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Unified matrix for environmental impact assessment applied to water resources, Chicamocha River case study

Matriz unificada para la evaluación del impacto ambiental; estudio de caso del río Chicamocha

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ABSTRACT: Environmental Impact Assessment – EIA makes a preventive and corrective study possible to avoid damages resulting from anthropogenic activities. Different methodologies are used for implementing EIA considering professional criteria and applying qualitative and quantitative parameters; however, for water resources, the methodologies that allow a deep analysis are limited. For this reason, the goal of the study is to design a tool for Environmental Impact Assessment applied to the Vado-Castro sector through the Transparency Overlay Methods, Leopold, and Battelle-Columbus. The methods' development was based on a diagnosis and monitoring of the water resource, articulating the characterization and quantification of the environmental impacts. Finally, a unified standard methodological tool was formulated which is applicable to the water resource sector and considers all the necessary criteria when carrying out a comprehensive EIA, as it is possible to demonstrate its applicability to the case of the Chicamocha River tributary area. Thus, the unified matrix becomes a fundamental tool to portray environmental public politics, providing means to recognize the current environmental conditions of water resources affected by anthropic activities. The results obtained will allow this research to be used as a reference source for academic and technical studies that require evaluating water resource effects, and as a tool that can be applied to another body of water.

RESUMEN: La evaluación de Impacto Ambiental – EIA posibilita un estudio preventivo y correctivo para evitar daños derivados de actividades antrópicas. Para la implementación de la EIA se utilizan diferentes metodologías tomando en cuenta criterios profesionales y la aplicación de parámetros cualitativos y cuantitativos, sin embargo, para el recurso hídrico las metodologías que permiten un análisis profundo son limitadas. Por ello, el objetivo del estudio es diseñar una herramienta de Evaluación de Impacto Ambiental aplicada al sector Vado-Castro a través de los Métodos de Superposición de Transparencia, Leopold y Battelle-Columbus. El desarrollo de los métodos se basó en un diagnóstico y monitoreo del recurso hídrico, articulando la caracterización y cuantificación de los impactos ambientales. Finalmente, se formuló una herramienta metodológica estándar unificada, aplicable al sector de recursos hídricos y que considera todos los criterios necesarios a la hora de realizar una EIA integral, ya que es posible demostrar su aplicabilidad al caso de la zona afluente del río Chicamocha.

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Así, la matriz unificada se convierte en una herramienta fundamental para retratar las políticas públicas ambientales, proporcionando medios para reconocer las condiciones ambientales actuales de los recursos hídricos afectados por actividades antrópicas. Los resultados obtenidos permitirán que esta investigación sea utilizada como fuente de referencia para estudios académicos y técnicos que requieran evaluar los efectos de los recursos hídricos, y como una herramienta que pueda ser aplicada a otro cuerpo de agua.

1. Introduction

The Chicamocha River is the most important water tributary in the Department of Boyacá in Colombia, since, on its way, it crosses several municipalities [1], it has a basin area of about 6127 km^2 forming the Chicamocha Canyon that enters the department of Santander and joins the Suárez River and the Fonce River to finally form the Sogamoso River [2]. It is important to point that, in the surrounding section of the Vado-Castro sector, located in the upper and middle basin of the river, extraction, trade and transformation of mineral resources, industrial, tourist, agricultural, and livestock sector activities are concentrated, which generate negative impacts on the environment. Besides the pollution associated with runoff derived from these activities, large amounts of untreated domestic waste contribute to the problem and add to the fact that this water resource is the second most polluted in the country [3, 4].

Even though the water quality problem of the Chicamocha River is evident, greater clarity is needed on the individual impact of each source of contamination. An Environmental Impact Study (EIA) constitutes a tool for planning, ordering, and decision-making on the actions of humans and/or nature to preserve or maintain an offer of natural assets for the sustainable development of society. The EIA seeks to identify, describe, evaluate, and control the effects that humans actions have on the environment, including individuals as the main agent that induces changes in the environment [5]. In this way, alterations are produced, which must be analyzed to avoid damage that can produce negative effects on the environment. In other words, the EIA is a process designed to estimate the impact that the execution of various business activities may have [6]. When it comes to quantifying aspects in the impact analysis, different methodologies can be used, methodologies ranging from qualitative and quantitative parameters partially or globally. The Leopold matrix, Battelle Columbus, and the network diagram, among others, are some of these tools [7]. Most of the existing methodologies were designed and structured to evaluate productive projects, whereas the evaluation of the water resource is extremely limited [8]. Choosing the environmental impact assessment methodology is one of the main determinants to carry out an adequate EIA [9]. EIA methodologies may not have uniform applicability in all countries due to differences in their legislatures, environmental standards, and environmental stewardship programs [10].

