BIBLIOGRAPHIC REVIEW OF WATER SUSTAINABILITY ASSESSMENT IN CENTRAL AMERICA

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ABSTRACT
Due to the alarming increase in the water consumption rate, it has become fundamental to study ways to diagnose the needs of society assuring a sustainable development. This article covers the evaluation of water sustainability in Central America comprising Nicaragua, Costa Rica, Belize, El Salvador, Honduras, Guatemala and Panama. After analyzing the articles, it was found that Costa Rica and Nicaragua are the countries that have developed the largest number of publications on water sustainability. Among the researchers studied, it is possible to conclude that the use of sustainable politics and laws in the country's resources management plays a fundamental role in the sustainability of water, since a sustainable management responds to the population's complex social and economic reality, whereby the authors propose to implement new technologies to monitor the actual resources conditions and to improve the use and consumption of water by the population.
Keywords: bibliographic review, Central America, water sustainability.

1 INTRODUCTION

Sustainable development intends to meet the needs of the present without compromising the ability of future generations to meet their own needs [1]. Development was conceptualized from an economic perspective in the 20th century; however, the increasing study of the impact of human activity on ecosystems has generated an evolution in the way of conceiving development towards an integral perspective. Thus, the term "sustainable development" emerged in the document "Caring for the Earth", defined as "improving the quality of human life without exceeding the carrying capacity of the ecosystems that sustain it" [2]. One way to address this problem is to implement a methodology capable of interrelating the variables associated with the use of water resources of the society under study and variables of the ecosystem itself.

This is what many researchers try to achieve, evaluating different aspects of society and its processes. For example, the water nexus is present in processes like the treatment distribution and consumption of drinking water, wastewater treatment disposal, water use for energy generation, water management in coastal systems, water consumption in agriculture, water resource management in the watershed and, finally, government policies and actions related to resource management. Since the water nexus is so intrinsic to human existence, it is studied by different countries in various approaches, which are studied in this article at the regional level of Central America. The region of Central America comprises the countries of Nicaragua, Costa Rica, Belize, El Salvador, Honduras, Guatemala and Panama.

This article is presented in four sections: Section 1 describes an introduction of the topic, Section 2 contains the methodology used, Section 3 includes results and discussion, and finally, Section 4 presents the conclusions of this research.

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2 METHODOLOGY

2.1 Literature search strategy

This work was based on bibliographic research on the evaluation of water sustainability in Central America. This research extracts information from the database Web of Science, which constitutes a single multidisciplinary platform for searching and retrieving bibliographic information on works published in the most prestigious scientific journals, as well as tools for analyzing the publications themselves. The search developed uses the following searching equation "TS=(water sustainability) AND TS=(country)". The results were 142 items that were once filtered by selecting those classified as "water resources" and eliminating others which were in formats different from articles; for instance books, reports, etc. Also, excluding the articles which did not evaluate water sustainability, 41 articles remained. Once the articles have been selected, descriptive statistics are applied to analyze the distribution of the data. The process explained is described in Fig. 1.

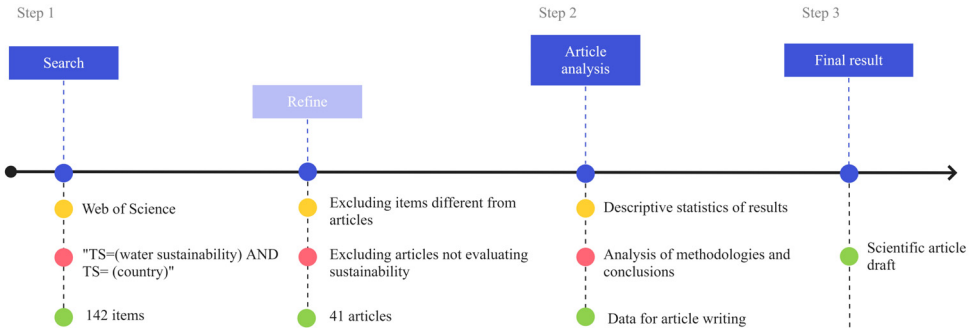

Figure 1: Methodology applied in the selection of articles.

2.1.1 Bibliography analysis

Once the articles to be examined have been established, it is possible to study their data to obtain the frequency of published articles and when these investigations of water. sustainability were developed. In addition, the location of the research made and the country that participated in the study. For example, Fig. 2. describes how many articles were published in each year. From Fig. 2 it is clear that research focusing on water sustainability, especially in Central America, has been increasing through the years making a peak between 2014–2016.

