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TRANSBOUNDARY GROUNDWATER IN THE MEXICO-GUATEMALA-BELIZE BORDER: OPPORTUNITIES FOR SHARED MANAGEMENT USING INDIRECT METHODS

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Abstract: Evidence on groundwater management policy in the Yucatan Peninsula indicates that Mexico, Guatemala, and Belize lack common scientific concepts for studying shared groundwater flows. Consequently, its current international boundary treaties do not integrate a systemic study and protection of transboundary groundwaters. In Europe, UNECE (2000) has established methodological guidelines and guidelines for the management of these shared groundwater courses. Therefore, the aim of this paper is to study the policy implications and environmental challenges under current national and international management policies on shared natural elements. This is an interdisciplinary critical approach to the theoretical conceptualization of the boundaries and social nature of water within Geography. In addition, the methodology of Gravitational Groundwater Flow Systems (hereinafter Flow Systems) is applied to develop a conceptual hydrogeological model that analyzes regional groundwater boundaries, flow conditions and environmental concerns. We conclude that conceptual modeling of groundwater flows can provide a common framework of knowledge on shared natural elements for authorities.
Keywords: Tothian flows; Transboundary groundwater; Water authority

INTRODUCTION

The United Nations Economic Commission for Europe (UNECE) published more than two decades ago a guide for the monitoring and assessment of transboundary groundwater (UNECE, 2000). This work is useful for identifying groundwater flow systems under a methodology closely linked to that of Tóth. It separates the methods needed to study separate groundwaters from transboundary surface waters and attempts to identify possible overlapping groundwater flow systems (multilayer systems) (UNECE, 2000).

In addition, it addresses the understanding of groundwater movement conditions through the study of depth, spatial and temporal variations of flow characteristics by recognizing the interaction between water and the geological framework and the ways in which groundwater moves in fractures or intergranular media (UNECE; 2000). Thus, it recognizes the need to determine the areas of recharge and discharge for the identification of human and environmental activities that could quantitatively or qualitatively affect groundwater systems.

Hatch-Kuri (2017) studied shared transboundary groundwater between Mexico and the United States, highlighting institutional asymmetries and scientific concepts to be evaluated in shared groundwaters. It proposes the design and use of scientific concepts and methods from an interdisciplinary matrix of Political Geography and Hydrogeology, to generate a shared groundwater policy based on the need to overcome the traditional definition of sovereignty in the face of probable collaboration between States, as proposed by interdependent sovereignty.

Hatch-Kuri, et al. (2021) identified in the municipality of Calakmul the administrative aquifer unit used by the National Water Commission (CONAGUA), uses the methodology of the "water balance" to establish a "water availability" that, once the method is analyzed, is divorced from the study of quality and environmental relations.

The administrative methodology used by CONAGUA, namely the "aquifer" and the "water balance", lacks consideration of the characteristics of groundwater, such as natural limits, chemical and isotopic signatures of water, and residence time, flow hierarchy and its functioning, as well as environmental interactions – following Tóth's (1963) proposal

of groundwater as a geological agent – and the implications derived from this interaction.

Abud-Russell (2019a) through a study of the municipality of Calakmul, Campeche, in the Yucatan Peninsula (bordering Guatemala and Belize) found that Mexican national policies on groundwater management are based on conventionally delimited polygons, called "aquifers", which are used to manage annual volumes of water, distributed among their users. This work concludes that it identified a lack of interest in groundwater quality, the functioning of its flows and its environmental manifestations.

In sum, it is increasingly crucial in Mexico to consider multidisciplinary studies in Geography that address the challenges faced by society in its economic development and related policies, which can have an impact on the quality of environmental resources. Groundwater is a fundamental line of research to understand the close connection between environmental systems and the consequences that can result from the transformation of the natural environment. The shared natural elements on Mexico's southern border require a systemic and comprehensive scientific framework to comply with environmental justice, enshrined in the Escazú Agreement (United Nations, 2018), with the aim of anticipating possible political conflicts between neighboring countries.

