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WATER POVERTY INDEX IN SUBTROPICAL ZONES: THE CASE OF HUASTECA POTOSINA, MEXICO

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ABSTRACT

Tools are needed in order to evaluate an integrated water resource management, and to encourage the management and coordinated usage of water resources along with the environmental and socioeconomic factors. One of those tools is the Water Poverty Index (WPI), which enables the evaluation of water poverty in terms of the physical and socioeconomic factors related to water availability. The WPI, as calculated in this study, is derived from the weighted sum of six key components –resources, access, usage, capacity, quality and environment– on a scale of 0 to 100. The objective of this work was to calculate the Río Valles Basin WPI for 2010. This region is a semi-tropical area with abundant water resources, such as large springs. Its annual mean precipitation is 1100 mm. In the Río Valles Basin, the volume of surface water used per year is 81.33 Mm^3, which represents 91 % of the total resource. The volume of groundwater used per year is 8.17 Mm^3, representing the remaining 9 %. Usually 45 Mm^3/year is stored in La Lajilla dam. These data indicate that surface water is the main source of supply for uses such as agriculture, which is the activity with the largest water demand. A WPI score of 59 was obtained for the Río Valles Basin.

Palabras clave: acceso al agua, calidad de agua, disponibilidad de agua, desarrollo humano, recursos hídricos, Río Valles

RESUMEN

Para evaluar la gestión integrada de los recursos hídricos se necesitan herramientas para fomentar su administración y uso coordinado con el ambiente y los factores socioeconómicos. Una de estas herramientas es el Índice de Pobreza del Agua (IPA), que permite evaluar la pobreza del agua en términos de los factores físicos y socioeconómicos relacionados con su disponibilidad. El IPA, como se calculó en este estudio, se deriva de la suma ponderada de seis componentes clave: el acceso, el uso, la capacidad, la calidad y el ambiente, en una escala de 0 a 100. El objetivo de este trabajo fue calcular el IPA de la cuenca del Río Valles para el año 2010. Esta región es semitropical, con abundantes recursos hídricos, como grandes manantiales y una precipitación media anual de 1100 mm. En la cuenca del Río Valles el volumen de agua superficial utilizada es de 81.33 Mm^3/año, lo que representa el 91 % del total del recurso utilizado. El volumen de agua subterránea utilizada es de 8.17 Mm^3/año, lo que representa el 9 % restante, normalmente se almacenan 45 Mm^3/año en la presa de La Lajilla. Estos datos indican que el agua superficial es la principal fuente de abasto para diversos usos como la agricultura que es la actividad con la mayor demanda de agua. El IPA que se obtuvo para la cuenca del Río Valles fue de 59 puntos.

INTRODUCTION

Integrated Water Resources Management (IWRM) is a process to foster the management and coordinated usage of water resources, as well as the environmental and socioeconomic factors in order to maximize social and economic benefits in an equitable manner without compromising the sustainability of vital ecosystems (IWRM-UNESCO 2009). To evaluate IWRM, tools are needed and those should take into account these elements. One of those tools is the Water Poverty Index (WPI), which makes it possible to evaluate water poverty in different study scales –countries, regions or communities– taking into account physical and socioeconomic factors related to the availability of water (Lawrence *et al*. 2002).

The WPI is evaluated based on five components: water resources, access, capacity, usage and environment. These components enable establishing connections between poverty, social marginalization, environmental integrity, water availability and health. The WPI has been applied at an international level by Lawrence *et al.* (2002) and recently in a semi-arid region such as the San Luis Potosí Valley (SLPV) by López-Álvarez *et al.* (2013).

The objective of this work was to calculate the WPI in a semi-tropical region with abundant water resources, specifically at the Río Valles Basin (RVB). This region is located in eastern Mexico on the boundary of the Eastern Sierra Madre (**Fig. 1**), in the states of Tamaulipas and San Luis Potosí (SLP). The latter is facing serious problems regarding the availability of water resources. The study was conducted in the specific region known as Huasteca Potosina where rainfall is higher than the national mean (Santacruz 2007). In 2010 the RVB had a population of 255 452 inhabitants (INEGI 2010) with 91 % dependence on surface water.

The RVB comprises the following cities and municipalities: municipality of Aquismón, Cities of Maíz, Ciudad Valles, El Naranjo and Tamasopo in San Luis Potosí and the municipalities of Antiguo Morelos, Nuevo Morelos, Ocampo and Tula in Tamaulipas (**Fig. 1**).

Development of the WPI for Huasteca Potosina

The WPI is based on the structure and methodologies proposed by UNESCO in the Human Development Index as part of the United Nations Development Programme (2002).

The methodology proposed by Lawrence *et al.* (2002) includes five key components. Nevertheless, the application of the WPI to the RVB included water quality as an additional component (**Table I**) since Mexico's surface and groundwater have serious levels of natural and/or anthropic pollution, thereby limiting its use (Santacruz 2007, Carranco-Lozada 2013).

Although this methodology includes six basic components, depending on different scenarios, subcomponents could be also considered. For instance, in the Resource component where groundwater is included, the aquifers in the system could be the subcomponents (López-Álvarez *et al.* 2013). In terms of the subcomponents of surface water these could be represented by different water bodies (reservoirs and rivers) in the study area. In addition, for the Quality of the resource both, groundwater or surface water subcomponent has its own quality value (López-Álvarez *et al.* 2013). Regarding the Usage component this could be subdivided into urban, agricultural and industrial usage as subcomponents. Socioeconomic data related to a population can be used as subcomponent of Access and Capacity. For the component of Environment, data such as land use, erosion rate, flood zones, natural protected areas, vegetation types, and endangered and protected animal spatial distribution could be used as subcomponents. In general the evaluation of each component can be as complex as the amount and quality of information available.

