CHEMICAL ENGINEERING TRANSACTIONS
VOL. 98, 2023
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it
Guest Editors: Sauro Pierucci, Carlo Pirola

ISBN 978-88-95608-97-6; **ISSN** 2283-9216
DOI: 10.3303/CET2398026

Socioeconomic and Environmental Analysis Based on Water Sustainability Index in the Juan Angola Creek (Cartagena, Colombia)

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Cartagena is one of the cities with the greatest historical and cultural heritage in Colombia. It is surrounded by a system of islands, lagoons, creeks, and swamps among other water bodies. The Juan Angola creek is one of the most representative water bodies in the city of Cartagena due to the areas it covers. However, it currently has serious pollution problems. In this research, the impact generated by the population settled on Juan Angola creek is studied through the evaluation of socioeconomic indicators. A characterization of the environment adjacent to Juan Angola creek which included social, economic, educational, environmental, and cultural aspects, based on information from government databases was done. Considering the above, the socioeconomic indicators based on the adaptation of the West Java Water Sustainability Index (WJWSI) method were evaluated. For the application of the method, the following indicators were considered: water availability, water supply coverage, education, sanitation, poverty, unemployment, informality, health impact, and the water quality indicator. The results showed that poverty, informality, unemployment, and water quality have the greatest effects and impacts on the environmental conditions of the water system. Therefore, to contribute in the reduction of the contamination levels in Juan Angola creek, it is necessary to prioritize the implementation of comprehensive activities that allow the population to strengthen human capital through training programs and linkage to the formal labour market.

1. Introduction

The pollution problems in Juan Angola Creek began with the construction of Santander Avenue and the extension of the runway of the *Rafael Nuñez International Airport*, causing the development of certain activities that generated a great loss of biodiversity, such as the cutting of mangroves and the construction of a parallel channel due to the suppression of the natural channel of the creek (Martínez, 2020). Unfortunately, in recent years, the water quality of Juan Angola Creek continues to be affected by the different urban activities, as well as by the bad habits and customs of the community (Delgado-García et al., 2017). Society always faces environmental problems through measures that allow the improvement of waste collection and disposal systems. Previous studies have stated that environmental education would be the key essence in curbing water bodies' pollution by adopting several mechanisms (Chin and Ng, 2015). In this way, the management of water resources promotes the conservation and use of water, guaranteeing environmental, hydrological, and ecological integrity (Ninalaya et al., 2021). Few studies are directed to the meaning of the environment from a socioeconomic point of view (Armirola, 2015), leaving aside the vision and meaning that the population has of their environment, their culture, their education and, therefore, ignoring the reasons that incite them to pollute the environment (López and Gentile, 2008). This work analyses the environmental problems of the Juan Angola creek at a global level and not only based on studies related to issues such as toxicological analysis (Calderon, Suárez, and Beltran, 2008) or on methods of monitoring and follow-up of water quality (Ruiz, 2018) but also allows to see the problem from the anthropic impacts caused by the communities settled in the vicinity of the water body and its cultural dynamics product of the social and economic condition of the population.

Paper Received: 3 December 2022; Revised: 19 January 2023; Accepted: 13 April 2023
Please cite this article as: Alvarado C., Velasco S., Leones J., Sanchez E., Ojeda K., 2023, Socioeconomic and Environmental Analysis Based on Water Sustainability Index in the Juan Angola Creek (Cartagena, Colombia), Chemical Engineering Transactions, 98, 153-158 DOI:10.3303/CET2398026

2. Materials and methods

The research was carried out along the Juan Angola Creek located in the city of Cartagena, taking four specific sampling points as illustrated in Figure 1, which are: Sampling point E-1 (10°25'38.1 "N 75°30'47.5 "W): creek mouth sector in the virgin swamp. Sampling point E1 (10°26'26.2 "N 75°30'49.6 "W): San Francisco and 7 of Agosto sectors. Sampling point E3 (10°26'31.1 "N 75°31'30.7 "W): Canapote sector. Sampling point E5 (10°26'05.1 "N 75°32'04.4 "W): San Pedro and Libertad sector; third section.

