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REVIEW OF STUDIES AND TOOLS FOR EVALUATING THE ENVIRONMENTAL IMPACT OF PURIFICATION AND WATER TREATMENT PROCESSES.

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Bolivia is a developing country. In recent years, it's betting on training and investment in technology for purification and water treatment; a pending issue in the country. Decision-making in industry and management requires quality, updated and reliable information. There are various tools and indicators that allow obtaining this information. Each one of them has time, human and financial resource requirements providing data of different characteristics. Among the most used tools, we can highlight the Life Cycle Analysis, the Ecological Footprint and the Carbon Footprint, among others. This article carries out a bibliographic review of the characteristics and case studies in water purification and treatment processes, with special attention to reverse osmosis (RO) processes, which are booming in research in Bolivia. The objective is to identify the most appropriate tools for the implementation in the management systems of the different phases of design, planning, development and operation of the water treatment and wastewater treatment plants.

Keywords: Project; phases; environmental; indicators.

REVISIÓN DE ESTUDIOS Y HERRAMIENTAS DE EVALUACIÓN DE IMPACTO AMBIENTAL DE PROCESOS DE POTABILIZACIÓN Y TRATAMIENTO DE AGUA.

Bolivia es un país en vías de desarrollo. En los últimos años, se está apostando por la formación e inversión en tecnología para la potabilización y el tratamiento del agua; una asignatura pendiente en el país. La toma de decisiones en industria y gestión requiere de información de calidad, actualizada y fiable. Existen diversas herramientas e indicadores que permiten obtener esta información. Cada uno de ellos, tiene unos requisitos de tiempo, recursos humanos y recursos económicos aportando datos de distintas características. Entre las herramientas más empleadas, se puede destacar el Análisis de Ciclo de Vida, la Huella Ecológica y la Huella de Carbono, entre otras. Este artículo realiza una revisión bibliográfica de las características y casos de estudio en procesos de potabilización y tratamiento de agua, con especial atención a los procesos de ósmosis inversa (OI), en auge en la investigación en Bolivia. El objetivo es identificar las herramientas más adecuadas para la implementación en los sistemas de gestión de las diferentes fases diseño, planificación, desarrollo y explotación de las plantas potabilizadoras y de tratamiento de aguas residuales.

Palabras claves: Fases; proyecto; indicadores; ambientales.

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1. Introduction

Currently drinking water is increasingly scarce in Bolivia. The human being uses it for their daily activities, as well as in industry, agriculture and livestock (Ortiz, 2007). In general, contaminated water is detrimental to public health (Ara, 2002). According to the World Health Organization (1996), it is estimated that 3 million people die every year in the world from drinking unsafe water. For this reason it is essential to have water of sufficient quality. Many processes and technologies such as: filtration, chlorination, reverse osmosis, among others, were used for this purpose (Berdonces, 2008; Romero García, 2008).

An increasingly applied and profitable technology in water purification plants is membrane filtration. Studies of its processes, such as ultrafiltration, nanofiltration, and reverse osmosis, have increased significantly in the last decade (Pressdee et al., 2006; Yang et al., 2019). The Reverse Osmosis (RO) acquired special relevance because it manages to remove very small contaminants (<1 nm) from the water, guaranteeing sufficient quality for human consumption (Hernández et al., 1990; Greenlee et al., 2009). RO is mainly focused on reducing the concentration of ionic pollutants and dissolved organic compounds (Fu & Wang, 2011). The removal efficiency of the RO is high, its implementation does not require a very large space, it is easy to operate and it is a quick process (Pearce, 2007; Alvizuri, et al., 2019).