Taking into account the need to appoint the impact of individual sources on the Chicamocha River, it is necessary to design a tool that allows a comprehensive assessment of the environmental impact based on the application of three methodologies and thus proposing a standardized methodology that is adapted to the proper evaluation of the environmental implications of the area.

2. Materials and methods

2.1 Study area

The study area is located in the Sugamuxi Province of the Department of Boyacá, in the section corresponding to the Vado-Castro sector, which belongs to the municipality of Tópaga, one of the most contaminated routes of the Chicamocha River. The geographical coordinates between 5° 45' 27,20" N y 72° 54' 45,85" O (Point 1) and 5° 46' 38,49" N and 72° 51' 1,17" O (Point 3) (Figure 1). The annual average temperature of the air is 15.5° C, being the absolute maximum with a resulting value of 16.1 ° C and the minimum of 14.8° C and the total average precipitation of the three meteorological stations that are found in the area (Belencito, Nobsa, and Sena) is 763,333 mm [11].

2.2 Environmental baseline and water sampling

The establishment of the environmental baseline of the study area was carried out using a qualitative checklist that was designed according to the suggestions of [12]. To identify representative biophysical characteristics such as geological constitution, edaphic composition, air quality, water quality and the biotic component of aquatic and terrestrial ecosystems. The composition of fauna and flora was determined by notification, the sighting of the community, and a literature review.

A sample was taken in situ in the river, which was analyzed by the laboratory certified by the Institute of Hydrology, Meteorology and Environmental Studies - IDEAM, Servi Químicos EU and SGI Consultoría e Ingeniería SAS (NIT 826.002.964), the date of sample taking was July 27, 2020, studying the following parameters: Biological Oxygen Demand - BOD, Manganese, Escherechia coli, Total Phenols, Nitrates, Phosphates, Chlorides, Hydrogen Potential - pH, Conductivity, Magnesium, Chemical Oxygen Demand - COD, Total Iron, and Turbidity, selected

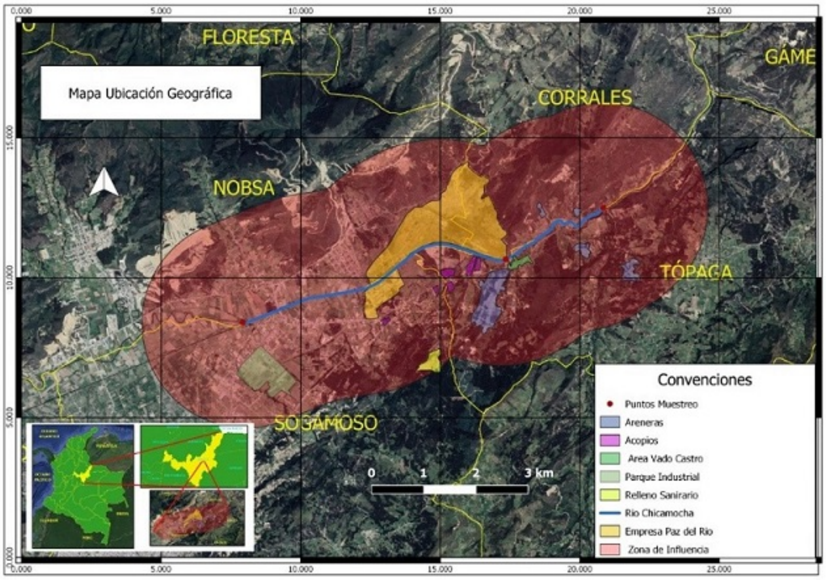

Figure 1 Map of the spatial location of the study area. Source: Image adapted from Google Earth. 2021

considering industrial activities and discharges that occur in the Vado-Castro sector.

2.3 Analysis of data

The use of Geographic Information Systems - GIS as a tool became very important in the development of the study; the cartographic referencing programs used for the research were: QGIS and ARGIS, and parameters and variables typical of the two programs were taken into account, but representing the same functionality, in the case of the development of layers that represent each of the polygons of the identified anthropic activities, GIS tools (labels, coordinates, symbology, font size, color, transparency, handling of lines, geographic images of Google Earth, scales, add margins and grid) included in the QGIS 3.4 Madeira programs [13] and ARCGIS 10.2 [14] for the development and publication of maps and territorial coordinate systems MAGNA-SIRGAS (Colombian reference system) used by Google Earth, QGIS and ARGIS as authorized programs for their use by the Agustín Codazzi Geographical Institute - IGAC, a cartographic regulator entity in our country.

The analysis and processing of the data were carried out through Microsoft Excel (2019) using algorithmic formulas of simple application, and mathematical equations to represent the existing relationships among the variables, which, in the case of the EIA, correspond to the attributes or characteristics of the impacts and also statistical formulation with the use of linear equations, trends and graphical representations, as well as the construction of matrices that as indicated by [12] allows synthesizing the attributes and variables that are commonly considered in the EIA.