A geographic analysis was made to determine which countries had done more investigations into water sustainability. The results are presented per country in Table 1 and Fig. 3. From this it is concluded that Costa Rica and Nicaragua are the countries with the largest number of publications on this subject, it might be due to the collaboration of its citizens who conducted research during their postgraduate studies. Additionally, Guatemala and Honduras follow up with the most articles published, this fact stems from the continuous efforts of these nations to improve their water sustainability, especially in areas with environmental and social vulnerability, like rural areas.

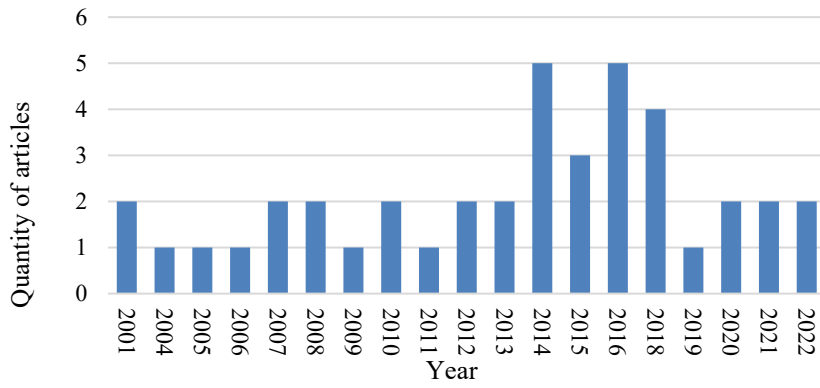

Figure 2: Publications on water sustainability by year of publication.

Table 1: Articles studied by country.

Country	Quantity	Searching equation	%
Belize	2	(TS=(water sustainability)) AND TS=(Belize)	4.88
Costa Rica	12	(TS=(water sustainability)) AND TS=(Costa Rica)	29.27
El Salvador	1	(TS=(water sustainability)) AND TS=(El Salvador)	2.44
Guatemala	8	(TS=(water sustainability)) AND TS=(Guatemala)	19.51
Honduras	7	(TS=(water sustainability)) AND TS=(Honduras)	17.07
Nicaragua	9	(TS=(water sustainability)) AND TS=(Nicaragua)	21.95
Panama	2	(TS=(water sustainability)) AND TS=(Panama)	4.88
TOTAL	41		100

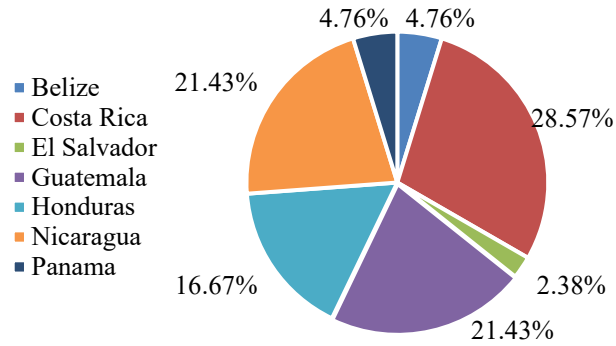

Figure 3: Articles studied by country.

The most recurrent research topics, as described in Table 2 and Fig. 4, are sustainability in drinking water, groundwater, wastewater treatment, integrated watershed management and water resource management. This may be due to the immediate needs of the population, which are the supply of drinking water and the treatment of their wastewater, which leads us to an integrated management of policies on the basins, where this resource is generated.

Table 2: Subject of articles.

Subject	Quantity	%
Watershed sustainability	9	21.95
Potable water sustainability	8	19.51
Governance of water	8	19.51
Sustainable agriculture	4	9.76
Wastewater sustainability	5	12.2
Groundwater sustainability	3	7.32
Archeological water sustainability	2	4.88
Coastal systems	1	2.44
Water for energy	1	2.44
TOTAL	41	100

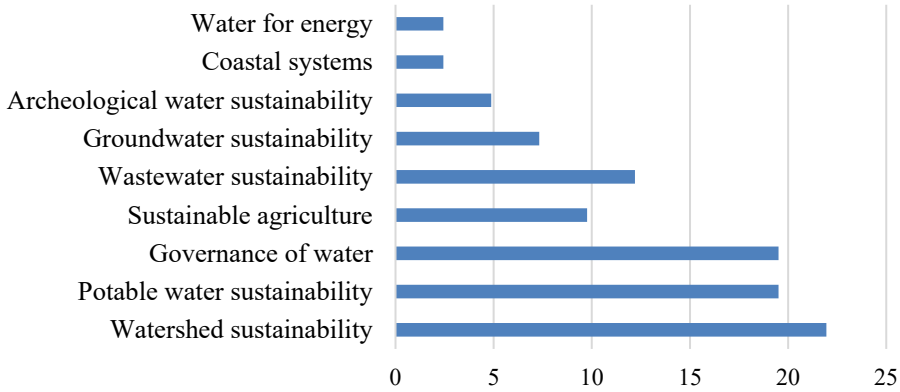

Figure 4: Article's subject by country.