The concern for environmental care and the impacts of making different products or services has increased. That exposes the need to include management tools, seeking sustainability in the processes (Perevochtchikova, 2013). These tools can be divided into: preventive, corrective/conservation and improvement. Among the environmental management tools we can mention: the Life Cycle Analysis (LCA), the Environmental Audit (EA) and the Environmental Impact Assessment (EIA) (Laura Massolo, 2015). These have been implemented in different sectors, projects and processes such as industrial landfills and water treatment plants (Rodríguez Miranda et al., 2016; Torrado et al., 2010). This work seeks the implementation of environmental management tools in water purification plants that focus on the use of new technologies such as reverse osmosis. In addition, it will be exposed which indicators could be applied within the management tools to facilitate and strengthen decision-making.

2. Methodology

The exploratory methodology will be adopted in the realization of this article. A variety of bibliographic databases will be reviewed (SCOPUS, Web of Science, and Google Scholar). For the review, books (Ebooks), final postgraduate projects and scientific articles with an impact factor greater than 3, according to the Journal Citation Reports, will be taken into account. The bibliographic review will be carried out around concepts of environmental management tools: Life Cycle Analysis (LCA), Environmental Audit (EA), Environmental Impact Assessment (EIA). It will also be related to definitions and application of environmental indicators: Ecological Footprint (EF), Water Footprint (WF) and Carbon Footprint (CF).

The found information will be filtered from outside previous experiences in water purification systems. Information will be extracted only from documents that provide relevant, generalized and standardized methods for the concepts addressed. In this work, the main characteristics of the environmental management tools and indicators will be defined and the most appropriate ones for their implementation in water purification plant management systems will be identified.

With special attention to plants that have reverse osmosis processes, depending on the phase of the project in which it is.

3. Synthesis and Results

Around 130 publications were analyzed, 59 were abstracted, which were organized according to the adopted methodology and divided into three sections: documents related to environmental management tools, documents related to environmental management indicators and documents on the importance of water and debugging processes. These are presented in Table 1.

Table 1. Synthesis of the information collected.

Type of documents	Number of documents reviewed	Observations
Documents related to management tools.	31	Among these files a higher percentage is directed to life cycle analysis of different projects, followed by environmental audits and finally environmental impact assessments.
Files containing information on environmental management indicators.	10	Same number of files and information regarding the three indicators studied.
Documents with topics around the problem of the importance of water and purification processes.	18	These documents contain information about purification processes with emphasis on reverse osmosis processes used for that purpose.

Source: Own elaboration, 2021.

The following sections comprise the synthesis of the information collected in the literature review. First, the environmental management tools LCA, EA, and EIA will be defined, their advantages and disadvantages will also be shown, and a comparison between them will be made. Then the characteristics of the environmental management indicator will be analyzed. Finally, the analysis for the application of environmental management tools and indicators in water treatment plants with reverse osmosis processes will be presented.

3.1. Environmental management tools

3.1.1. Life Cycle Analysis (LCA)

The Life Cycle Analysis (LCA) is based on the collection and evaluation of the resources consumed (inputs), emissions (outputs), social and environmental impacts of a system (International Organization for Standardization [ISO] 14040, 2006), from the extraction of resources, production, use, recycling and to final disposal (European Commission, 2010). In recent years, LCA has been implemented mainly in industrial processes. Some LCAs carried out were in the production of cement, ceramics, nanoparticles as flame retardants, in the management of solid waste, among others (Benveniste, 2011; Borunda, 2012; Bovea et al., 2010; De Carvalho, 2001; García Parra & Plazas, 2019; Tong et al., 2013).

This tool includes four phases:

a. Objective and scope definition phase

In this phase, the purpose of including the assessment of environmental impacts in the decision-making process is defined. In addition, the information necessary for decision-making, the accuracy of the results, and how to interpret these results to make them meaningful are determined (Hertwich et al., 2000). The scope of an LCA includes the functional unit, the system limits, the procedure to be used when assigning loads, the impacts to be taken into account and the methodology for evaluating the impacts (ISO 14040, 2006).

b. Inventory analysis phase (LCI)

