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Environmental impact study on sanitation system alternatives for addressing wastewater discharges in the coastal area of the Riohacha district in La Guajira, Colombia

Estudio de impactos ambientales sobre alternativas de sistemas de saneamiento para la solución de vertimientos en la zona costera del distrito de Riohacha, en La Guajira, Colombia

MSc. Yamileth Patricia Herrera Campuzano[1], PhD. Carlos Albeiro Pacheco Bustos[2]

[1] IDEHA, Universidad del Norte, Barranquilla, Colombia, Orcid: https://orcid.org/0009-0002-5650-9706, Email: campuzanoy@uninorte.edu.co
[2] IDEHA, Universidad del Norte, Barranquilla, Colombia, Orcid: https://orcid.org/0000-0002-5198-8122, Email: cbustosa@uninorte.edu.co

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ABSTRACT

This research highlights the urgency of addressing pollution in the marine waters and coastal zone of the Riohacha district, aggravated by the discharge of untreated municipal wastewater. The lack of an efficient treatment system has caused soil damage, destruction of marine fauna and flora, impacts on local health, and a decrease in tourism, which is vital for regional income. To solve this problem, three basic sanitation alternatives are proposed: conventional treatment plant, submersible membrane bioreactor and submarine outfall. The environmental impact assessment using the Leopold matrix is essential to understand and compare the possible effects of these alternatives. The Environmental Impact Assessment (EIA) provides crucial data to identify the environmental impacts of each option, facilitating sustainable decision making. This approach demonstrates a commitment to protecting the local environment. Community and other stakeholder involvement will complement this approach, and the results of the EIA and its influence on the choice of the most appropriate alternative are eagerly awaited.

Keywords:

Wastewater, Alternatives analysis, Bioreactor, Outfall, Renewable energy, Environmental impact study, Environmental impact study, Activated sludge, Leopold matrix.

RESUMEN

Esta investigación resalta la urgencia de abordar la contaminación en las aguas marinas y la zona costera del distrito de Riohacha, agravada por la descarga de aguas residuales municipales sin tratar. La carencia de un sistema eficiente de tratamiento ha causado daños al suelo, destrucción de la fauna y flora marina, impactos en la salud local y la disminución del turismo, vital para los ingresos regionales. Para resolver esto, se proponen tres alternativas de saneamiento básico: planta de tratamiento convencional, biorreactor de membrana sumergida y emisario submarino. La evaluación del impacto ambiental mediante la matriz de Leopold es esencial para comprender y comparar los posibles efectos de estas alternativas. La Evaluación del Impacto Ambiental (EIA) ofrece datos cruciales para identificar los impactos ambientales de cada opción, facilitando la toma de decisiones sostenibles. Este enfoque demuestra un compromiso con la protección del entorno local. La participación comunitaria y de otras partes complementará este enfoque, y se espera con interés conocer los resultados de la EIA y su influencia en la elección de la alternativa más adecuada.

Palabras clave:

Aguas residuales, Análisis de alternativas, Biorreactor, Emisario, Energía renovable, Estudio de impacto ambiental, Lodo activado, Matriz de Leopold.

1. Introduction

The Riohacha District tackles an issue related to the lack of a wastewater treatment infrastructure, leading to the unfiltered release of untreated wastewater into the coastal area. The detrimental effects, as shown by unpleasant smells and changes in the coastal ecology, are noticeable in the proximity of the coast [1].

To address this issue and minimize pollution in the coastal area, there is a proposal to use environmentally friendly solutions for treating and properly disposing or reusing wastewater, as laid down in Resolution 1207 of 2014. The process of selecting the most efficient solution will involve identifying and evaluating potential environmental implications through an Environmental Impact Assessment (EIA).

The EIA will utilize the Leopold matrix, a methodology that organizes the correlation between the actions to be executed and their potential impacts on environmental aspects This technique will enable a thorough examination of different fundamental sanitation options, guaranteeing

Corresponding Author
Email: campuzanoy@uninorte.edu.co (Yamileth Patricia Herrera Campuzano)

the selection of a solution that minimizes ecological consequences and fosters sustainability in the region.

2. Background Information

In 2003, Dixon, Simon, and Burkitt published "Assessing the environmental impact of two options for small-scale Wastewater treatment: comparing a reedbed and an aerated biological Filter using a life cycle approach" [2].