The mathematical structure on which the WPI is based is expressed as:

$$WPI_i = \frac{\sum_{i=1}^{N} w_{Xi} X_i}{\sum_{i=1}^{N} w_{Xi}} \tag{1}$$

where WPI_i is the Water Poverty Index for a particular region, w_{Xi} is the weighted factor and X_i is the value

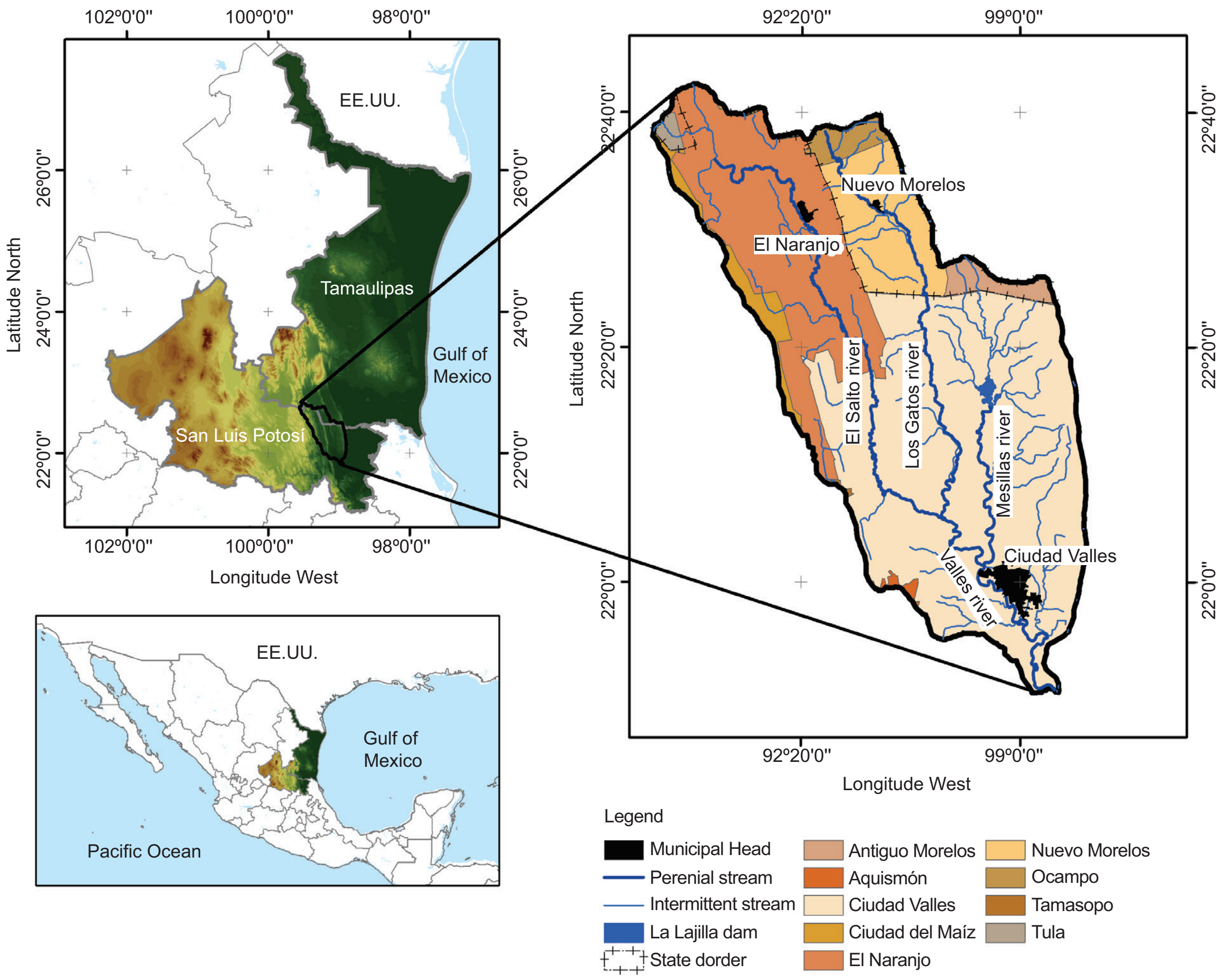


Fig. 1. Location of the Río Valles Basin

of component *i*. The WPI is the result of the weighted sum of the components: Resources (R), Access (A), Usage (U), Capacity (C), Environment (E) and Water Quality (Q).

Equation (1) can also be expressed in a further developed form (equation 2). To standardize the results and produce a WPI value between 0 and 1, the sum needs to be divided by the sum of the weights, as shown:

$$WPI_i = \frac{w_r R + w_a A + w_c C + w_u U + w_e E + w_q Q}{w_r + w_a + w_c + w_u + w_e + w_q} \qquad (2)$$

For most components a weight analysis is applied to define the importance of each subcomponent (Ramos 2002). The weight analysis is expressed as (equation 3):

$$Wx_i = \frac{Xr_i * Xw_i}{\sum_{i=1}^{N} W_i} \qquad (3)$$

where Xr_i and Xw_i are the scores for each X_i component and their theoretical weights and W_i is the sum of the theoretical weights.