In the second phase, Life Cycle Inventory, the flows of energy and materials that enter and leave the studied system during its life cycle are quantified (Castillo & Mora, 2000). The data necessary to fulfill the objectives of the LCA is collected. Parameters such as: land use, radiation, noise, vibrations, affected biodiversity can also be included (Herrera, 2004).

c. Life cycle impact assessment phase (LCIA)

In this phase, additional information is provided to evaluate the results of the LCI and to better understand its environmental importance (ISO 14040, 2006). Global warming potential (GWP) and eutrophication potential (EP) are commonly considered impact categories. These are included due to their importance at a social, political and environmental level (Gallego and Tarpani, 2019).

d. Fase de interpretación del ciclo de vida

It is the final phase of an LCA. Where the results of the LCI, LCIA or both are discussed to reach conclusions, recommendations and decision-making to meet the defined objective and scope (ISO 14040, 2006). In general, in extensive technologies, sensitivity analysis is focused on methane (CH4) emissions (Cornejo, Zhang & Mihelcic, 2013).

3.1.2. Environmental Audit (EA)

According to Bolivian Law No. 1333 (1992), the Environmental Audit (EA) is "a methodological procedure that involves analysis, testing and confirmation of procedures and monitoring, which determine the environmental situation of a project, work or activity and the verification of the level of compliance with current environmental regulations ". An EA can be applied in different stages of an Activity, Work or Project (AWP) in its zero state, during its operation and at the end of its useful life (Padin, 2017). EA is considered an indispensable tool for environmental management, it contributes to the sustainable use of natural resources in companies and institutions. Due to constant concern, EAs were implemented to a greater extent (Antúnez, 2025). Through the audit and its application, it will be possible to know the impacts generated, and the actions to mitigate or eliminate them. The audit includes methods of controlling resources and the decision-making process in the company (Rodríguez Córdova, 2016).

When conducting an EA, the following should be observed: initiatives to prevent, reduce or remedy damage to the environment, the conservation and use of renewable and non-renewable resources, and the consequences of the violation of environmental laws and regulations. ISO 19011 (2018) contains the Guidelines for Environmental Audits: general principles of environmental audits. In addition, the types of audits and the steps to carry them out are described in Table 2.

Table 2. Types of audits

First party audit	Second party audit	Third party audit
Internal audit	External supplier audit	
	Other external stakeholder audit	Legal, regulatory or similar audit

Source: ISO 19011, 2018.

Rodriguez C. R. (2016) indicates that companies that want to implement any type of audit should follow the following steps:

a. Environmental Policy

This must be defined by the highest authority. It must contain a declaration of principles and intentions of the company with the environment, which has well-defined objectives and goals.

b. Planning

The planning stage is one of the most important. The environmental aspects to be evaluated are identified, the most significant will form part of the company's environmental policy. Regulations linked to the processes carried out by the company must be compiled. In addition, the audit plan is prepared and tasks are assigned to the audit team.

c. Execution or implementation

In this stage, what is planned in the audit plan is carried out, the information provided is compiled and verified, the findings are generalized and the audit conclusions are specified. The current state of the company, weak points and solution proposals are identified.

d. Corrective action

The audit report contains the result of the audit. The responsibilities of the authorities to deal with non-conformities are defined. These are the corrective actions that the company will take to comply with the regulation.

e. Monitoring

It consists of periodic reviews carried out and documented by senior management, regarding the changes made and their efficiency. It seeks reformulation and redirection in the company's environmental policy, as well as improvements in environmental objectives and goals.

3.1.3. Environmental Impact Assessment (EIA)

It is a preventive tool that seeks to identify, prevent or correct the impacts that AWPs cause on the environment, but before they are executed (Massolo, 2015). The impacts are an alteration in the environment as a consequence of human actions. According to Massolo (2015) these impacts can be classified depending on: their character (positive and negative), their intensity (high and low), their extent (punctual, partial and total), their cause-effect relationship (direct and indirect), the capacity of recovery of the environment (irreversible, reversible, mitigable and recoverable) and its periodicity (continuous, discontinuous and periodic).