2.4 Applied Environmental Impact Assessment Methodologies

To develop the environmental impact assessment phase in the Chicamocha River in the Vado-Castro sector, three widely known methodologies were used for this purpose: the transparency overlay methodology, which includes the determination of impact maps obtained through a matrix. [15]. Their assessment is given by identifying of the geographical space occupied by each anthropic activity and its origin in the environmental impact [16]. Likewise, the Leopold methodology was implemented [17, 18]. Basically, it is a matrix that presents, in the columns, the actions of the project and, in the rows, the components from the surroundings and their characteristics.

This matrix is one of the most used methods in the EIA, for almost all types of projects. It is limited to a list of 100 actions that can cause an impact on the environment represented by columns and 88 environmental characteristics and conditions represented by rows, which means a total of 8800 possible interactions. However, in practice, not all of them are considered (topics of Science and Technology, 2013). The Battelle Columbus methodology considers four large "environmental categories" that include a total of eighteen "environmental components" for the environmental impact assessment [19].

2.5 Unified matrix

The proposed methodology has a quantitative and qualitative development, which allows generating an analysis according to the needs of environmental impact assessment in the study area. Its development is established through the convergence of representative characteristics of the evaluated methodologies and specific aspects that allow us to satisfactorily analyze, assess, and demonstrate the qualification of anthropic activities in the study area [20].

These Environmental Impact Assessment methodologies were selected and developed under subjective valuation parameters. Eight parameters were established to propose objective and accurate conditions for evaluating the environmental impact. The valuation conditions assigned and recommended for environmental assessment impact on the Chicamocha River, Vado-Castro sector, are the following:

- Activity: it has a previous development from the identification of the present anthropic activities (industry, mining, agriculture, livestock, and domestic activities).
- Proximity: proximity is determined based on a numerical scale that allows contextualizing the presence of anthropic activities in the study area. The values taken conform to a scale from 0 to 9, with three values of low, medium, and high representativeness, together with a series of divisions depending on the presence of activities in the study area; thus, a scale of 0 to 3 is assigned to the value of low representativeness, thus dividing it into: low-very low (0), low-low (1), low-medium (2), and low-high (3) with distinction in light-yellow color, 4 to 6 the average value illustrated as follow: medium-low (4), medium-medium (5), and medium-high (6) with a dark-yellow color and 7 to 9 the highest identification with these categories: high-low (7), high-medium (8), and high-high (9), with a red color.
- Incidence: it has a valuation according to a scale proposed for the assessment of water resources, which allows establishing the durability and occurrence of the environmental impact in the anthropic activity carried out. Its valuation is based on a scale from 0 to 9 divided into three categories (low, medium, and high) and a series of evaluative divisions that depends on the durability and occurrence of the environmental impact, being 0 to 3 for the low evaluation, thus dividing into: low-very low (0), low-low (1), low-medium (2), and low-high (3) with distinction in light-yellow color, 4 to 6 the average value illustrated as follow: medium-low (4), medium-medium (5), and medium-high (6) with a dark-yellow color and 7 to 9 the highest identification with these categories: high-low (7), high-medium (8), and high-high (9), with a red color. This parameter allows determining the periodicity of the productive sector in the study area.
- Affecting Actions: they were selected based on the qualitative identification characteristics provided by Leopold Matrix. [17]. This choice was made taking into account the action that developed the most significant impact for each of the anthropic activities evaluated, being analyzed comparatively through the determining application in Magnitude and Importance.
- Elements of Affectation: these allow developing a more detailed result of the components that directly concern the study area due to anthropic activity. This condition makes it possible to identify the components that lead to the affectation of the water resource, considering those with the most significant environmental damage due to chemical composition and physical characterization. This way, a clear analysis of the environmental damage with the highest environmental risk is obtained from the physicochemical and microbiological analyses established in the Battelle Columbus Matrix. [19]
- Assessment of Damage: its development is linked to the identification of elements affected by anthropic activities through the Environmental Quality - EQ of the harmful element. The assessment can be determined through a mathematical or graphic development, a rating of 0 will be directly proportional to a more significant environmental impact, and a rating of 1 will be the least environmental impact or implication.
- Weighted assessment of involvement: its determination is subject numerically to the average assessment of involvement multiplied by the number of elements of affectation resulting from anthropic activities, being an operational development that manages to categorically represent the total involvement of the activity developed in the study area. The formula that represents it is:

  Weighted Evaluation of the Impact =Average Assessment of the Affectation x Number of Elements of Affectation

- Alert signal: it constitutes the final score caused by anthropic activity. Its categorical representation is evaluated based on the result of the weighted assessment of involvement; the scale proposed by the warning sign in the matrix has the following assessment: 0 to 2 very low with representation in dark green, 2 to 3 low with light-green illustration, 3 to 4 medium with light-yellow hue, 4 to 5 high with dark-yellow hue and 5 to 6 very high with red color.