Subsequently, in the paper "Environmental performance of a municipal wastewater treatment plant" [3], an assessment was conducted to characterize the physical and chemical properties of wastewater and to compile a detailed record of all the materials entering and leaving a Wastewater Treatment Plant (WWTP), which resulted in a complete collection of empirical data on the flow of water, sludge, and gas between 2000 and 2001. In line with the aforementioned, two impact categories stand out in terms of their significance: eutrophication and terrestrial ecotoxicity. Therefore, the elements that need to be reduced to decrease the environmental impact of the system are the number of pollutants released into the watercourse and the emissions into the soil when the sludge is used for agricultural purposes.

In 2012, a paper was published in Sweden that focused on Systems analysis for environmental assessment of urban water and wastewater systems, in which two urban wastewater systems were evaluated with contrasting characteristics, specifically examining their environmental impact [4]. The first system embodies a centralized, advanced, end-of-pipe framework, whereas the second system primarily relies on source separation tactics.

Based on simulations, it was determined that both systems exhibit outstanding performance in comparison to the majority of conventional urban water systems.

In 2014, research was conducted on the Environmental Assessment of Wastewater Treatment Plants (WWTP) for the Old Rustamiya Project in Baghdad., The study measured various parameters including pH, Total Suspended Solids, Chemical Oxygen Demand (COD), and Biological Oxygen Demand (DBO5), which could be concluded that the removal of BOD was the highest throughout the year, as the efficiency of the WWTPs varied between 92.21% and 92.95% during this study period [5].

An article was published in Romania titled "Environmental assessment of municipal wastewater discharges: a comparative study of evaluation methods": in which three methods were evaluated: Life Cycle Assessment (LCA), Environmental Impact Quantification (EIQ), and Water Footprint (WF), These methods were presented, implemented, and critically analyzed using a specific set of data related to the WWTP in the city of Iasi [6]. The findings have indicated that the primary causes of the observed effects on surface waters are nutrients (namely, nitrogen and phosphorus compounds), which can lead to eutrophication, as well as contaminants that contribute to toxicity impacts, although to a lower degree.

A research project was discovered in 2022 that aimed to develop a monitoring system for temperature, pressure, and pH variables in an anaerobic biodigester, and whose focus was to create a supervision system that allows analyzing the involved variables in data collection using a virtual instrument. The purpose of this system was to regulate the amount of organic waste produced by agricultural components, which is typically released into water bodies and open fields without proper treatment [7].

The study focused on the generation of energy using a system consisting of solar panels and batteries. Also, it examined the behavior of a system that generates electrical energy by utilizing an array of solar panels and a bank of batteries. This study is based upon simulations of established mathematical models from the literature to analyze power generation from photovoltaic solar panels and the condition of charge and power supply in the battery bank [8]. This research is highly relevant to this study since the options to be examined will consider its utilization of solar energy in response to the inadequate electrical system in the District of Riohacha.

3. Methodology

Matrices are a qualitative methodology that is well-suited for analyzing multiple alternatives in a project, which can be applied in several sectors, including mining, agriculture, and construction [9], [10]. The Leopold matrix, established in 1971 for the purpose of assessing environmental effects, guarantees a thorough examination of these effects at every stage of the project [11].

The approach comprises three fundamental components: identification of variables and effects, allocation of scores ranging from 1 to 10 to assess the extent and significance of the impact, and assessment of almost 8,800 potential interactions between actions and environmental factors. It is stressed that it is not necessary to assess them but only those that are most pertinent to the project.

In order to enhance productivity and minimize errors, it is recommended to utilize a checklist or scoping table that clearly defines both positive and negative aspects. It is advised to conduct the matrix assessment with a team of professionals who may provide multiple viewpoints to maintain objectivity which avoids the subjectivity related to individual bias [11].

The Leopold matrix technique outlines three fundamental components for conducting an Environmental Impact

Assessment (EIA):

3.1 Identification of Factors and Effects
A matrix is used to gather the factors and effects of each project activity. Boxes with significant environmental impacts are marked with a diagonal line.

Scoring Allocation:
The scores range from 1 to 10 and reflect the extent of the action's impact on a particular environmental feature. These scores are displayed in the upper left-hand corner and can be either negative or positive.

3.2 Significance Rating
A rating is assigned in the lower right-hand corner, indicating the significance of the impact on the project, using the identical scoring system.

The Leopold matrix assesses around 8,800 potential interactions between actions and environmental factors. It is important to mention that evaluating all these contacts is not required; it is advisable to prioritize the ones that are directly related to the project and are more significant in terms of quantity and importance [11].