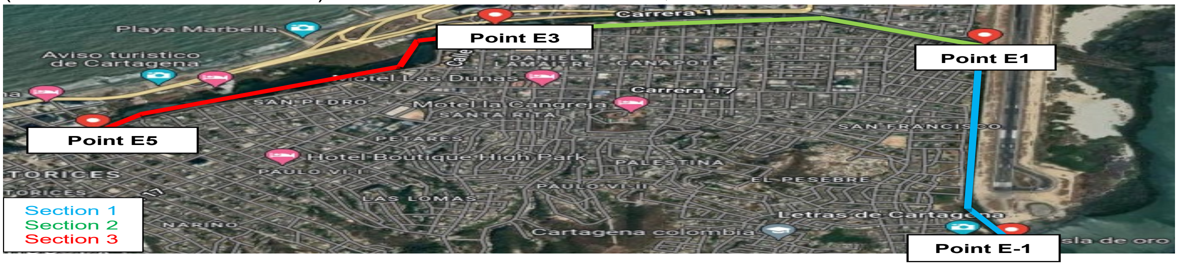

Figure 1: Georeferencing pints used for the Juan Angola Creek research.

2.1 Identification of socioeconomic and sociocultural activities

To identify the activities in the area of influence, two exploratory visits were made along the Juan Angola Creek, limiting the study area to 4 sampling points between the creek mouth sector in the virgin swamp and the San Pedro and Libertad Sector-third section, supported by photographic records of the environment in and between points E-1, E1, E3, E5, mapping to determine the sites with the greatest visible or direct impacts.

2.2 Identification of indicators

For the selection criteria of the final indicators, we considered the amount and availability of information recorded in the literature and government reports, as well as that collected during the exploratory visits. As this is not a project where a method for measuring indicators was created, a search was made for different scientific papers that already had stipulated methods that would allow an evaluation and subsequent analysis of indicators to be carried out. The methodology of Juwana et al. (2016) was chosen, based on the water sustainability index (West Java Water Sustainability Index - WJWSI), which considers environmental, economic, and social aspects. The evaluation of this index includes indicators and sub-indicators (such as water availability, coverage, education, sanitation, poverty, health, etc.) categorized by components (conservation, water use, policy and governance). Juwana (2012), developed the water sustainability index and reported that «the index can be applied to any part of the world with some modifications»; this information allowed adding the unemployment and informality indicators to the evaluation methodology, relating it to the policy, and governance component.
To calculate the water sustainability index, it was necessary to establish the maximum and minimum values for each of the selected indicators, according to their concept and the information available in the literature, as shown in Table 1.

Table 1: Threshold values for each indicator

Component	Indicator	Sub-indicator	Unit	Threshold values	
				Max.	Min.
Conservation	Water Availability		m^3/cap/year	144.16	18.25
	Water Quality		-	-	-
Water use	Water Service Provision	Water Coverage	%	100	0
Policy and	Education	Education Coverage	%	100	0
Governance	Sanitation	Sewerage Coverage	%	100	0
	Poverty	Poverty	%	65	0
	Unemployment	Unemployment	%	20	0
	Informality	Informality	%	100	0
	Health	Health Impact	cases/(1000 population)	2.39	0

This method includes the water quality indicator, considering it an important aspect of the evaluation of water resources management and sustainability. The water quality indicator was calculated using the STORET index, allowing the evaluation and comparison of the physical, chemical, and biological parameters measured in the creek with the standard values according to the World Health Organization (WHO) regulations. For this indicator, the results of sampling in the rainy and dry seasons were used for the following parameters: conductivity, pH, dissolved oxygen, nitrates, alkalinity, salinity, phosphate, and sulfate, with the purpose of evaluating, analyzing, and knowing the state of the creek. The maximum, minimum, and average values of each parameter were defined. They were assigned a score of 0 if the quality standards were met or another score based on the criteria established in the total sample size of ≥ 10 (Sulthonuddin et al., 2019). Thus, a total score was defined in 4 classes: Class A (equal to 0), which indicates compliance with quality standards, Class B (from -1 to -10) which represents slightly contaminated, Class C (from -10 to - 30) for polluted moderately, and Class D (less than -30) for heavily polluted.