Since each component can be formed by more than one subcomponent, the weight *w* applied to each subcomponent (Xa_i) in the WPI structure can be obtained from the values associated with the subcomponents. For example, in the case of the Resource component percentages related to the management of the different supply sources can be used as weights. For the Access component, percentages of the population with access to drinking water or with water treatment systems and percentages of agricultural lands with access to irrigation can be considered as weights for these subcomponents. For the Capacity component socioeconomic conditions, population income data, mortality rates of children under 5 years of age, the education index and the Gini coefficient can be used as weight elements. Percentage of water used for domestic, agricultural

TABLE I. KEY COMPONENTS IN THE WATER POVERTY INDEX (Adapted from Lawrence *et al.* 2002)

Water Poverty Index Component	Definition	Sub-components
Resource (R)	Physical availability of surface and groundwater, considering its use and water balance	• Surface water • Groundwater • Volume used
Access (A)	Level of access to clean water for human use	• % of the population with access to drinking water • % of population with access to water treatment. • % of agricultural land with access to irrigation
Capacity (C)	Efficacy of the human population's capacity to manage water	• Income • Mortality rate of children under 5 years • Education index • Gini coefficient
Usage (U)	Ways in which water is used for different purposes, including domestic, agricultural and industrial uses	• Domestic water use (L/day) • Adjusted % of water used for agriculture and industry, based on the sector's contribution to the GDP
Environment (A)	Evaluation of environmental integrity related to water	• Land use • Natural Protected Areas
Water quality (Q)	Evaluation of water quality for human use	• Surface and groundwater quality data

and industrial purposes can be used as weights for the Usage component. Whereas percentages in land use changes in natural protected areas can be considered weights for the component of Environment. Finally for the Quality component the management of different supply sources can be used as weight for indices to evaluate water quality.

For each component, the sum of the subcomponents multiplied by a weight factor must equal 1. To obtain the final value, the WPI needs to be normalized by weighting once more the subcomponents and the sum should equal 1. The assigned weights depend on the degree of importance or influence of each component in each region. The weight *wi* is assigned to each component (X_i) in the WPI structure for that region. It is worth mentioning that the results can be expressed as a score ranging from 0 to 100.

The results for each component in this methodology can be graphed as a polygon whose edges represent 100 % of each component. When normalized, the maximum is 1 and the center of the polygon is 0. The ideal polygon is that in which all the WPI components have values of 1 and form a hexagon. As more values with less than 1 are present, they move further away from the hexagon and form an irregular polygon.

Resources (R)

The RVB is in Hydrological Region 26. It has an approximate area of 3216 km^2 and is divided into four subbasins: "Río Los Gatos", "Río El Salto", "Río Mesillas" and "Río Valles". It is located in the drainage area of the Eastern Sierra Madre as evidenced by the large springs found in the Huasteca Potosina region (**Fig. 1**).

The climates are sub-humid with medium and high humidity and summer rains, and semi-hot and sub-humid with summer rains. The annual mean precipitation is 1100 mm –higher than the national mean of 772 mm (Santacruz 2008). The volume of water used in the RVB is 81.33 Mm^3/year for surface water, which represents 91 % of the total resource used and 8.17 Mm^3/year for groundwater, representing the remaining 9 %. Usually 45 Mm^3/year are stored in La Lajilla dam. These data indicate that surface water is the primary resource in the studied basin.

The weights assigned to the Resource subcomponents were derived from the percentages of surface and groundwater sources used as seen in equation 4 in the following mathematical expression (López-Álvarez *et al.* 2013):

$$R = 0.91 A\sup + 0.09 Asub \tag{4}$$

$$Asur\left(Mm^3\right) = \frac{Stored\ volume}{Vol.\ annual\ precipitation} \qquad (4.1)$$

$$Agrn(Mm^3) = \frac{Recharg\ - Extraction}{2Extraction} \qquad (4.2)$$

Access (A)

Seventy-five percent of the population in the RVB lives in Ciudad Valles, El Naranjo and Nuevo Morelos. These three population centers contain most of the drinking water (90 % coverage) and water treatment (30 % coverage) services (**Fig. 2**). The rest of the population (38 694 inhabitants) lives in small and dispersed localities lacking public services (INEGI 2010a).

A total of 81.2 % of the Economically Active Population (EAP) works in the three population centers mentioned, performing secondary and tertiary activities. The remaining percentage works in the primary sector (agriculture and livestock). For this sector there are 84 405 ha of agricultural land, 12 399 of which have some kind of irrigation system (INEGI 2007).

The Access (A) component includes the percentage of the population with access to piped water (A_{ap}) for their basic needs, the percentage of water that is treated (A_t), and the relationship of agricultural land with and without access to irrigation (A_i). The expression (equation 5) that defines this component is (López-Álvarez *et al.* 2013):

$$A = 0.6A_{ap} + 0.3A_t + 0.1A_i \qquad (5)$$

The subcomponents were weighted using a weight analysis (Ramos 2002, López-Álvarez *et al.* 2013) which shows subcomponent A_{ap} as the most significant and A_i as the least significant.

