Indicator} = \frac{X_i - X_{min}}{X_{max} - X_{min}} \quad (1)$$

Where:

Indicator = Resource, Access, Capacity and Use

X_i = Real value of each parameter of ***i*** country
X_{max} = Real value of each parameter of the country with the highest value
X_{min} = Real value of each parameter of the country with the lowest value

The fifth parameter (Environment) is determined by averaging the values obtained for each one of its components: quality, stress, regulation and management capacity, information and data capacity, and biodiversity.

The index shows the position with relation to a country or region. To determine each index, the value obtained of each parameter (resource, access, capacity, use and environment) through equation (1), will give as a result a value between 0 and 1, adjusting the maximum and minimums values for avoiding values that exceed the unit. The resulting value for each parameter is multiplied by 20 and the results are added to obtain the WPI final that should be found between 0 and 100 (Lawrence, Meigh and Sullivan, 2002).

II.2 Component Values of the WPI

For the calculation of the first four parameters that comprises the WPI (Resource, Access, Capacity and Use) is necessary to know the maximum and minimums values of it in different countries. For the fifth parameter (Environment) this was carried out by the average of the five components that integrate it. Table 1 shows the better and worse conditions on a worldwide basis of the parameters.

Table 1. Maximum and minimum values for the calculation of the WPI parameters

Country	Resource	Access	Capacity	Use
Iceland	**19.9**			
Kuwait	**0**			
Finland		**20**		
Eritrea		**2.8**		
Iceland			**19.2**	
Sierra Leone			**4.3**	
Guyana				**14.9**
Djibouti				**3.5**

II.3 The Climate Vulnerability Index (CVI)

Based on the experiences in the flood management during July and August 2006, an estimation of the vulnerability of the municipality was carried out. The estimate was included in the WPI, in order to re-examine the control water works situation of the region.

The Vulnerability factor is the level of exposition of an element or several elements to suffer negative effects as a consequence of the occurrence of a flood or another anthropogenic disturbance (Stephen O. Bender, 2006). The WPI has included the climate change, in order to know the whole human vulnerability. According to this the WPI is narrowly related to poverty. The incorporation of the vulnerability permits the government institutions to consider climatic changes that make vulnerable to a community or country.

The integrated CVI considers six important parameters, the five first are determined in the WPI (resource, access, capacity, use, and environment) and the sixth one is the Geospatial, parameter which is based on geographical characteristics of the region or country. In this manner, for developing cities and with mountainous zones as in the case of the Municipality of Juarez, the geospatial parameter takes into account the following subcomponents:

- Population Density
- Population living in informal housing
- Dependence to the imported food
- Dependence on water storage
- Geomorphologic, geographical and topographical characterization of the region
- Temperature
- Degree of soil degradation
- Loss of natural vegetation
- Social and economic infrastructure
- State protection through infrastructure and investment statewide and in the municipality.
- Health infrastructure (hospitals in case of disasters)
- Civil Protection
- Economic Sectors affected (Agriculture, industry, energy and transportation). Human aid agencies.
- Organizations interested in sustainable development and natural disasters mitigation
- Identification of potential basins to be affected. Mitigation programs
- Hydrologic analysis for warning systems. Monitoring (weather stations) contingency plans, etcetera.
- Flood areas delimitations

The Climate Vulnerability Index is determined by the equation (2):

$$\mathrm{CVI} = \frac{\sum_{i=1}^{N} w_i X_i}{\sum_{i=1}^{N} w_i} \qquad (2)$$

Where: X_i = Value obtained of each parameter
w_i = Weight of the component

The CVI includes the WPI parameters and considers at the same time the extreme events such as floods, hurricanes, droughts, etc. In this study the CVI was calculated based on the floods occurred in the municipality of Juarez and scored between zero and hundred.

III. RESULTS

The WPI value obtained in the Municipality of Juarez, Chihuahua, is **44.26**, which indicates a detrimental water condition for this region (Sulllivan, 2005). It is important to mention that the WPI at a regional level should be similar to the value at national level, if

climatic, physical, and geographical similarities in the different regions of the country exist (Lawrence, et al. 2002).

In this case, the value obtained is found to be under the national value (57.5), due to the low water management efficiency, the collapse of the Bolson del Hueco aquifer which is the main water supply source for the city, the lack of administrative autonomy of the local Water Utilities and Sanitation (JMAS) and excessive water use by some population sectors. Besides, the municipality is located in a desert zone of the country. This contributes to the reduction of the WPI value in this region.