One of the most used methods is the Leopold Matrix. This consists of a double entry box. In the rows the affected environmental factors are arranged, and in the columns the actions to be carried out that will be the cause of the possible impacts (Massolo, 2015). Once the entries are filled, the next step is to interpret them and weight them with a number from 1 to 10 considering the mentioned properties (Pinto, 2007).

3.2. Advantages and disadvantages of environmental management tools

The application of environmental management tools can be a great help in making decisions about a project. Certain difficulties or limitations that may influence when choosing the tool to use must be taken into account. The advantages and disadvantages of the management tools studied are found in Table 3, this will allow us to visualize which is the most convenient for its implementation.

Table 3. Advantages and disadvantages of environmental management tools

Tool	Advantages	Disadvantages
LCA	• It can be used alone or together with other tools, with the EIA for example (Romero Rodríguez, 2003). • Estimate the potential effect and how to reduce the environmental impact on a global or regional scale (Benveniste, 2011). • It helps prevent pollution, promotes sustainable development on different scales (Keoleian, 1988). • Thanks to the continuous advancement of the methodology, current uncertainties and disadvantages can be clarified and resolved (Finnveden, 2009)	Among the main disadvantages according to Finnveden (2009) we have: • It requires a lot of data, and a lack of data can distort the study's conclusions. • There are uncertain points in its application, such as study time limits. • It is recommended not to implement an LCA in small companies. It has high costs, is time consuming and involves micro-management in private companies (Government of Chile, 2001).
EA	According to Rodríguez C. R. (2016) conducting an EA grants the following benefits: • It could enjoy a good competitive insertion in the market by being accredited. • It may have greater performance with respect to the use of resources and better management of energy and economic costs. • The company is not obliged to carry out an EA. But, it is getting better and better to have these certifications.	Among the disadvantages are: • To obtain a certification, the company must implement a management system, and allow an external party to make an evaluation of it. Which requires help from third parties. • Carrying out an AA for accreditation requires high costs, since it must adopt improvements in its processes or acquire more environmentally friendly technologies (Padin, 2017; Rodríguez Córdova 2016).

EIA	Some advantages of an EIA according to Massolo (2015) are: • The tool manages to integrate different components of the environment (air, water, soil, etc.) and different disciplines. • It helps focus on the significant impacts that the AOP will have if it is implemented. • It is a flexible tool. It can be implemented in different cases. • It is a participatory tool, it incorporates citizens as actors. • It helps to eliminate negative environmental actions, to mitigate impacts over time.	Among the disadvantages that according to Pinto (2007) arise when conducting an EIA are: • The action vectors change depending on the AWP. • When the affected environmental factors change, the entire evaluation method changes. • This tool is subjective, it depends on the person / people who carry it out.

Source: Own elaboration, 2021.

Table 3 shows that the 3 tools studied have more advantages than disadvantages. However, much depends on the situation of the company for its implementation. Because it requires a lot of information that could be difficult for a newly established company to obtain.

3.3. Comparison between studied tools

LCA has been evolving since the 60s, which has been developed for different disciplines (Corominas, 2013). Year after year, uncertainties about its implementation are clarified, thanks to experience in different sectors, it is becoming common for LCA to be used in different parts of the world. China, Mexico, the Dominican Republic, among others, applied LCA in the management of their water treatment and purification (García J. S. et al., 2013; Li et al., 2013; Rodríguez Miranda et al., 2019).

The EAs were a response to the need for a third party to endorse the company, with the aim of obtaining advertising benefits. Because since the 80's the issue of corporate social responsibility and social and environmental accounting began to gain relevance (Padin, 2017). Although the ISO 14 000 and 19 011 standards are voluntary, they are more requested by the private sector (Antúnez, 2014).