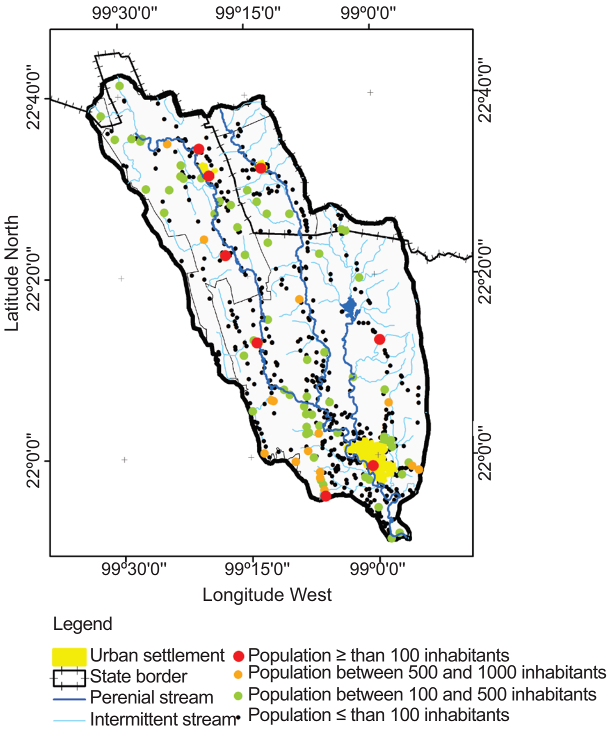


Fig. 2. Distribution of the human population in the Río Valles Basin

Capacity (C)

In Mexico, the Human Development Index (HDI) is evaluated at municipal level. Although the RVB covers several municipalities, only three have notable social and economic influence (Santacruz 2007): Nuevo Morelos, El Naranjo and Ciudad Valles. The municipality of Nuevo Morelos, Tamaulipas, had a HDI of 0.753 (placing it at 35 out of 43) in 2005, which was below the state mean (0.85) for that year. El Naranjo and Ciudad Valles, in San Luis Potosí, had an HDI of 0.810 (9 out of 58) and 0.838 (4 out of 58), respectively. Of these municipalities only Ciudad Valles was above the state mean of 0.816.

The (C) component was evaluated based on the HDI. It evaluates the socioeconomic variables that can affect access to water or reflect access as well as its the quality. The Gini coefficient is introduced to adjust the capacity to access clean water according to a measurement of the unequal distribution of income (Lawrence *et al.* 2002).

The subcomponents are: income index (I_i), mortality rate for children under 5 years of age (M_i), education index (I_e) and the Gini coefficient (C_G).

Capacity is evaluated by the equation 6 (López-Álvarez *et al.* 2013):

$$C = 0.5I_i + 0.1M_i + 0.2I_e + 0.2C_G \qquad (6)$$

Weights were assigned to the subcomponents using a weight analysis (Ramos 2002, López-Álvarez *et al.* 2013), which indicates that subcomponent I_i is the most significant, I_e and C_G have medium significance and M_i is the least significant.

Usage (U)

The RVB presents biophysical conditions that favor certain water uses. Its subbasins have particular conditions that make them more or less "suitable" for a specific use. Since the last decades of the 19th century and the early decades of the 20th century, the

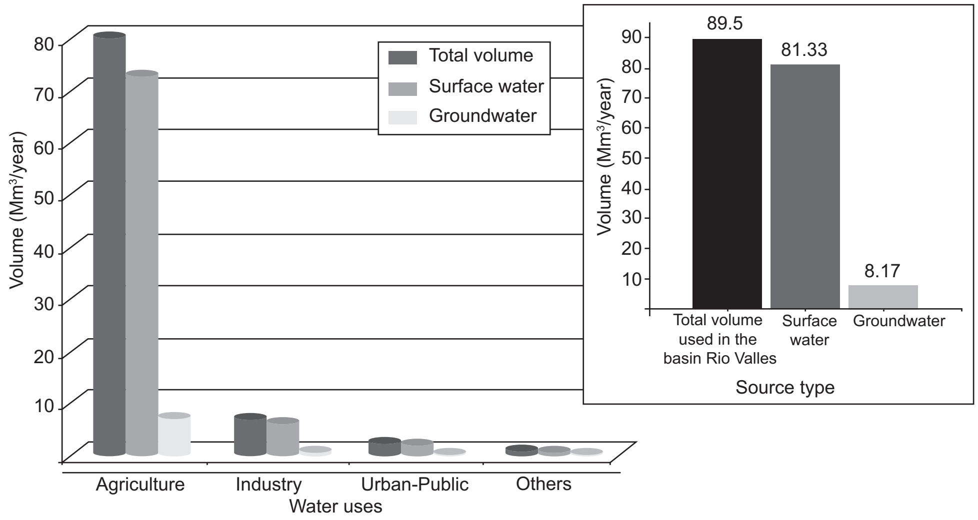


Fig. 3. Volume of water used and extracted from different water bodies, mainly in the Valles River. Poner "mm" en minúscula las dos en ambas gráficas

water usage has reflected the advances in technology of the period. The volume of water used and extracted from different water bodies, primarily the Valles River is 89.85 Mm^3/year, according to the Comisión Nacional del Agua (National Water Commission, CONAGUA, Spanish acronym) and the Registro Público de Derechos del Agua (Public Water Rights Record, REPDA, Spanish acronym). From this 89.85 Mm^3/year, 89.2 % is used in agriculture for irrigating crops, such as sugar cane (*Saccharum officinarum)*. A total of 81.06 % of the volume of water used in agriculture comes from surface sources and the rest from groundwater (**Fig. 3**).

In the RVB 7.53 % of the water volume extracted is for agro-industrial uses and 2.43 % for public-urban uses.

This component includes three subcomponents: water for domestic use (U_d), water for agro-industrial use (U_i) and water for agricultural use (U_a). It is determined from equation 7 (López-Álvarez *et al.* 2013):

$$U = 0.02U_d + 0.08U_i + 0.9U_a \tag{7}$$

The weight assigned to the subcomponents is based on the percentage of water used in the RVB.