2.2.1 Application of the Water Sustainability Index method (WJWSI)

To obtain the index it was necessary to divide the indicators or sub-indicators according to their characteristics into two groups; a specific equation is used for each group.

- Continuous rescaling method: water availability, water supply coverage, education, and sanitation. The higher the value of the indicator or sub-indicator, the better the result (Eq. (1)).

$$S_i = \left(\frac{X_i - X_{min}}{X_{max} - X_{min}}\right) \times 100 \ \ when \ \ X_{min} \leq X_i \leq X_{max} \tag{1}$$

$$S_i = 0 \ when \ X_i < X_{min}; \ S_i = 100 \ when \ X_i < X_{max}$$

Where S_i corresponds to the index value of the indicator; X_i to the actual value; X_{min} and X_{max} are the maximum and minimum thresholds for each indicator.

- Modified continuous rescaling method: poverty, unemployment, informality, and health impact. The lower the value of the indicator or sub-indicator, the better the result (Eq. (2)).

$$S_i = 100 - \left(\frac{X_i - X_{min}}{X_{max} - X_{min}}\right) \times 100 \ \ when \ X_{min} \leq X_i \leq X_{max} \tag{2}$$

$$S_i = 100 \ when \ X_i < X_{min}; \ S_i = 0 \ when \ X_i < X_{max}$$

The variables in this equation are the same as those used in equation 1, but for this case, X_{min} would be the desired value and X_{max} the least preferred value.

It is important to clarify, that, for the water quality indicator, the index is calculated from the STORET water quality index (Rintaka et al., 2019; Sulthonuddin et al., 2019).

2.2.2 Interpretation of the index

The interpretation of the index is the final step in determining the status of each indicator or sub-indicator assessed. It is based on four quartiles with different levels of performance:

Good (75 ≤ value ≤ 100); Medium-Good (50 ≤ value < 75); Medium-Poor (25 ≤ value < 50); Poor (value < 25).

2.3 Socioeconomic indicators analysis

Once the socioeconomic indicators associated with the zone of influence of Juan Angola Creek were measured using the WJWSI method, an analysis was carried out to identify the factors that most influence the contamination problems present in this body of water. Based on this analysis, recommendations were made for the recovery of the water body and its future intervention.

3. Results and Discussion

3.1 Qualitative identification of socioeconomic activities in the area

The results obtained through the exploratory visits regarding the identification of socioeconomic and sociocultural activities are presented in *Figure 2*, *Figure 3*, and *Figure 4*.

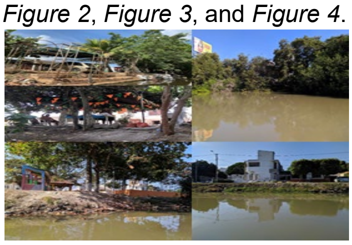

Figure 2 shows the findings between points E-1 and E1 (Section 1), including illegal settlements, car and motorcycle parking, aeronautical activities, and dumping of solid waste and domestic wastewater. Figure 3 corresponds to the findings obtained in the tour between points E1 and E3 (Section 2), where it was possible to identify the presence of informal restaurants selling food and beverages on the banks of the creek, recreation, and sports areas, billboards in the middle of the mangroves and stretches of banks conditioned with barricades covered with sea stone. And finally, Figure 4 shows the findings between points E3 and E5 (section 3), in which areas with improvised docks on the banks of the creek, buildings under construction with great contamination impact on the body of water, and the Benjamín Herrera bridge can be seen. Each of the previous figures represents activities or situations that generate certain affectations on Juan Angola Creek, for example, the expansion of the Rafael Núñez International Airport had a great landscape impact on this body of water, since it modified the environment, eliminating species that are not compatible with aeronautical activities. Likewise, so that billboards in the middle of the mangroves can be visible and favor businesses and institutions without being affected by the leaves of the mangroves, these are anti-technically trimmed propitiating with this the death of the fauna, since certain animals such as iguanas and wetland snakes, not finding branches that communicate the bushes, move along the ground, where they are exposed to humanity (the largest predators) (Alvarez, 2010). On the other hand, urban development processes (buildings and constructions) very close to the banks of the creek also damage its ecosystem, supplanting the natural capital for real estate; for this reason, a 50-meter strip belonging to the Nation was established, since they are spaces of biodiversity and water conservation, which over the years have been disrespected (Álvarez, 2010).