In order to enhance productivity and minimize errors, it is recommended to utilize a checklist or scoping table that clearly defines both positive and negative aspects. It is recommended to conduct the matrix assessment with a team of professionals who may provide multiple viewpoints to maintain objectivity which avoids the subjectivity related to individual bias Furthermore, it is advisable to refer to Tables 1 and 2 for a comprehensive evaluation of significance and scale of the effects on the project.

Table 1. Suggested values for the Leopold Matrix – Magnitude

Intensity	Effect	Rating
Low	Low	(+/-) 1
Low	Medium	(+/-) 2
Low	High	(+/-) 3
Medium	Low	(+/-) 4
Medium	Medium	(+/-) 5
Medium	High	(+/-) 6
High	Low	(+/-) 7
High	Medium	(+/-) 8
High	High	(+/-) 9
Very High	High	(+/-) 10

Source: [11]

Table 2. Suggested values for the Leopold Matrix – Significance

Duration	Influence	Quantification
Temporary	Specific	1
Medium	Specific	2
Permanent	Specific	3
Temporary	Local	4
Medium	Local	5
Permanent	Local	6
Temporary	Regional	7
Medium	Regional	8
Permanent	Regional	9
Permanent	National	10

Source: [11]

To calculate the interaction values for the final assessment of the Leopold matrix, the significance of each box is multiplied by its magnitude and also it is determined the number of project activities that have an influence on the environment and identifies the specific elements that are modified, which are then categorized as either positive or negative impacts.

Then, the impacts created by each activity are determined by calculating the algebraic total of each column and row. Also, an aggregate sum is calculated by adding up the values in the columns and rows, ensuring that the signs (positive or negative) of the values are constant. If the evaluation determines that the project is not ecologically feasible, environmental management strategies can be formulated, such as preventive, corrective, or mitigating measures, to ensure the environmental feasibility of that alternative.

The Leopold matrix will be used to conduct an environmental impact analysis, and based on the outcomes, the most ecologically sustainable wastewater treatment system will be defined. This comprehensive approach would enable the making of well-informed decisions and the implementation of suitable steps to reduce the environmental effects of the project.

4. Analysis Outcomes and Discussion

The assessment of the alternative matrices was conducted by taking into consideration the criteria of diverse professionals in fields such as environmental engineering, biology, civil engineering, and industrial engineering. The experts, who are specialized in environmental impact assessment, civil engineering, industrial engineering, chemistry, and other relevant fields, offered a range of viewpoints to study the potential effects of the alternatives. By including professionals who possess specialized knowledge, the outcomes are guaranteed to be unbiased and accurate.

To ensure precise outcomes, the assessors meticulously scrutinized the activities of each choice from several angles. Below, the research results and discussions will be shown of each of the case studies covered. To comprehend the outcomes of the matrices, table 3, which shows the assessment of criteria, will serve as a benchmark for making decisions and choosing the most suitable option. The use of a multidisciplinary approach enhances the quality and comprehensiveness of the evaluation, hence facilitating informed and sustainable decision-making.

Table 3. Final Assessment of Impacts

Low impact	1 - 30
Medium impact	31 - 61
Severe impact	62 - 92
Critical impact	>93

Source: [12]

4.1 Case Study 1

Construction of a traditional wastewater treatment facility that is operated using solar panels. This also embodies a sustainable advancement in the management of water resources. This system utilizes activated sludge technology, which exploits the fluid and mixed growth of microorganisms under aerobic conditions. This method enables the utilization of organic substances found in wastewater as substrates, eliminating them through microbial respiration and synthesis processes [13]. Figure 1 displays a diagram of this system.

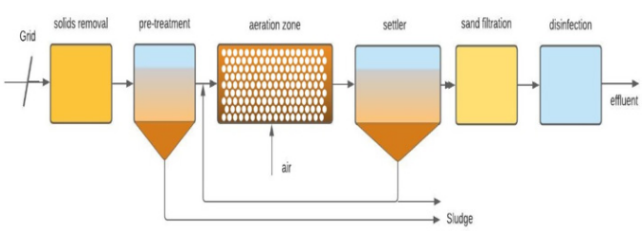

Figure 1. Activated Sludge WWTPs diagram.