It is worth mentioning that for domestic use, the amount of drinking water used per inhabitant per day must be taken into account. For the RVB the average amount of drinking water used is 200 L/hab/day (PHE 2000).

To determine agro-industrial water usage, a relationship was established between the proportion of the gross domestic product (GDP) generated from this activity and the amount of water used. This relationship was applied to water for agricultural use and provides an approximate measurement of the efficiency of water usage (Lawrence *et al*. 2002). Agro-industry and agriculture in the RVB represents 4 and 1 % of the state GDP, respectively (INEGI 2010b).

Environment (E)

Rainfed and irrigated agriculture in the RVB are based on sugar cane crops. The increased area planted with this crop had also led to a growing demand for irrigation water and has expanded the agricultural boundaries into areas that formerly contained tropical forests.

This expansion of the agricultural boundaries was evaluated with information related to land use and vegetation type from the years 1970 to 2000 (**Table II**). Rainfed agriculture expanded during the study from 313.2 km^2 to 717.79 km^2. While this activity is significant in all four subbasins, rainfed agriculture grew 177.66 km^2 in the "Río Los Gatos" and 92.55 km^2 in the "Río Valles" subbasins (**Fig. 4**).

The increase in rainfed agricultural area mostly coincides with the decrease in the lowland deciduous and sub-deciduous woodland during the study. Over 24 years the area of the "Río Los Gatos" subbasin, with lowland deciduous and sub-deciduous woodland, decreased from 546.63 km^2 to 351.00 km^2. That is a reduction of 195.63 km^2 (35.78 %). The same situation occurred in the "Río Mesillas" subbasin that lost 173.97 km^2 of deciduous woodland during the same period of time (Santacruz 2007).

TABLE II. RATE OF CHANGE (% AND km^2) IN VEGETATION TYPE AND LAND USE IN THE RÍO VALLES BASIN BETWEEN 1976 AND 2000

Land use and vegetation	Entire basin			
	1976	2000	Change	
			(km^2)	(%)
Irrigated agriculture	82.32	135.19	52.86	64.22
Rainfed agriculture	313.02	717.79	**404.78**	129.31
Introduced and cultivated pastures	372.2	481.86	109.65	29.46
Jungle medium evergreen sub-evergreen	48.4	32.51	-15.88	–32.83
Lowland deciduous and sub-deciduous woodland	1857.5	1329.11	**–528.38**	–28.44
Palm forest	88.54	41.23	–47.31	–53.43
Human settlements	9.27	29.32	20.04	216.28
Water bodies	8.16	9.23	1.07	13.11
Oak forests	399.94	410.78	10.84	2.71
Mountain mesophytic forest	11.21	10.42	–0.79	7.04
Xeric shrublands	7.74	1.45	–6.28	81.13

Source: Santacruz (2007 and 2012).