III.1 WPI values for the Municipality of Juarez

Based on the available data, the calculation of the values for each of the components of the five parameters was carried out. Table 2 shows the value of each parameter of the WPI.

Table 2. Values obtained of each parameter of the WPI

Region	Component Values					
Municipality of Juarez	Resource	Access	Capacity	Use	Environmental	WPI
	17.64	51.33	54.36	56.22	41.75	44.26

III.2 Climate Vulnerability Index applied to the Municipality of Juarez

The CVI was calculated based on the values obtained from the WPI parameters and the inclusion of the geospatial parameter established for the region. Table 3 illustrates the variables that compose the CVI.

Table 3. Values obtained of each parameter of the CVI

Region	Component Values						
Municipality of Juarez	Resource	Access	Capacity	Use	Environmental	Geospacial	CVI
	17.64	51.33	54.36	56.22	41.75	65.12	47.74

The values of each of the six components of the Climate Vulnerability Index (CVI) can be shown in a hexagram to understand the behavior of each of them in a simple and clear way, which permits the comparison and analysis of the values obtained (See Figure 1).

The CVI obtained is **47.74**, which corresponds to a classification of upper-middle vulnerability and among countries as Nepal with 46.3 and Bhutan with 45.0. The CVI shows the vulnerability of the people before extreme situations as the torrential rains (return period of 100 years) occurred in 2006 in the Municipality of Juarez caused by the climatic change and as a result of the global warming. The damages produced by the floods were considerable. The environmental, economic, and social costs are difficult to overcome, but is possible to minimize them though wise and preventing programs, projects and activities aimed to reduce the vulnerability of the social and economic infrastructure.

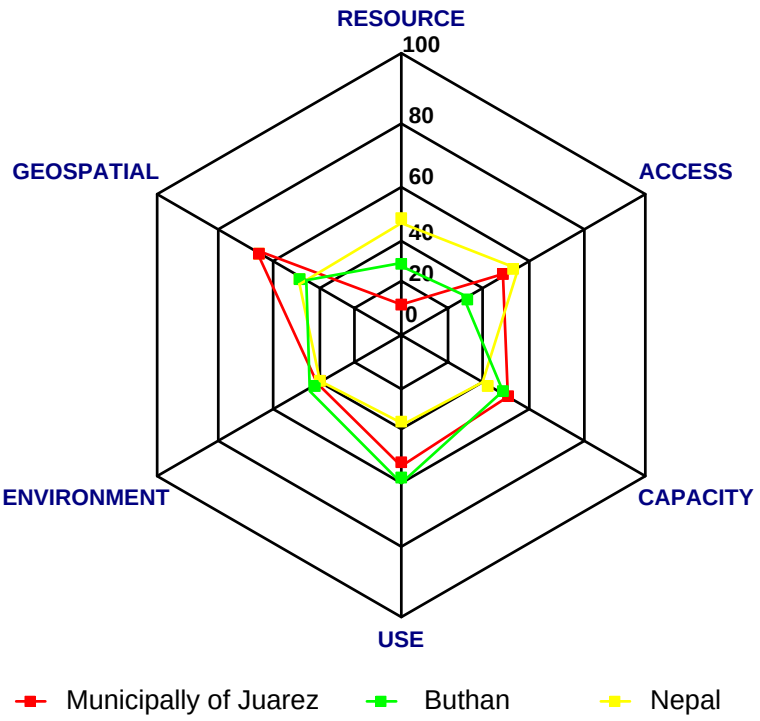

Figure 1. Results for each component of the CVI

IV. CONCLUSIONS

The observed Water Poverty Index reflects the vulnerable situation of the Municipality of Juarez in regards to water resources as a consequence of the inefficient water management, the excessive water use in the three sectors (domestic, industrial and agricultural) and the geographical location of the municipality. A desert zone will contribute to the decrease of the WPI value, however an improvement of the WPI for this region would come mainly from the enhancement of the factors that play a role on the access, capacity and use variables.

Diminishing the urban daily consumption, water recycling and reuse etc can enhance the water poverty situation. It is worthy to emphasize the necessity of establish water conservation and preservation projects for the whole region. Particularly the component Capacity should be improved through better water policies and actions

The industrial growth has generated a strong immigration rate for this region and that is reflected in the observed annual population growth of 4.5%. This has increased the pressure on water demand and as a consequence to the prevailing conditions it is expected that the Bolson del Hueco aquifer would be exhausted by the year 2030.

On the other hand the Climate Vulnerability Index as an additional part of the WPI provided the necessary elements to describe the vulnerability for future water contingency situations. The CVI is an important tool for the implementation of policy plans by the corresponding governmental institutions.

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