2.6 Derivative work statement

This work is derived from the degree work carried out by the main author of this academic paper [20]. The writing and complementary data of results and analysis contribute to the co-authors input.

3. Results

3.1 Environmental baseline and water sampling

The wastewater from urban areas and, specifically the populated sector Vado-Castro, does not have sewage systems, which generates significant contamination of the water resource and soil. Mining, industrial, and domestic discharges occur in the river without prior treatment, thus increasing pollution. Agricultural and livestock activities generate bad odors and represent a health risk for the inhabitants due to agricultural use for irrigation of crops [21]. (2a). The geology of the sector is represented through the Guaduas formation [22]. Being the origin of coal beds, sandstone intercalations, and blackish fissile arcillites. There are moderately mountainous areas on the sides of the hydrographic basin, predominating soils of organic origin (sandy loam) and clay soil [23]. (2b). Air quality is one of the most notorious problems in this area; there are direct emissions from fixed sources identified as: pottery company, iron and steel industry, cement factories, coal and wood stoves. In a diagnosis on the emissions generated by the different sources of pollution in Sogamoso and its surroundings [24]. It was determined that 56.39% of atmospheric pollutants are generated by the pottery and, iron and steel industry (2c).

The fauna includes mammals such as Mustela nivalis (Weasel), Oligoryzomys fulvescens (Mouse) and Anoura geoffroyi (Bat) and birds such as Zonotrichia capensis (Rufous-collared sparrow), Turdus merula (Blackbird) and Hirundo rustica (Barn Swallow). Cold climate vegetation is predominant, being the diversity of Eucalyptus (Eucalyptus), Acacia melanoxylon (Australian Blackwood) and Salix chilensis (Willow) the most representative periodically [25].

Regarding the baseline for water quality, according to [26]. The monitoring of pollutants emitted by specific human activities and the location of sources of contamination was carried out through specific monitoring at strategic sites, especially at industrial and residential discharge points. In Table 1, the results obtained from the water quality analysis are presented, which are the basis of the study for the development of the Battelle Columbus methodology.

Table 1 Water quality analysis results

Parameters	Valuation units	Results	Ref values Res. 631/15
pH	Units	7.15	6.0 – 9.0
Conductivity	$\mu S/cm$	618	N/A
DBO_5	mg/LO_2	62	90
DQO	mg/LO_2	114	180
Chlorides	mgCl/L	53.8	N/A
Phosphates	$mgPO_4^{3-}/L$	2.63	N/A
Turbidity	UNT	33.4	N/A
Total Iron	mg Fe/L	1.53	N/A
Magnesium	mg Mg/L	42.3	N/A
Nitrates mg	NO_3/L	39,6	N/A
Total dissolved solids	mg/L	326	N/A
Potassium	mg K+/L	13.167	0.950
Sodium mg	Na+/L	88.223	0.900
Manganese	mg /L	1.4771	0.087
Total Phenols	mg /L	<0.002	0.002
Escherichia coli	UFC / 100 ml	100000	N/A

Table 2 Transparency overlay technique evaluation

Factors, parameters and / or aspects	% of compliance
1. Biological conditions in fauna and weighted proximity index	24.00
2. Biological conditions in flora and plant cover	24.00
3. Land use in the hydrographic basin and a reas or banks surrounding the river	35.00
4. Identification of anthropic activities of affectation	36.25
5. Location of anthropic activities of affectation	90.00
6. Quality of the water resource	1.00
7. Impact on and contamination of water resources	1.00
8. Synergy of environmental impacts on the river	39.00
9. Ecological relationship in dumping, solid waste and deforestation in the area of influence	33.33
10. Cultural factors in dwelling and social interaction	20.00
11. Factors of road, civil and public infrastructure, and/or commercial services	40.00
12. Visual and landscape contamination in the area or riverbank surrounding the tributary	20.00

3.2 Transparency Overlay Technique

This methodology made it possible to identify, in the first instance, the anthropic activities developed in the polygon area, obtaining the initial characterization through the spatial location of the tasks carried out and that generate impact on the water resource. In Figure 3, the methodological application is presented graphically.

A compliance percentage is presented according to a 100% comparative scale between the three methodologies. Table 2 indicates the rating by factors, parameters and/or aspects for the transparency overlay technique.