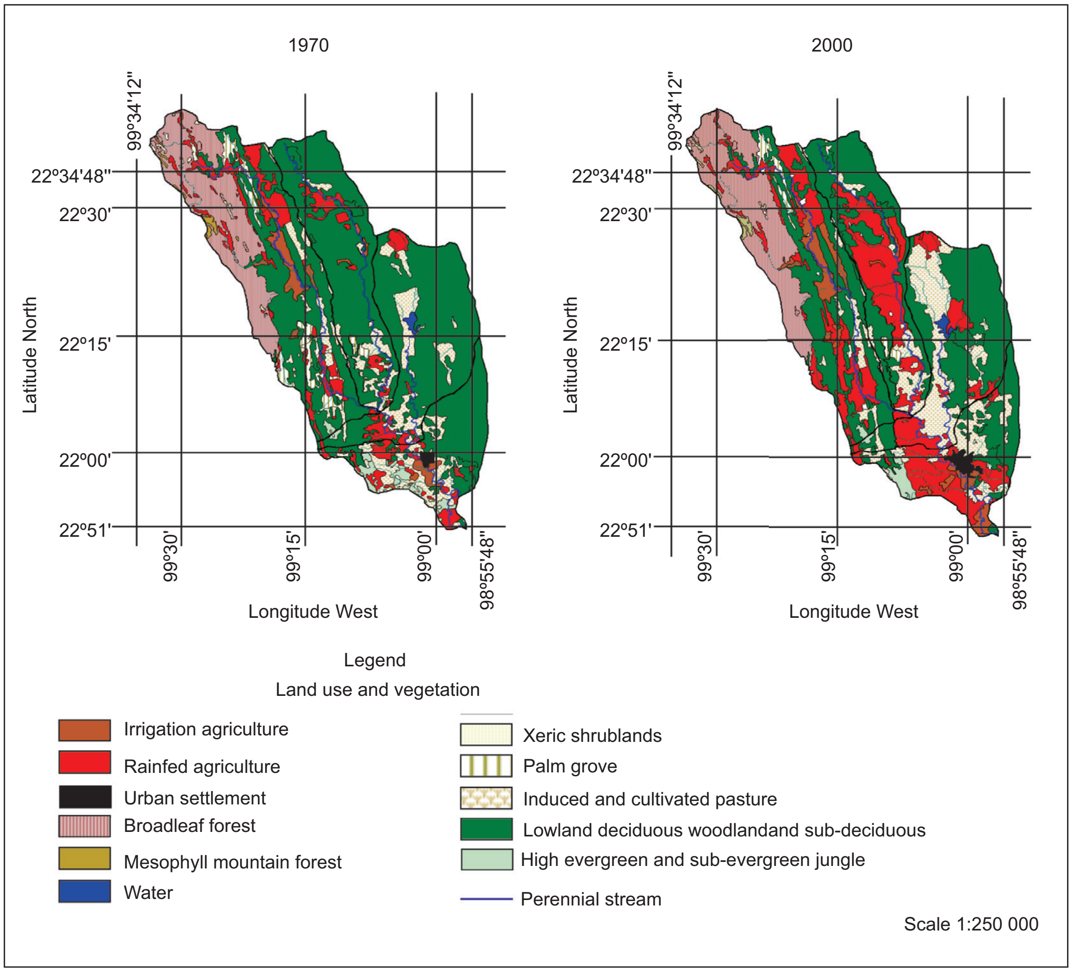


Fig. 4. Vegetation type and Land Use in the Río Valles Basin between 1970 and 2000. CAMBIAR “Low deciduous jungle and sub-deciduous” POR “Lowland deciduous and sub-deciduous tropical forest” Y “High evergreen jungle y sub-evergreen” POR “Highland evergreen and sub-evergreen tropical forest”

Overall the RVB lost 544.26 km^2 of its jungles and 10.84 km^2 of its forests between 1976 and 2000, resulting in a deforestation rate of 1.18 % (Santacruz 2007). This value is slightly higher than the annual 0.65 and 0.76% at national level, with similar vegetation types during the same studied period (Reyes *et al.* 2006).

The evaluation was carried out at a scale of 0 to 100 %, where the category of 0 to 20 represents very small changes, 20 to 40 small changes, 40 to 60 medium changes, 60 to 80 large changes and 80 to 100 very large changes. Therefore, the score of 0 to 20 % would be the most favorable to the WPI, since it would represent little change in the natural vegetation. On the other hand, the score of 80 to 100 % would represent nearly a total loss of natural vegetation in the basin.

Quality (Q)

Water is indispensable for human life. Both, its quality and quantity are important and its degradation impacts the environment and, in particular, human health (Azqueta 2002, Soares 2003). Water pollution can occur from natural or anthropogenic causes. The improper management of water resources is one of the main reasons for its deterioration. UNESCO (1998) indicates that an evaluation of the quality and quantity of available water is a prerequisite for the development and management of water resources.

In the RVB, CONAGUA has different water quality monitoring stations, primarily in the "Río El Salto" and "Río Valles" subbasins. In terms of the physical, chemical and bacteriological information regarding water quality at these monitoring stations, the temporal behavior of quality parameters were determined and compared with the maximum allowable limits according to the Mexican regulation NOM-127-SSA1-1994. It is important to mention that only Ciudad Valles has wastewater treatment plants (whose operations and efficiency is questionable). Domestic wastewater is discharged directly into receptor water bodies, increasing the presence of pollutants, especially those that are bacteriological.

The values for total and fecal coliforms (NMP/ 100 mL) were over 0 (**Fig. 5**) in all the samples taken in the "Río El Salto" subbasin.

The presence of bacteriological pollution in the main water supply source reduces considerably the availability of water for human use purposes in the basin. At the monitoring stations named AADAPA and Birmania by CONAGUA –the latter being downstream from the former– the most probable number (MPN) in the samples taken in the year 2005 varied from 47 000 to 700 000 MPN/100 mL. Sánchez and Hernández (1996) found total coliform

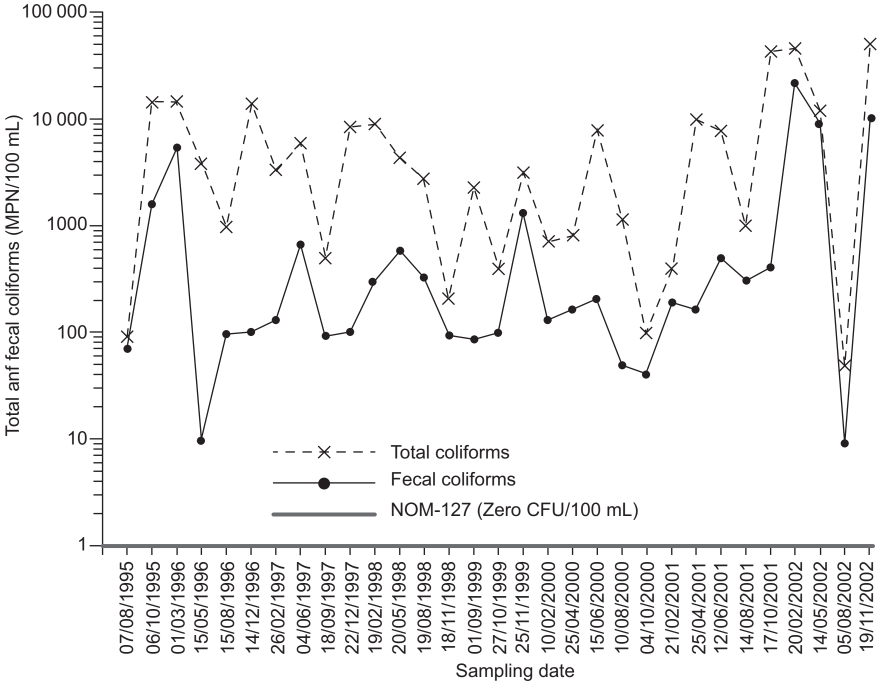


Fig. 5. Bacteriological analysis of water from the "Río Valles" and the "Río El Salto" subbasins.
Source: Santacruz (2007) and NOM-127-SSA1 (1994)

values of 2500 MPN/100 mL at different points located throughout the main channel in this subbasin. They also detected the presence of enterobacteria such as *Escherichia coli, Proteus, Klebsiella pneumoniae, Shigella dysenteriae* and *Serratia marcescens*.