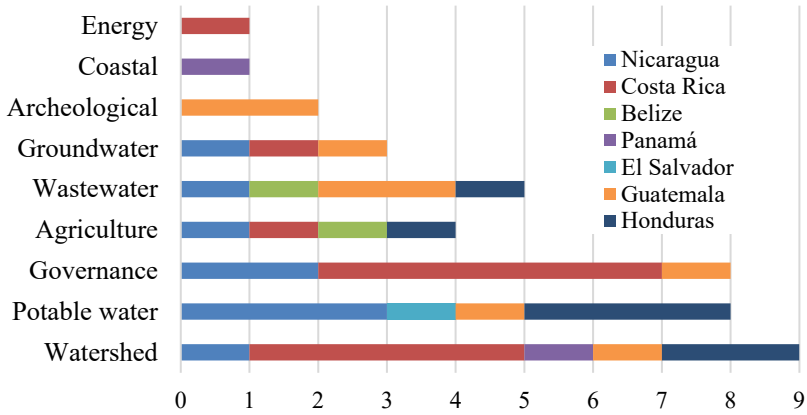

Figure 5: Article's subject by country.

3 RESULTS AND DISCUSSION

This section presents a comparison of results for all the articles discussed. As it is indicated above, the selected articles studied different subjects about water sustainability, in which each country led its methodology and investigation towards a specific view. To better cover the analysis, a study of each topic is presented individually as follows.

3.1 Wastewater sustainability

Wastewater is understood as water flow contaminated by human activities, including natural activities producing fecal matter, as well as agricultural activities with agrochemicals [3]. The discharge of wastewater directly into the environment not only impacts the water resource, but also the health of people with diseases such as diarrhea, causing deaths, especially in infants [4] reducing the quality of human and environmental life. The most vulnerable places are those outside the cities, which lack adequate sanitation, safe water supply, durable housing materials and/or adequate living space [5].

While the pursuit of sustainability in drinking water treatment systems seeks water quality standards (environmental feasibility) in an affordable manner (economic feasibility) with considerations in adapting people by their educational level [6], wastewater treatment achieves its sustainability by considering the social, economic, and environmental factors of the studied community. Many failures in the analyzed projects have their cause in maladjustment designs brought from other peripheries to the culture and society of Central America. For instance, not taking into account the geology, botany or meteorology of the place would make it difficult for the inhabitants to pay for the maintenance of the system due to lack of materials, funds or for the system to be deteriorated to the climate [3], [7].

Among the obstacles with the greatest impact when implementing a new system are: (i) users perception of the need for a change to be made, both in the domestic and agricultural sector [6]; (ii) lack of commitment of the State in following up the project and educating the population, as well as corruption that deviates project funds; (iii) absence of data for an efficient and sustainable design [3], [5]; (iv) lack of adaptation of the design to the community, taking into account factors such as climate [7].

The researches encompass methodologies to solve these obstacles such as (i) using social and behavioral change techniques for the adoption of the new wastewater treatment system, achieving to increase sustainability from 17% to 75% [6]; (ii) the use of stabilization ponds is proposed for being low cost in maintenance, generating jobs and an economic income by selling treated sludge, and using local plants [8]; (iii) in Sabogal et al. [7] they proposed the use of latrines, however, sustainability was not achieved due to a design that did not consider the climate and natural disasters of the site, as well as a deficiency in the education of the villagers; also Ali [5] emphasized that the point of treatment for wastewater can create problems of recontamination, in case of leaks, or cost surcharges in the collection system; while a centralized system, although requiring greater capital investment, can generate jobs and is more sustainable in the long term.