In case study 1, the operations that have the most significant environmental impact is the removal of vegetation and debris, extensive excavation, and the construction of several treatment facilities, including the intake channel, grit chamber, primary clarifier, aeration tank, and secondary clarifier. These operations lead to the release of significant amounts of particulate matter, gasses, and odors, as well as the destruction of the natural landscape and the negative effects on local wildlife. The deployment of this particular system requires significant land space and may produce noxious odors if proper preventive measures and suitable technologies are not employed.

The average value of the anticipated impact magnitudes falls within the range of critical consequences, as shown in Table 4. This indicates that the aforementioned activities have the capacity to produce substantial environmental consequences. It is crucial to identify and thoroughly evaluate these impacts in order to develop efficient solutions for mitigating and minimizing them, which can ensure sustainability and reduce any potential negative effects on the local ecosystem.

Table 4. Impact Outcome – Construction of a WWTPs

Activities causing most damage	Factors	Total activities	Total factors
Removal and clearing of vegetation cover	Concentration of particles, gases, and odors	-20	-146
	Loss of landscape nature	-30	
	Fauna	-20	
Deep Excavations> 3 m	Concentration of particles, gases, and odors	-30	-206
	Physical and chemical properties of the soil	-42	
	Loss of landscape nature	-36	
Construction of treatment structures (inlet channel, grit chamber, primary clarifier, aeration tank, secondary clarifier)	Concentration of particles, gases, and odors	-35	-165
	Physical and chemical properties of the soil	-36	
	Introduction of new structures	-36	

4.2 Case Study 2

Development of a Submerged Membrane Bioreactor utilizing solar panels: MBRs are an innovative wastewater treatment system that combines traditional biological treatment methods, such as activated sludge, with advanced membrane separation technology. Therefore, this technology uses microporous membranes to trap aerobic and anaerobic bacteria in the reactor, resulting in improved material degradation efficiency [14]. Figure 2 depicts the schematic representation of this sanitation system.

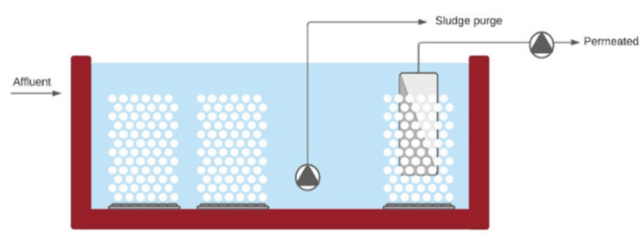

Figure 2. Internal Submerged Membrane System. Source: [15]

Table 5 displays the assessment associated with case one utilizing the suggested approach.

Regarding study 2, activities such as vegetation and debris removal, deep excavation, and construction of treatment facilities (intake channel, grit chamber, primary clarifier, aeration tank, and secondary clarifier) have the most significant environmental impact, similar to the previous option. These activities result in the production of large levels of particulate matter, gas, and odor emissions, as well as the destruction of landscape and flora, and alterations in the physical and chemical properties of the soil.

This technology differs from activated sludge by just necessitating prior treatment with a grid system and potentially an equalization, particularly when dealing with a substantial flow rate. Following the pretreatment stage comes the submerged membrane bioreactor, which utilizes submerged membrane technology to significantly decrease the tank dimensions. Lastly, there is a sample or storage tank that can also function as a chlorination tank, enabling the water to be reused for car washing or irrigation, in accordance with the prevailing legislation in the country where the project is being implemented. This method has a smaller land requirement compared to the previous one, which leads to a substantial decrease in the negative impact resulting from the described activities.

Although there have been improvements, the average projected impact magnitudes still fall within the range of critical consequences. This highlights the necessity of examining other options that are more ecologically sustainable or developing a complete plan for environmental management that incorporates preventive, corrective, and mitigative actions to efficiently minimize adverse effects.

Table 5. Impact Outcome – Construction of MBRs

Activities causing most damage	Factors	Total activities	Total factors
Removal and clearing of vegetation cover	Concentration of particles, gases, and odors	-20	-124
	Loss of landscape nature	-30	
	Physical and chemical properties of the soil	-18	
Deep Excavations> 3 m	Concentration of particles, gases, and odors	-30	-200
	Loss of landscape nature	-40	
	Physical and chemical properties of the soil	-45	
Construction of treatment structures (inlet channel, grit chamber, primary clarifier, aeration tank, secondary clarifier)	Concentration of particles, gases, and odors	-42	-147
	Physical and chemical properties of the soil	-36	
	Fauna	-18	

A submarine outfall is a lengthy conduit that is embedded in the seabed and used to release effluents into the deep region, resulting in effective dilution [16]. Figure 3 provides a visual representation of the functioning process.