3.3 Leopold Matrix

The percentage of compliance in the Leopold Matrix of factors, parameters and/or aspects was determined

Figure 2 a) Wastewater from urban areas and the populated sector of Vado-Castro. b) Geological constitution. c) Air quality. Source: Authors

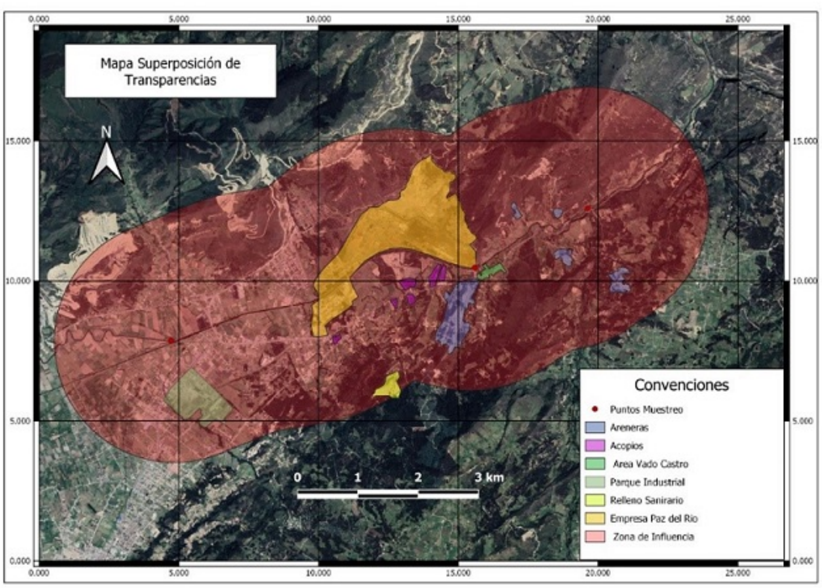

Figure 3 Overlay map of transparencies in the study area. Source: Adapted from Google Earth by the authors. 2020

according to the comparative development scale (Table 3).

Table 3 Leopold Matrix evaluation

Factors, parameters and / or aspects	% of compliance
1. Biological conditions in fauna and weighted proximity index	41.00
2. Biological conditions in flora and plant cover	42.00
3. Land use in the hydrographic basin and a reas or banks surrounding the river	36.00
4. Identification of anthropic activities of affectation	43.75
5. Location of anthropic activities of affectation	7.00
6. Quality of the water resource	19.00
7. Contamination and impact on water resources	19.00
8. Synergy of environmental impacts on the river	40.00
9. Ecological relationship in dumping, solid waste and deforestation in the area of influence	33.33
10. Cultural factors in dwelling and social interaction	40.00
11. Factors of road, civil and public infrastructure, and/or commercial services	40.00
12. Visual and landscape contamination in the area or riverbank surrounding the tributary	59.67

3.4 Battelle Columbus Method

Compliance with the factors, parameters and / or aspects in the Battelle Columbus method was calculated according to the comparative scale (Table 4).

Table 4 Battelle Columbus Method Evaluation

Factors, parameters and / or aspects	% of compliance
1. Biological conditions in fauna and weighted proximity index	32.00
2. Biological conditions in flora and plant cover	32.00
3. Land use in the hydrographic basin and a reas or banks surrounding the river	27.00
4. Identification of anthropic activities of affectation	20.00
5. Location of anthropic activities of affectation	2.00
6. Quality of the water resource	80.00
7. Contamination and impact on water resources	80.00
8. Synergy of environmental impacts on the river	20.00
9. Ecological relationship in dumping, solid waste and deforestation in the area of influence	33.33
10. Cultural factors in dwelling and social interaction	39.00
11. Factors of road, civil and public infrastructure, and/or commercial services	19.00
12. Visual and landscape contamination in the area or riverbank surrounding the tributary	20.00

3.5 Proposed unified methodology

Compliance with the factors, parameters and/or aspects according to the scale used comparatively is shown in the proposed unified methodology (Table 5).

Table 5 Proposed unified methodology evaluation

Factors, parameters and / or aspects	% of compliance
1. Biological conditions in fauna and weighted proximity index	97.00
2. Biological conditions in flora and plant cover	98.00
3. Land use in the hydrographic basin and a reas or banks surrounding the river	98.00
4. Identification of anthropic activities of affectation	100.00
5. Location of anthropic activities of affectation	99.00
6. Quality of the water resource	100.00
7. Contamination and impact on water resources	100.00
8. Synergy of environmental impacts on the river	99.00
9. Ecological relationship in dumping, solid waste and deforestation in the area of influence	99.67
10. Cultural factors in dwelling and social interaction	99.00
11. Factors of road, civil and public infrastructure, and/or commercial services	99.00
12. Visual and landscape contamination in the area or riverbank surrounding the tributary	99.67

3.6 Percentage methodological evaluation

The comparison of the percentage of compliance with each of the factors, parameters and/or aspects for the three standard methodologies, as well as the proposal in this study, were compared individually (Figure 4) and the total summation (Figure 5).