From the preceding, it can be established that sustainability in wastewater lies in the social, economic, political and environmental adaptation of the system to the user society. To achieve this adaptation, the designer must include a transition for the population, carried out through forums, interviews and training; it must also incorporate physical characteristics of the site into the design and empower the user to oversee the monitoring and maintenance of the system by them and the government

3.2 Groundwater sustainability

Groundwater has emerged as a source in the event of scarcity or impossibility of using surface water as a supply, especially for domestic or agricultural use. The main problems addressed in the selected articles are: groundwater contamination by mining, wastewater discharge and agrochemicals; overexploitation of the resource and saline intrusion, and access to groundwater [9], [10].

The search for sustainability, in groundwater, refers to the preservation of water supply, encompassing the quality and quantity of water, for different uses and consumption without compromising other communities in the present and future. This is achieved through the study of the impact that economic and social activities have on groundwater [9].

The proposed methodology encompasses population studies such as surveys, as well as subsurface exploration techniques for the extraction of the resource and evaluation of the studied area. What refers to the factors to be considered to evaluate sustainability, such as social-economic, political and environmental, studied as follows:

- In the social-economic context, the authors proceeded to conduct surveys of decision-makers within the population and users, especially farmers. The studies emphasized the importance of user participation and their power of voice within decision making at the political level [9].
- An active participation of the community, moved by the awareness of a water crisis, generates changes in practices, such as intensive agriculture to sustainable crops with efficient irrigation technologies, and the creation of organizations by the community.
- In the political context, the final impact of legislation and the enforcement of such regulations by the State of each country is highlighted. In countries where there was governmental support, the objectives were achieved and the actions acquired a greater impact not only in the community, but also as an opportunity for the whole country, facilitating sustainability over time with governmental support. However, other countries did not have the support of the government, whose legislation and execution turned to economic activities that compromised the quality of groundwater, despite the movement of the inhabitants against it [9].

The obstacles experienced achieving sustainability in groundwater were the lack of money, the scarcity of data, the lack of interest on the part of young people to maintain sustainability practices in the community, and the increasing change of land use violating protected areas. The authors recommended creating legislation to regulate land use and groundwater consumption, developing data collection for a better correlation of results, and evaluating the exploration methodology according to data availability and soil characterization [9]–[11].

3.3 Coastal water sustainability

A pilot coastal management plan was carried out in Panama; they proceeded to study and identify the areas of greatest risk and developed a management plan. Among the problems identified for water sustainability are the lack of a wastewater treatment system since the inhabitants discharge directly into bodies of water; lack of potable water in the area; and a solid waste disposal system that ends up in the bodies of water and contaminates the subsoil.

The plan could not be carried out due to a lack of financing and support from the State, so it was only possible to propose solutions. Another of the causes mentioned was the barrier

created by institutional instability due to changes of governors, which hindered the continuity of the project.

This led the author to conclude that water sustainability can only be achieved if the State is actively involved in it, since without this, the plans made by external consultants will not be implemented or will be limited [12].

3.4 Water sustainability in agriculture

Water management in agriculture not only affects rivers and groundwater – the last being the alternate source in times of drought – but also impacts the nutritional value of crops that contribute to the health of the population, social equity, and environmental well-being [13]–[17].

Most countries in Central America register approximately half of their inhabitants in rural populations [16] that usually develop an agricultural activity. However, only a small portion employs irrigation equipment (3%–4%) [16]. Hence the importance of bringing improvements to farming techniques to users, to make agriculture more efficient and sustainable. One of the techniques used was land leveling, which optimizes water distribution, reducing erosion in times of drought and flooding in times of rain, which increases production and expenses that impact the farmer, as well as reducing the amount of water used for agriculture; this type of system requires an investment capital that is recovered in the long term [17].

Along with more sustainable techniques, also Bro et al. [18] propose the implementation of cooperatives to empower farmers, as a solution to various problems present in their reality such as lack of roads or transportation networks [19], price and market information [20], and poor access to raw materials [21]. Cooperatives break down these barriers and gaps by increasing financing that boosts productivity and value of agricultural products [22], increases farmers' bargaining power and reduces transactional cost [23]–[26], help finance technologies for agriculture [27] which increases adoption to technology [28], helping to mitigate impacts due to climate [29]. The effect of the cooperative on producers was studied with the implementation of sustainable practices such as proper pest management, mulching, erosion prevention barriers, water retention techniques, water harvesting, use of soil analysis, green cover application, shade management, pruning, and stumping, where it was observed that cooperative members were more active in adopting these practices.