EIAs were implemented since the 1970s. Because the environmental variable was considered as a factor to guarantee progress (Cruz, Gallego & González, 2009). It is important since it incorporates variables that traditionally have not been considered during its planning, design or implementation.

Table 4. Comparative table of the management tools studieds

Environmental management tool	Object	Objective	Process
LCA	Product or service	Evaluation and improvement of environmental impact	*Inventory *Impact assessment *Actions
EA	Company or facility	Adaptation to an environmental standard	*Situational analysis *Weaknesses *Proposals
EIA	Proyect	Decision on a project	*Environmental and social impact assessment *Corrective measures *If the project is necessary

Source: Gallego y Tarpani, 2019

3.4. Indicators that help environmental management tools

There are various indicators that can contribute to improving the environmental management of companies. Such as electricity consumption, fossil fuel consumption, water consumption and paper consumption, among others (Chavarría, Garita & Gamboa, 2016). However, they were grouped into three groups that contain them: Ecological Footprint (EF), water footprint (WF) and carbon footprint (CF). These contemplate the variation of the different pollutants in all the environmental components.

Table 5. Characteristics of the environmental management indicators

Indicator	Characteristics
Ecological Footprint	According to Larralde, González and Marrero (2014) it is an indicator of sustainability. It measures the impact of a certain community, person, company, etc. on the environment. It takes into account the population involved in space and a defined period of time. It involves the environment and what is obtained from it, for example: - Crops → food, fibers and oils - Grazing → meat, milk, leather, wool etc. - Forests → wood → production of goods, fuel. The EF allows us to know the limitations of the environment on human activity, resources. (Martinez, 2007) This maximum limit is called the carrying capacity of the planet (Wackernagel, 2001), which may not be exceeded or if not entering a phase of overexploitation.
Water Footprint	It is an indicator that measures the total volume of fresh water consumed by a specific unit under study (Rendón, 2015). It is divided into three components: - blue: water consumption from surface sources and aquifers. - green: volume of water consumed from the rains. - gray: amount of water required to dilute pollutants in the water used in production processes. The WF allows us to know if the water consumed comes from places with risk of scarcity or if it affects ecosystems. And it estimates how much water would be necessary to counteract the polluted streams (Tolón, Lastra & Fernández, 2013).
Carbon Footprint	Represents the amount of greenhouse gases (GHG) emitted into the atmosphere derived from the activities of production or consumption of goods and services. Some methodologies take into account the greenhouse gases (GHG) of the Kyoto Protocol, that is: carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons, perfluorinated hydrocarbons and sulfur hexafluoride (SF6) . And others only consider CO2 (Espíndola & Valderrama, 2012). The calculation of the CF allows a company to: be transparent in its processes and actors involved, increase awareness about GHG emissions by involving those responsible and identify areas to reduce emissions to optimize operations and costs (Valderrama, Espíndola & Quezada, 2011).

Source: Own elaboration, 2021.

The indicators must be periodically reviewed. This will determine if they continue to be adequate to measure and improve the environmental situation. It should be verified if they still reflect the environmental impacts of the company. In addition, it should be evaluated whether new indicators can be developed or used or improved (Moncada, 2012).

3.5. Analysis for the application of environmental management tools and indicators in water purification plants with reverse osmosis processes

Reverse osmosis (RO) is an efficient technology to obtain water suitable for human consumption (Ruiz & Coronado, 2016). Promising results were obtained in membranes used in prototypes, without the need for previous physicochemical processes (García et al., 2014). This means that the RO process is implemented in water purification plants. The following is an analysis of the environmental management tools and indicators for their application in water purification plants that have RO processes.

Previous experiences carrying out LCA in different areas, processes and projects, allows it to be implemented in water purification systems that have RO. One existing difficulty would be the lack of statistical data on inputs and outputs of the plant. However, the use of OI is increasing and covering that demand. LCAs performed for RO membranes but on a pilot scale could be taken into account (Senán, 2019). There are projects for the recycling of membranes (Sahuquillo, 2015; IMDEA, 2019), which allow evaluating the project until the end of the useful life of the membranes. It is for this reason that an LCA helps in any phase of the project, be it before implementation, during and at the end of a project.