According to the results obtained (Table 6), domestic activity and mining activities feature the highest warning signal by environmental category, followed by the iron/steel industry, cement industry, service and commerce, agricultural, electromechanical, and automotive service, livestock, and transportation.

4. Discussion

The Chicamocha River is a highly important water source for Colombians due to its coverage and scope in agriculture, industry, and domestic use. However, the contamination and damage caused by these same activities are a reality. From this study, we were able to verify the impact of anthropocentric activities on the river, analyzing the Vado-Castro sector, through 3 standard methodologies and an integrated proposal, the unified matrix, which can be applied to other sectors of this river and water resources. The EIA guided by this proposal turns out to be a promising input for the development of environmental policy and research projects and its extrapolation to other studies is recommended. This research highlights due a unified matrix was obtained as an essential tool for policymaking because it adopts the most objective conditions for EIA in the field. From the assessed conditions of activity, proximity, incidence, affecting actions, elements of affectation, assessment

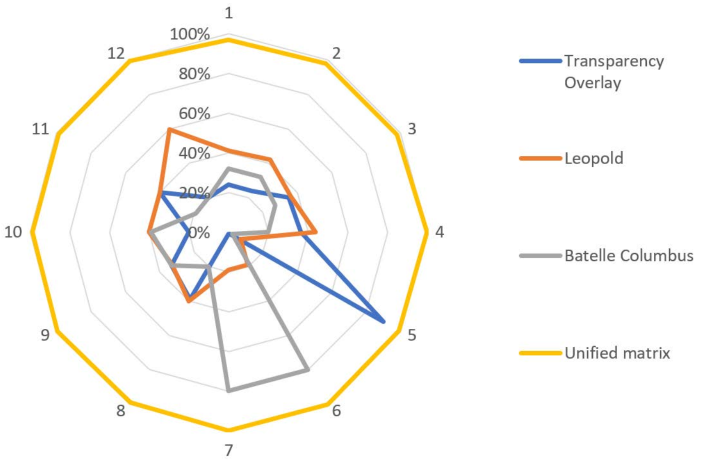

Figure 4 Comparison of percentages of compliance with the methodologies used in this study

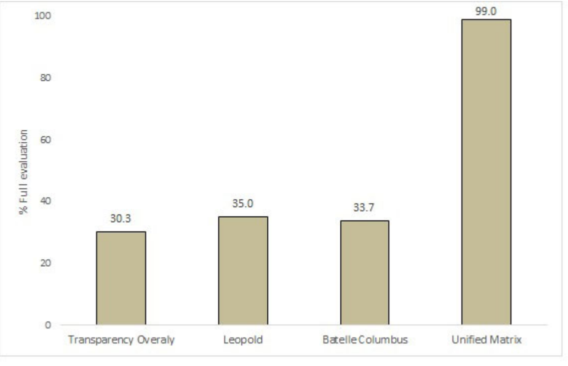

Figure 5 Percentage contribution of each EIA methodology Source: Authors

of damage, weighted assessment of involvement, and warning signal. The application of a unified matrix generates an easy-to-interpret visual representation of environmental impacts.

Domestic and mining activities constitute the most significant source of contamination of the Chicamocha River

Mining activities, whether associated with the production of sands, clays, limestones, iron or coal, constitute a high source of contamination for the water resource because large amounts of water are used in their operational processes to clean the minerals; they also use solvents that facilitate extraction. Being the soil of the Department of Boyacá, a great source of minerals for industrial or construction use, positioning itself around the Chicamocha River becomes strategic for obtaining and disposing of water. In this way, the mining industry constitutes one of the main sources of environmental problems at the regional level, which is associated with little environmental demand, failures or anomalies in the licensing process, non-compliance with Environmental Management Plans - EMP, absence of technical staff for environmental management, little institutional commitment on the part of the environmental authorities and the actors involved in the management of the basin [27].

On the other hand, domestic activities become an important problem because of the lack of education of the users of the water resource, evidenced in the overexploitation of the resource, uncontrolled discharges, expressed in terms of reduction of flow, contamination of the water resource, water scarcity, illegal catchments, and the appearance of conflicts between users who are competing for this resource.