3.2 Characterization and evaluation of the socioeconomic indicators

After obtaining information on the socioeconomic activities associated with the zone of influence of the Juan Angola Stream, a characterization was made considering the socioeconomic indicators that allow evaluating the quality of life of the population settled in the vicinity of this body of water, using governmental and/or district reports previously mentioned, such as *Cartagena Como Vamos*, DANE, etc. Since the official reports on the quality of life of the city of Cartagena are mostly organized in a general way, the characterization was carried out with this information; but, in turn, in the factors where there is specific information by Community Units of Government (CUG), were investigated in this way. For the evaluation of the socioeconomic indicators, the West Java Water Sustainability Index (WJWSI) was used, which was very useful for carrying out the different analyses related to these indicators. In order to apply the WJWSI methodology, a selection and/or classification had to be made taking into account the availability of information and characteristics of each indicator, according to the components (Conservation, Water Use, and Policy and Governance).

3.2.1 District-level analysis over the last 3 years (2019-2021)

Table 2 shows the actual values and the final index corresponding to the indicators and sub-indicators evaluated with the WJWSI method. There was a «good» performance in terms of water availability, aqueduct coverage, sewerage coverage, and education coverage, reaching more than 75% in each of them.

Table 1: Results of the water sustainability analysis at the district level (2019-2021).

Indicator/Sub-Indicator	Unit	2019		2020		2021	
		Index	Performance	Index	Performance	Index	Performance
Water Availability	m^3/cap/yr	75.6	Good	75.9	Good	75.1	Good
Water Coverage	%	93.0	Good	93.0	Good	93.5	Good
Education Coverage	%	89.0	Good	90.0	Good	91.0	Good
Sewerage Coverage	%	85.5	Good	86.0	Good	85.7	Good
Poverty	%	47.2	Medium poor	26.5	Medium poor	37.9	Medium poor
Unemployment	%	66.0	Medium good	25.5	Medium poor	27.5	Medium poor
Informality	%	46.8	Medium poor	43.8	Medium poor	37.1	Medium poor
Health impact	cases/(1000 population)	35.2	Medium poor	53.1	Medium good	-167.3	Poor

While the indicators of poverty, unemployment, and informality obtained a final index between 25-50%, which indicates a «poor medium» performance. On the other hand, the health impact indicator showed a «poor» performance, since the number of cases per thousand inhabitants for the year 2021 was very high; therefore, when the corresponding average was calculated, the value was above the established limit, resulting in a negative index.

3.2.2 CUG-level analysis (CUG 1, 2 and 3)

Table 3 shows the actual values and the final index corresponding to the indicators and sub-indicators for CUGs 1, 2, and 3 in the city of Cartagena. CUGs 1, 2, and 3 obtained «good» performances in the indicators of water availability, aqueduct coverage, sewerage coverage, and health impact, exceeding 75% of the final index. Informality remained constant in all CUGs, which obtained an index of 37.1% (medium poor). In addition to the above, the indicators of education coverage, poverty, and unemployment obtained a «medium good» performance, with more than 50% of the final index for CUG 1. Meanwhile, in CUG 3, a decrease in educational level could be observed, obtaining a lower coverage and «poor average performance» and, in turn, indicators such as poverty and unemployment are the most affected with a «poor performance» and an alarming final index.

Table 2: Results of the water sustainability analysis at the CUGs level (CUG 1, 2 and 3).