There are EAs carried out in companies or facilities that have RO among their processes. With positive results and complying with the current regulations of the place (Compañía Contractual Minera Candelaria, 2021). However, the EAs found are focused on water desalination systems or procedures carried out in laboratories (Zúñiga and Avilés, 2013). Therefore, no published information was found on EA carried out in water purification systems that have RO processes. But this is not a limitation of being able to implement it. The advantages of carrying out an EA in a water purification plant would be optimizing the management system within it, a better insertion in the market or in the competition against other water purification plants and even achieving international accreditation. For this, an EA must be carried out in the operation phase of the project, or when thinking about expanding the plant to include new processes such as RO.

EIAs have the flexibility to be carried out in any AWP, which allows their implementation in water purification plants that contain RO processes. Despite this, the application of EIA in water purification plants is scarce, or they are not open to the public. It is ideal to carry out this study in the previous phase of the implementation, since from this phase the company will be able to anticipate impacts and think about how to solve them. This also applies when incorporating processes into the project, to study its viability and if it is a positive or negative change.

For any of the tools previously analyzed, it is necessary to have the indicators described as they will provide important information in any scenario. With what is described in table 4 it is possible to observe how the indicators come to contribute to a company or organization. The Water Footprint with respect to a purification plant allows to know if the water consumed is at risk of scarcity or if the project comes to jeopardize the survival of flora and fauna of the environment. The Carbon Footprint also provides important data regarding GHG emissions and energy consumed by the plant, data that can be taken into account for the adoption of environmentally friendly energy sources. In the same way, the calculation of the Ecological Footprint is important since it considers general aspects of the company's impacts on the environment, to know the limitations of its environment and not to over-exploit it. Knowing these limits does not compromise the resources for future generations, taking another step towards sustainable development.

4. Conclusions

To carry out the review, around 130 documents were reviewed and 59 were selected and analyzed in depth. Of these, 31 were on environmental management tools denoting more information on LCA, followed by EA and EIA at the end, 10 documents on environmental management indicators, and 18 on important issues related to environmental management tools and indicators in water treatment and purification processes.

The tools analyzed are a great help in decision-making in environmental management systems. For this reason, the appropriate ones must be selected for the different phases of the project. In the case of water purification plants, an EIA could be carried out before the plant is built. In the event that the project is already underway or you want to acquire the reverse osmosis membranes, you could choose to carry out an EA or an EIA (only for the expansion of the plant). If you choose to carry out a general evaluation of the entire project, it is convenient to carry out an LCA that considers the impacts from the beginning to the end, which allows to visualize alternatives at the end of the useful life of the osmosis membranes.

These management tools need data to be able to use them properly. Consequently, environmental indicators are used that contemplate the impacts made, in this case, by the water purification plant. The Water Footprint allows us to know if the plant would put the water resource or its environment at risk, which means a great loss for the company and for society in general. Similarly, the Carbon Footprint calculates the emissions and energy consumed by plant machinery, such as reverse osmosis membranes, which become a cost for the company and would contribute to climate change. Finally, the Ecological Footprint allows us to know the pressure that the plant has on the environment. If the regeneration limits of the environment are exceeded, measures will have to be taken to avoid over-exploiting the resources.

This article is introductory to the analysis of environmental management tools. These tools have been applied in projects that seek continuous improvement or are directed towards sustainable development. Considering that water purification plants are a type of company that provides an important service to the community, it is necessary to incorporate the tools studied to strengthen their management systems and optimize decision-making. Further research on the study or optimization of processes in water purification plants should implement management tools and environmental indicators that help achieve sustainability.

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Comunicación alineada con los Objetivos de Desarrollo Sostenible