Without neglecting the individual secondary sources of contamination of the Chicamocha River, such as the steel and cement industries, service and trade activities, or agriculture, the results presented in this study become a fundamental input for the creation and implementation of environmental education policies and agro-industrial regulation for the care of the resource. Additionally, the characterization of ecosystem services and a study for the application of environmental bonds could greatly mitigate

Table 6 Unified matrix methodology

Proposed unified matrix methodology																								
Chicamocha River - Vado-Castro Sector																								
Activities	**Prox.**	**Inc.**	**Tur.**	**pH.**	**DBO.**	**Man.**	**Esc. Col.**	**Fen Tot.**	**Nit.**	**Fos.**	**Hie. Tot.**	**Mag.**	**Con.**	**DQO.**	**Ind. Prox. Fau.**	**Cob. Veg.**	**Uso. Sue. Cir.**	**Clo.**	**Cons. Mat. Bio**	**Cons. Mat. Pla.**	**Pob.**	**Sat. Vis.**	**Prom. Val. afec.**	**Pon. Val. Afec.**	**Señ. Aler. Cat.**
Domestic Activity	7	6	0.073	0.979	0.225	NA	0	NA	NA	0.895	NA	NA	0.752	0.498	0.4	0.493	0.75	0.784	0.16	0.192	0.1	0.5	0.453	6.801	Very High
Sand Mining	7	6	0.073	0.979	0.225	0	0	0.728	0.208	0.895	NA	0	0.752	0.498	0.4	0.493	0.75	NA	NA	NA	NA	0.5	0.433	6.501	Very High
Clay Mining	6	5	0.073	0.979	0.225	0	0	0.728	0.208	0.895	NA	0	NA	0.498	0.4	0.493	NA	NA	NA	NA	NA	0.5	0.357	4.642	Very High
Limestone Mining	6	5	0.073	0.979	0.225	0	0	0.728	0.208	0.895	NA	0	0.752	0.498	0.4	0.493	0.75	NA	NA	NA	NA	0.5	0.433	6.501	Very High
Iron Mining	6	6	0.073	0.979	0.225	0	0	0.728	0.208	0.895	0.198	0	0.752	0.498	0.4	0.493	0.75	NA	NA	NA	NA	NA	0.413	6.199	Very High
Coal Mining	6	6	0.073	0.979	0.225	0	0	0.728	0.208	0.895	NA	0	0.752	0.498	0.4	0.493	0.75	NA	NA	NA	NA	0.5	0.433	6.501	Very High
Steel industry	7	1	NA	0.979	0.225	NA	0	0.728	0.208	NA	0.198	NA	0.752	NA	0.4	0.493	NA	NA	NA	NA	NA	0.5	0.448	4.483	High
Cement industry	6	1	NA	0.979	0.225	NA	0	0.728	0.208	NA	NA	NA	0.752	NA	0.4	0.493	NA	NA	NA	NA	NA	0.5	0.476	4.285	High
Electromechanical and Automotive Service Activities	6	2	0.073	0.979	0.225	0	0	0.728	0.208	NA	NA	0	0.752	NA	NA	NA	NA	NA	NA	NA	NA	0.5	0.347	3.465	Medium
Service and Commerce Activities	7	5	NA	0.979	0.225	NA	0	NA	NA	0.895	NA	NA	NA	0.498	NA	NA	NA	0.784	0.16	0.192	NA	0.5	0.470	4.233	High
Agricultural Activities	7	3	0.073	0.979	0.225	0	0	NA	0.208	0.895	NA	NA	NA	0.498	NA	0.493	0.75	NA	NA	NA	NA	NA	0.4121	4.121	High
Livestock Activities	6	3	NA	0.979	0.225	NA	0	NA	0.208	0.895	NA	NA	0.752	0.498	NA	0.493	NA	NA	NA	NA	NA	NA	0.475	3.8	Medium
Transportation Activities	6	3	0.073	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.752	NA	0.4	0.493	0.75	NA	0.16	0.192	NA	0.5	0.443	2.216	Low

the problem. Likewise, the environmental authority must exercise control that guarantees compliance with the regulations of specific discharges to surface water bodies, as well as the regulated use of the resource, because, although the users of the basin are aware of the existing regulations, discharges that do not comply with the parameters and permissible limits established in the regulations, continue to be carried out [27].

The unified matrix is a new alternative for the comprehensive EIA of any water resource

When developing the three EIA methodologies for the case under study, it is of great importance to consider both the determination and evaluation of the present anthropic activities, as well as the process of assessing the current state of the Chicamocha River. However, the methodologies individually do not evaluate all the water resource indices, which is due to the fact that each one presents a characteristic evaluation method that does not allow integration of these data. According to [28]. The Leopold methodology has the advantage of allowing subjective estimation of impacts, which is possible because it has a numerical scale that allows alternatives to be compared, interactions to be determined, and project actions to be identified. Regarding the disadvantages, in addition to the degree of subjectivity used in the impact assessment, it does not consider the ones that indirectly concern projects or activities. The overlay methodology has great advantages in geo-referencing and territorial identification of anthropic activities developed in the study area through GIS; it is a geographic-type methodology that performs environmental assessment through the spatial position of these damages and their direct and indirect environmental implication in the water resource, its disadvantages are manifested in the assessment and characterization of the environmental implications of damages identified by the activities carried out.