Another methodology proposed by Kammerbauer et al. [30] used aerial photographs to study the evolution of land use over 40 years in a watershed, while covering the social aspect through interviews at the same time, to survey the perception of the population over 20 years. This study showed a change in land use that increased the percentage of crops during the first years and decreased by half once agriculture was established; changes were observed in the forest cover due to its use as firewood, which regenerated naturally at a similar rate to that of deforestation. Therefore, it was advised to change the energy source to conserve the forest cover since this equilibrium may not resist population growth; also improve the monitoring of natural resources and increase the support fund by the State.

The obstacle to these methodologies lies in the corruption and institutional incapacity that manages the funds or supervises the implementation plans [31] as well as the lack of support in the private sector or NGOs [32]. Another obstacle is the marginalization of women, reducing their participation in the economy and decision-making, as well as the implementation of technologies. Likewise, the factor of education is fundamental, since it was observed that the more education the higher the probability of adopting a practice was increasing [18]. Lack of data and monitoring of resources hinders the design and

implementation of technologies [30]. Scarce financing to support investment capital. Lack of farm and land entitlement that makes it impossible to access credit to invest in new technologies or raw materials [18], [30].

Many of the methodologies propose the evaluation of sustainability through indicators of diverse natures such as energetic [17], social, economic and environmental [30], which reflects the complex process of achieving sustainability in a system that seeks to support agricultural activity, which feeds on natural resources, in demand of human presence.

3.5 Water sustainability in energy

This study took place in Costa Rica and Nicaragua, evaluating the water sustainability through ecosystem services. Ecosystem services are those resources provided by the environment for the development of the human activity, different ecosystems provide different resources and generate several users. This system is complex to represent, especially when ecosystem services are not taken into account in political decisions due to a lack of awareness and market failures [33].

The method proposed by Locatelli et al. [33] consists of mapping three factors: (i) spatial distribution of ecosystems and users, (ii) spatial relationship between them, and (iii) presence of filters or barriers between ecosystems and users [34]. Due to the lack of data, only the hydrological approach was performed, considering the various ecosystems of forests, pastures and crops. Generating maps of ecosystem services, achieving through the superimposition with vulnerability maps, determines the areas for conservation and restoration [33].

The results showed that, for Costa Rica, the restoration area coincided with the protection area, being the upper part of the watershed, due to human activities and topography combined with hydroelectric plants; however, for Nicaragua the areas did not coincide due to the lack of pattern for human activity and non-uniform resources. However, the author has insisted that the lack of data did not allow the generation of a reliable hydrological model to provide conclusions that would allow decisions on the economics of conservation and restoration [33].

4 CONCLUSION

Based upon this data it can be concluded that Costa Rica and Nicaragua are the countries with the largest number of publications on this subject, which might be due to the collaboration of their citizens who conducted research during their postgraduate studies. Also, Guatemala and Honduras follow up with the most articles published, this fact stems from the continuous efforts of these nations to improve their water sustainability, especially in areas with environmental and social vulnerability, like rural areas.

Water sustainability can only be achieved if all the variables that influence it are involved in the study. Along with this, one of the most determining factors is the population, since they are not only the users of the systems, but the ones responsible for their maintenance and operation in most cases. Many of the projects developed failed due to the lack of customization in the design of the infrastructure that did not fit the culture of the communities. On the other hand, another factor is the properties of the site, especially the climate, which influences the availability of water throughout the year, and can also generate landslides or floods that compromise the water systems life. Likewise, the politics and government of each country may support and guarantee the system or, it may corrupt and limit the success of the project. The latter is interrelated with the population, as the government provides the population with tools to develop their quality of life, such as

education and it also supports funds to help them access to technologies and infrastructure improvements.

According to water sustainability topics, we can emphasize that potable water sustainability was covered by most of the countries, whose articles proposed an improvement of the distribution web, especially for those rural communities who are more vulnerable to social inequality and resource scarcity; they also proposed new ways of treating water to achieve a sustainable process. Additionally, the wastewater treatment is reviewed, where some scientists describe critical problems in the wastewater plant treatment their country faced, such as low efficiency or an obsolete design which engages to sustainability of its functioning. To resolve it, a scientist proposed several improvements that could be implemented such as filters or try new treatment systems as stabilization ponds. Even though the articles intended to reach a sustainable way for water processing, the methods vary greatly. One factor that explains this behavior is the difference in population along with the culture and activities of each country involved in this research. Among all their concerns one that excelled is the sustainable management in watersheds. Furthermore, other factors that came out where deforestation and affections in different communities of one watershed, which resulted in the implementation of politics that assured the integrity of the ecosystems inside the watershed.

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