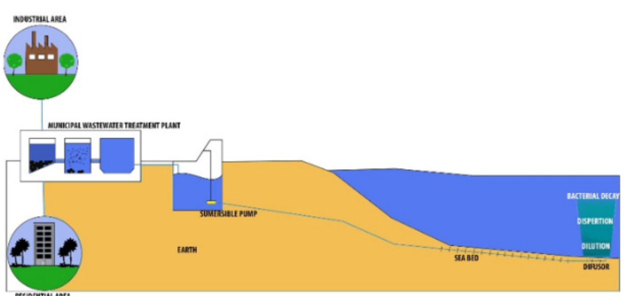

Figure 3. Submarine outfall system. Source: [17]

Within case study 3, the activities that have the most significant influence on the environment are the excavation and drilling operations conducted in the seabed, the deep excavations carried out for pretreatment and vegetation removal, and the stripping of topsoil. The latter action has a lesser impact in comparison to the two former situations since it solely entails the removal of a limited area for the construction of the camp and pretreatment. These activities have negative consequences, like impacting the benthos and altering the seascape. Table 6 displays the assessment associated with case three utilizing the suggested approach.

Table 6. Environmental Impact Outcome of Outfalls.

Activities causing most damage	Factors	Total activities	Total factors
Removal and clearing of vegetation cover	Concentration of particles, gases, and odors	-8	-69
	Impact on vegetation cover	-18	
	Loss of landscape nature	-18	
Deep Excavations> 3 m	Higher noise levels	-20	-82
	Soil geomorphology	-15	
	Physical and chemical properties of the soil	-36	
Seabed drilling and excavation	Soil geomorphology	-42	-125
	Impact on habitats or areas of interest (corals, fish, microorganisms).	-24	
	Impact on benthos	-32	

Multiple studies have shown that the per capita expenses of submarine outfalls are lower than those of a wastewater treatment plant. Furthermore, submarine outfalls offer various benefits, such as efficient wastewater treatment and disposal, lack of visual and olfactory pollution, low energy consumption, limited maintenance needs, and reduced land usage [16].

It is important to mention that the overall average value of the expected impact magnitudes falls within the range of average effects, indicating that this choice has moderate environmental implications compared to other alternatives. These results confirm the feasibility and effectiveness of the undersea outfall as an ecologically advantageous choice for wastewater treatment.

Table 7 shows the outcomes and assessments stemming from the environmental impact analyses conducted for each assessed alternative.

Table 7. Outcomes.

ALTERNATIVE	RESULT	RATING
WWTP (Activated Sludge)	-621.25	Critical
MBR	-280	Critical
Outfall	-47.5	Medium

5. Conclusions

The research aimed to provide a conclusive and efficient solution to the issue of untreated wastewater discharge in the coastal region of Riohacha, the capital of La Guajira. By using the Environmental Impact Assessment (EIA) it was evaluated the potential impacts of various treatment systems, ranging from traditional options like activated sludge to advanced technologies like submerged membrane bioreactors, which produce treated water with reduced pollutant levels and take up less space during construction. A simpler alternative, such as a submarine outfall, was also assessed. This analysis shall guide the planning of actions with the ultimate goal of restoring the original state of the coastal and maritime waters of the Caribbean Sea near Riohacha, by improving the quality of life of the inhabitants and boosting the local economy through tourism.

The outcomes of the environmental impact study, in which the Leopold matrix technique was used for the three options, unveiled the environmental consequences at every phase of the project, assessing each environmental component and its overall impacts. This evaluation aids in identifying the most ecologically viable choice.

According to this approach, it is determined that the establishment of a traditional activated sludge treatment plant is the endeavor that produces the most significant adverse effects, necessitating a substantial land area and causing noteworthy harm to the local wildlife and vegetation. However, the development of an undersea outfall is considered the most environmentally beneficial option, as it has few and insignificant negative impacts. This latter alternative has been chosen as the preferred one, ensuring minimal adverse effects and more advantages for both the environment and society as a whole. This study can be replicated in any geographical region.

6. Acknowledgements

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7. Supplementary Data

The input data linked to this contribution can be found at: https://data.mendeley.com/ datasets/4hk72jxx32/1

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