THEORETICAL FRAME

Minghi (2018) argues that there are few scientific studies of Political Geography aimed at examining the implications of "common resources" in a border context between nation-states. For surface waters, he argues, boundaries drawn on rivers control power relations around "upstream" and "downstream" use from a basin perspective; As in the case of competition for the use of natural elements in the oceans, it is of utmost importance to have a more precise definition of the concept of "sovereignty". In addition, it cites "insufficient knowledge" of shared natural elements as a central issue to consider in the context of questions about the policy implications of their management for neighboring states.

The debate on sovereignty deepens in Ribeiro (2012), who argues the concept of "interdependent sovereignty" in order to understand how States implement the necessary conditions for the development of joint action frameworks, aimed at resolving conflicts and tensions that arise in border areas.

Since it was proposed in 1962 as a simple analytical model of the distribution of groundwater flow in a small drainage basin, the one proposed by Tóth (1963), the Theory of Gravitational Systems of Groundwater Flow has become a complete theory of regional groundwater flow (Tóth, 2009). It is an "umbrella theory" composed of two subtheories: 1. The hydraulics of groundwater flow at the basin scale and 2. The Geological Agency for Groundwater Flow (Tóth, 2016). The theme of "Sub-Theory-1" is the spatial pattern and dynamic intensity of groundwater flow in topographically defined drainage basins.

This flow is organized into cross-forming flow systems driven by elevation differences in the water table through a hydraulically continuous rock frame. Because of the hydraulic continuity of the flow domain, flow systems develop ubiquitously and simultaneously throughout the porous portion of the Earth's upper crust. "Sub-Theory-2", on the other hand, deals with the processes, products and manifestations of the interaction between moving groundwater and its natural environment on and below the earth's surface (Tóth, 2016). A new hydrogeological paradigm has emerged as a result of that proposal,

implying a transition from the traditional idea of "confined or artesian aquifers" to the contemporary perception of "regionally unconfined, cross-forming flow systems."

The study of the water cycle has traditionally been fragmented, where surface and groundwater are examined as separate elements; with methodologies that do not analyze the environmental implications of water circulation (Kachadourian-Marras, et al. 2020).

Flow Systems (Tóth, 2009) consists of a theoretical and methodological framework from which groundwater is studied as a composite system of different hierarchy and contrasting conditions of movement under interaction with other environmental systems.

Following Kachadourian-Marras, et al. (2020) changes in land use may affect the environmental conditions of regional groundwater recharge zones, suggesting a change in the conditions of their discharge zones.

METHODOLOGY

The case study of the Yucatan Peninsula aims to determine the hydrogeological framework of groundwater flow systems and their lateral and vertical spatial boundaries, in the countries of Mexico, Guatemala and Belize. Comparative studies of existing databases with current analysis of groundwater samples will be conducted to understand groundwater dynamics and the evolution of national and international policies for shared groundwater management in this region.

Following Kachadourian-Marras, et al. (2020), surface water, topography, edaphology, vegetation and land use data were retrieved from Guatemala and Belize, as spatial variables that were analyzed to determine the regional zones (polygons) of groundwater discharge and recharge. Due to the nature of the methodology, that is, it involves various quantitative and qualitative variables that correspond to natural elements, the resulting polygons are interpreted as environmental zones. The sources of information used correspond to:

1. MODIS *Land Cover of South America* from NASA's Scientific Visualization Study. This information dates to the 1990s and provided information on vegetation and land cover use. It is a satellite-generated database that provided more than 3 thousand entries of information for Guatemala and Belize (NASA, 2022); and

2. The Soil and Terrain Database (SOTERLAC) for Latin America and the Caribbean (SOTERLAC) in its version 2.0 provided information on regional relief structures, soil, vegetation, and water bodies for both countries. More than seven thousand data entries were provided by this publicly available information collected through a four-decade effort between ISRIC, the Food and Agriculture Organization of the United Nations (FAO) and the United Nations Environment Programme (UNEP (ISRIC, 2022).