This component was evaluated using the Water Quality Index (WQI) developed by Mcclelland (1974). This index is a numerical representation of the chemical parameter analyzed. The index is obtained from adding and pondering the specific weights obtained from a geometric mean (equation 8):

$$WQA = k\frac{\sum C_i P_i}{\sum P_i} \tag{8}$$

where C_i is the percentage value assigned to the parameters, P_i is the weight assigned to each parameter, k is the constant which takes the value of 1 for clear water with no apparent pollution, 0.75 for clear water with a slight color, foam, and slight unnatural apparent turbidity, 0.50 for water with a contaminated appearance and 0.25 for sewage with fermentations and odors.

To obtain the water quality component for the surface and groundwater available in the study area, the following expression is used (López-Álvarez *et al.* 2013, equation 9):

$$Q = 0.91Q_{Asur} + 0.09Q_{Agrn} \tag{9}$$

where Q_{Asur} and Q_{Agrn} are the WQI for surface and groundwater from the aquifer, respectively. The weight factors (0.91 and 0.09) used in this component were assigned according to the percentage of usage from these sources in the region.

On a scale of 0 to 100, the maximum value of 100 represents excellent quality and values under 50 represent serious pollution problems.

RESULTS AND DISCUSSION

The following results were obtained after analyzing the information to evaluate each component for the RVB.

Resources

Given the orographic and climatic conditions in the RVB, during the rainy season large flows occur, frequently causing flooding in the lower parts of the basin. Consequently, surface water is abundant and provides the main source (91 %) of water for different activities in the region.

From a geological perspective, groundwater circulates in highly fractured limestone with dissolution cavities (karst area), resulting in large recharges of the aquifer (Morán-Ramírez *et al.* 2013). The abundant surface water generates low demand for groundwater, therefore, the amount of deep wells is low compared to other regions in Mexico. Very little groundwater is used, representing only 9 % of the total water use in the RVB.

To evaluate the normalized R parameter, value 1 represents abundant water resources. This component was evaluated with an equation that includes extreme scenarios, in which the value 0.5 represents a balance of the resource in the aquifers and values less than 0.5 represent the depletion of the aquifer (López-Álvarez *et al.* 2013).

In the case of the RVB, a value of 0.97 was obtained for this component, which is consistent with the climatological conditions and the abundant water resources in the study area.

Quality

Although surface water is abundant and serves as the main source for a variety of economic activities, its domestic use is limited because its quality is very poor for human consumption. For example, water from the Río Valles contains total coliform values of as much as 273 000 CFU and fecal coliform values of 170 000 CFU, causing gastrointestinal and dermatological illnesses among the human population (Gómez and Velarde 1996).

The WQI score was 51 for surface water and 66.7 for the aquifer (Santacruz and Ramos 2010). These values were used in equation (9), based on which the score of 0.52 for component *Q* was obtained. While this limits its use for human consumption, it is acceptable for agricultural irrigation (Santacruz and Ramos 2010).

Usage

Regarding this component, agricultural activity plays an important role and demands a high volume of the resource for gravity irrigation systems, whose maximum efficiency is estimated at 50 %. The value of its production has little influence on the state's GDP and the regional economy.

Domestic use is deficient because most of the drinking water services are located in the municipal capital of Ciudad Valles while the rest of the localities lack these services.

The evaluation of this component resulted in a normalized U value of 0.052, which reflects the socioeconomic conditions in the study zone.

Access

The rural population in the RVB is dispersed, while most of the urban population is gathered in three municipalities where drinking water services are centralized, particularly wastewater treatment in Ciudad Valles. The rest of the municipalities have less and dispersed population, therefore, access to these services is limited.

A normalized value of 0.31 was obtained due to the centralization of drinking water and treatment services in the main population centers and the lack of those services in rural localities.

Capacity

In the city of San Luis Potosí, a notable concentration of services and economic activity exists. This situation polarizes the socioeconomic conditions in the rest of the state, and therefore the HDI in the study zone is low.

The mortality rate, income and Gini coefficient used to evaluate the Capacity component gave similar values to those obtained in the SLP Valley (López-Álvarez *et al.* 2013), while the education indices were lower than those obtained in the SLPV, which is reflected in the normalized score of 0.35 for this component.

Environment

Land use changes in the RVB were considered to evaluate the environment component. The modified natural area is approximately 588 km^2, which represents 24 % of the total area of the RVB, a value of 0.9 was assigned to this component. This is consistent with land use changes in the region, where tropical rain forests have been converted into irrigated agricultural land. This land use change has less impact than in other regions of SLP where natural vegetation has been turned into urban use or deforestation without recovery had occurred (López-Álvarez *et al.* 2013).

Water Poverty Index for the RVB

The resulting polygon for the RVB reflects serious problems with usage, access and capacity. On the other hand water quality, for instance, is the least problematic in its evaluation, and the environmental and resource components also have favorable conditions (**Fig. 6**).

Table III presents the scores obtained for each component and their weights, as well as the overall WPI for the RVB, with a score of 59.

TABLE III. VALUES OBTAINED FOR EACH COMPONENT OF THE WATER POVERTY INDEX OF RÍO VALLES BASIN

Component	Score	Weight	Water Poverty Index
Resource	0.97	30	59
Quality	0.52	20	
Use	0.05	10	
Access	0.31	15	
Capacity	0.35	15	
Environment	0.90	10	

If we compare this value with those obtained by Lawrence *et al.* (2002), that are not normalized, it is far from the scores of developed countries, such as Finland with a WPI of 78. The WPI in the RVB is higher than those in underdeveloped countries with water poverty problems, such as Haiti with a WPI of 35.1, and is even higher than the WPI for Mexico and the SLPV, with values of 57.5 and 46, respectively.