The Battelle Columbus method presents a quantitative research approach, being its main advantage the use of numerical values that can guarantee a complete and comprehensive evaluation; that is, if parameter monitoring and water quality analysis results are delivered, the disadvantage is that, being a methodology developed for the evaluation of water resources, it must first consider the environmental categories and criteria to be evaluated in other scenarios where such methodology would be implemented, and when it does not involve the evaluation of water quality parameters. Within the main limitations of the techniques and instruments commonly used for the evaluation of EIA, a tool is formulated to integrate fundamental and objective characteristics in the evaluation of the environmental impact on water resources. Currently, research on EIA methodologies in different fields is presented from the environmental perspective; very few studies are presented that support the comparative search and the methodologies application for an evaluation in specific contexts. EIA research presents methodological proposals in other fields or sectors; in the case of the infrastructure field, there is a qualitative methodological proposal towards the search for proper development and productive approach for projects in the country [29].

The proposed unified methodology brings together the main characteristics of qualitative and quantitative evaluation, which is why we consider a mixed research approach, since the parameters under study, play an important role in complementing the environmental assessment that should be applied to a more detailed evaluation of the damage presented, thus achieving the mitigation of environmental damage.

The evaluation of environmental impacts in Colombia does not have a rigorous scientific and technical study that clearly determines the environmental assessment; it does not take into account the richness in biodiversity and the unique characteristics of the nation in this matter, which makes the application of methodologies have its starting point through methodologies of international scope and the constant search for the most related, congruent and affordable matrix development with the main objective of the study become a necessity, this shows that the non-guarantee is a constant of a successful evaluation with the application of a single evaluation method in our country [30].

5. Conclusions

As a result of the implementation of the unified methodological matrix for the Environmental Impact Assessment, it is possible to propose lines of action oriented to the formulation and execution of basin management and regulation plans that consider qualitative, quantitative, and geographical aspects of water resources. This is relevant for the implementation of policy projects within the framework of integrated water resources management and environmental research.

Recognizing the importance that the Chicamocha River represents as an axis of economic, social, and environmental development, the environmental authorities must guarantee compliance with the uses established in the framework of the PORH (by its acronym in Spanish - Water Resource Management Plans) planning and regulation plan documents, and the provisions of the POMCA (by its acronym in Spanish - Watershed Ordinance and Management Plans). Likewise, this must be complying with the execution of the projects, building indicators that allow evaluation of their real progress and the achievement of the decontamination goals of this important water resource for the Municipality and the Department. The use of the unified matrix for the Evaluation of Environmental Impacts could be used in other contexts, in which parametric variables are also integrated; As in the case of air quality assessment, where the results of monitoring of atmospheric pollutant emissions can be integrated as input for the analysis, it could even be a tool to verify environmental impact assessment studies that have already been carried out based on other methods. Additionally, the unified matrix allowed determining the real condition of a water resource affected by anthropic activities. Consequently, it has become an essential tool for environmental public policies through policymaking for the prevention, mitigation, and solution of environmental pollution.

6. Declaration of competing interest

We declare that we have no significant competing interests, including financial or non-financial, professional, or personal interests that interfere with the full and objective presentation of the work described in this paper.

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9. Author contributions

Each author contributed significantly to the research process and the construction of the article. The main author contributes his undergraduate degree project as a fundamental input from which this written document is derived, as well as the co-authors provided advice in the research process for the construction of the project. Contributions to the paper: Camilo Alejandro Corregidor Fonseca: Gathering information for EIA, EIA matrix preparation and unified matrix formulation. Biviana Esperanza Rocha Gil: Analysis of statistical data, advisory in gathering information and writing of this paper. Juan Sebastián Chiriví Salomon: Preparation of discussion section, advisory in method application and writing and translation of this paper. Guisett Adelina Gómez Siachoque: Coordination of Project, advisory in EIA application and writing of this paper.

10. Data availability statement

The data were collected in the area under study "Sector Vado Castro" which corresponds to a section of the lower-middle basin of the Chicamocha River in the the Municipality of Tópaga, Department of Boyacá, during the period between February and October 2020. The origin of the data corresponds to the information gathering activities through primary sources of information (dialogues with the community in the project's area of influence, application of surveys, field visits to collect biotic and abiotic information through instruments such as checklists, interviews, survey, monitoring and characterization of physicochemical and microbiological parameters of the water source) and secondary sources of information through which the different existing methodologies for the evaluation of environmental impacts and the bases for the proposed unified matrix were investigated.

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