Indicator/Sub-Indicator	Unit	CUG 1		CUG 2		CUG 3	
		Index	Performance	Index	Performance	Index	Performance
Water Availability	m^3/cap/yr	75.1	Good	75.1	Good	75.1	Good
Water Coverage	%	97.6	Good	91.4	Good	94.7	Good
Education Coverage	%	51.3	Medium good	64.9	Medium good	43.2	Medium poor
Sewerage Coverage	%	98.5	Good	84.0	Good	93.4	Good
Poverty	%	69.2	Medium good	23.1	Poor	7.7	Poor
Unemployment	%	60.0	Medium good	45.0	Medium poor	15.0	Poor
Informality	%	37.1	Medium poor	37.1	Medium poor	37.1	Medium poor
Health impact	cases/(1000 population)	98.0	Good	97.9	Good	97.9	Good

Therefore, it was possible to identify that the CUG that obtained the worst results was CUG 3, corresponding to the neighborhoods of Canapote, Daniel Lemaitre, Santa María, 7 de Agosto, and San Francisco.

3.2.3 Water quality indicator analysis

The WJWSI method uses the STORET water quality index to evaluate the physical, chemical, and biological parameters of water quality to determine which have met or exceeded the water quality standard (Juwana, 2012). Through this index, the limit values (maximum and minimum) of the indicator are defined, which are 0 and -30, respectively (Rintaka et al., 2019). For instance, a value of «0» indicates that the water satisfies the quality parameters and has an «A» classification. On the other hand, negative values indicate that the water does not satisfy the quality parameters and their classification goes from «B» to «D». Different water quality parameters for two seasons of the year (dry and rainy) were analyzed at 4 points (E-1, E1, E3, and E5) in Juan Angola Channel. Sulthonuddin et al., (2019), explain the methodology of the STORET index, which compares the standard values of the parameters with the actual values obtained in the field trips (minimum-maximum - averages of each parameter), to obtain a total score that determines the classification of the water´s quality. Applying the aforementioned method, the classification of the quality level of the Juan Angola Creek for the rainy and dry seasons gave a class D score, that is, «Heavily polluted» with a total score of -50 for the rainy season and -36 for the dry season.

3.2.4 Recommendations for improvement

Based on the results obtained from the analysis, taking into account the socioeconomic indicators and water quality parameters, recommendations for improvement were made for the indicators and sub-indicators that performed poorly in the evaluations at the city level and in all the CUGs studied such as poverty, unemployment, informality, and water quality; however, recommendations were added for the education and health impact indicators, since all their results were not always good and, therefore, were considered of great importance in the study. *Unemployment and Poverty:* Identification, geo-referencing, and monitoring of the population. Poverty reduction plans include the relocation of families in risk areas or invasions. Implementation of comprehensive activities that allow the population to strengthen their human capital. *Informality:* Develop training programs and linkage to the formal labour market. Search for entities that offer job training programs and those related to what the private sector demands. Offer Cartagena's labour force to investors and new companies. *Water quality*: Constant dredging of the area of influence. Campaigns and re-cleaning campaigns. *Education and health impact*: Carrying out awareness campaigns, both theoretical and practical, in schools and surrounding neighbourhoods, related to basic knowledge of hygiene, health, and the environment. Deepening of environmental issues in the institutions.

4. Conclusions

Juan Angola creek is one of the most important bodies of water in the city of Cartagena (Colombia); however, through the WJWSI methodology application, it was possible to observe that the water quality is inadequate. Although surrounding communities have potable water supply, still require improvements in coverage of public services, measures, or actions of improvement against poverty and unemployment. Juan Angola creek does not have good water quality, therefore, it is necessary the establishment action for the recovery of this ecosystem, although the water creek is not used for supply, affects the quality of life, health, sanitation, and biodiversity in the water body. Therefore, the importance of this study was based on the evaluation and analysis of indicators for the search for improvements related to projects towards the community focused on the aspects of greatest effect and impact on environmental conditions, such as the prioritization regarding the integral activities implementation that allow the population to strengthen their human capital through training programs and linkage to the formal labor market, as well as the incorporation of accompaniment by professional entities that help the community to find their routes out of poverty and unemployment.

Acknowledgements

The authors acknowledge the Universidad de Cartagena for their support with the development of the project «Toxicological and environmental evaluation of the effect of heavy metals in the ecosystems associated with the Juan Angola Creek (Cartagena-Bolivar) (Act 086-2019)».

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