The WPI value for the RVB (59) is probably due to the high availability of water and the low environmental effects in this area. Nevertheless it indicates that the rural population does not have access to the resource, its socioeconomic situation is unequal and the use of water is deficient (**Fig. 6**).

Contrasts can be seen when comparing the WPI in the SLPV with that of the RVB (**Fig. 7**). The resource is abundant in the RVB while scarce in the SLPV. In addition, access and the capacity components are deficient in the RVB whereas in the SLPV there is a more efficient management of this resource.

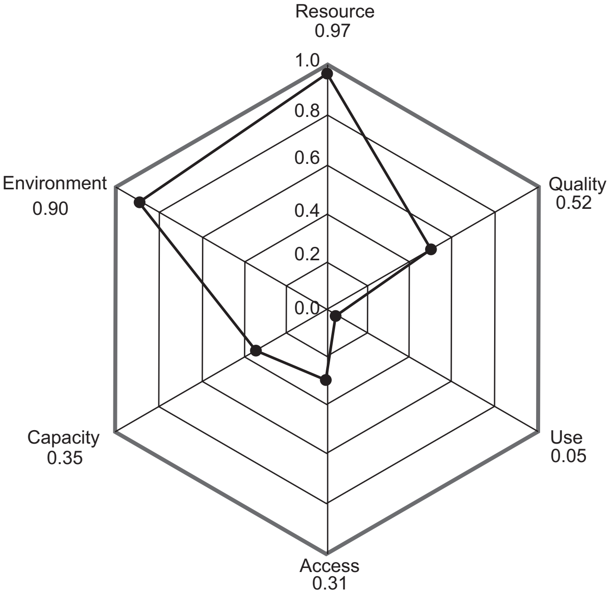
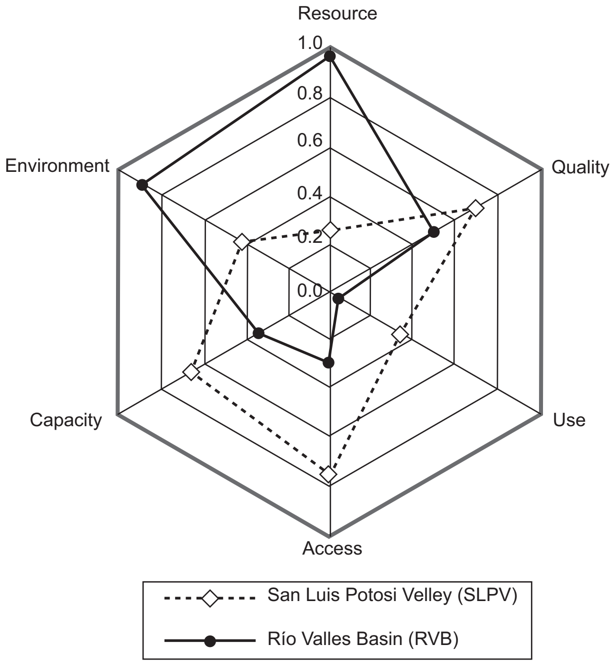


Fig.6. Normalized Water Poverty Index Hexagon for the Río Valles Basin



Component	Score	
	SLPV	RVB
Resource	0.26	0.97
Quality	0.74	0.70
Use	0.29	0.05
Access	0.75	0.31
Capacity	0.63	0.35
Environment	0.40	0.90

Fig. 7. Normalized Water Poverty Index Hexagon for the Río Valles Basin and the San Luis Potosí Valley

Throughout history, the environment in the SLPV has undergone irreversible changes, such as deforestation and depletion and pollution of surface and groundwater resources. Nevertheless, the environmental changes in the RVB are reversible and deforested zones may be recovered in a short period of time. In terms of the resource, recharge is high and flows are very dynamic because of the karstic characteristic of the rock.

The above analysis shows that the abundance of the resource does not ensure better socioeconomic development in a region.

CONCLUSIONS

Geographic, geological, orographic and climatic conditions are factors that enhance the abundance of the resource (R), resulting in a value of 0.97.

Land use changes in the RVB have had little impact on the environment because the loss of natural vegetation cover was replaced by irrigated agriculture, resulting in a value of 0.9 for the environmental component (E).

In terms of the quality (Q) of water for human consumption, treatment is required. Nevertheless, it is adequate for agricultural uses and a value of 0.52 was obtained.

Regarding capacity (C), a value of 0.35 was achieved, which reflects the centralization of the economical activity in the area, that is focused mainly in one municipality, while the rest of the localities are left behind.

Seventy five percent of the human population living in the RVB is localized in Ciudad Valles, El Naranjo and Nuevo Morelos. This population has access to clean water, but there are deficient wastewater treatment services and adequate access to irrigation water. The rest of the population (25 %) has deficient or no access (A) to the resource, as reflected by a score of 0.31.

The main use of water is for agriculture, which is the largest activity in the region. Nonetheless, the usage (U) does not significantly contribute to the state´s GDP, as reflected by a value of 0.05 for this component. In addition, domestic use is centered primarily in Ciudad Valles, whereas services for the rest of the population in the RVB are deficient.

The evaluation of the WPI for the RVB demonstrates that water poverty levels in a region are not determined by the quantity of the resource but rather by its efficient management and use. Therefore, the WPI could be a useful tool for integrated water resources management.

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