Finally, the Abud-Russell (2019a) study was recovered to know what the current schemes of scientific study and groundwater management in Mexico, Guatemala and Belize are. This information was contrasted with analysis of the attributions of the Mexican authorities in matters of water, in accordance with the Organic Law of the Federal Public Administration and the Political Constitution of Mexico.

RESULTADOS

In the prospective document prepared by the Working Group on Access Rights and Regional Instrument (CEPAL, 2013), they explain that the binding nature of an

international agreement is given once the parties agree that this agreement is governed by international law. Indeed, the Law on the Conclusion of Treaties states that treaties in Mexico will be governed by public international law (Cámara de Diputados del H. Congreso de la Unión, 2021), which implies the binding nature for the action of the parties involved. In this regard, two Interinstitutional Agreements have been identified that are of interest:

1. Agreement between the United Mexican States and the Republic of Guatemala on the Protection and Improvement of the Environment in the Border Zone (Gobierno de México, 2022b), and

2. Agreement between the United Mexican States and Belize on the protection and improvement of the environment and conservation of natural resources in the border area (Gobierno de México, 2022a)

However, when examining the documents referred to, there is no clause expressly recognizing that this agreement is regulated by public international law, which allows us to assume that, at least in the case of Mexico, and derived from what has been analyzed here, these agreements are indeed binding on the federal government, since the Law on the Conclusion of Treaties defines it.

In both Conventions it is referred to that the governments of each country will instruct the corresponding CILA a series of actions to apply these legal provisions. Before moving on to the analysis of the provisions, and the consequent proposals, it is pertinent to frame the CILA in the context of the knowledge acquired in the Research Seminar. The Federal Public Administration has a centralized structure, which are the Secretariats of dispatch with their specific powers and competences. From these emerge decentralized administrative bodies hierarchically subordinate to the secretariats, with specific powers to decide on the matter within the scope of the territory determined for each agency.

In this vein, the Boundary and Water Commissions is a decentralized body of the Ministry of Foreign Affairs, as established in its organizational manual for the Southern sections in article 43, which precisely refers to the administrative deconcentration of the Ministry of Foreign Affairs (Dirección General de Programación, Organización y Presupuesto, 2010, p. 18). Hereafter, a proactive analysis is made on the current provisions contained in the Conventions studied here.

Article 4 of the Agreement between the Governments of Mexico and Guatemala, as well as Article 5 of the Agreement between the Governments of Mexico and Belize, instruct the signatories that the corresponding Boundary and Water Commissions are to carry out studies of environmental aspects related to the protection and improvement of the environment in the border area. This instruction identifies three concepts that are interested in providing greater certainty as to the specific action that will perform it. The concepts are:

1. Environmental studies;

2. Protection and improvement of the environment, and

3. Border area.

Given that these are all broad definitions, scientifically studied for decades from various scientific disciplines, whether social or "natural", and placing ourselves in the context that it is surface water bodies that have been established as the boundaries that delimit the border between Mexico, Guatemala and Belize, it is essential to have a thorough understanding of the hydrological cycle, as well as the most current discussions regarding the definition of what a "border zone" is.

Therefore, the interdisciplinary conjunction of modern Hydrogeology (Tóth, 1963 and Kachadourian-Marras, et al., 2020), as well as contemporary discussions on border spaces in transboundary water contexts (Ribeiro, 2012; Hatch Kuri, 2018), the CILA Sur has signed treaties in which it establishes as one of the actions to be carried out is the improvement of the environment in the border area. However, no evidence was found from technical documents prepared by this authority regarding the determination of environmental zones subject to protection and no indicators, parameters or scientific criteria from which to determine the extent and nature of the necessary environmental protection.

In order to know the potential environmental zones shared by these countries, the methodology developed by Kachadourian-Marras, et al. (2020) for Guatemala and Belize was replicated.

The result (see Figure 1) constitutes an unprecedented advance in the identification of regional groundwater discharge and recharge zones based on environmental indicators (surface water, topography, soil science, vegetation and land use) in these countries.

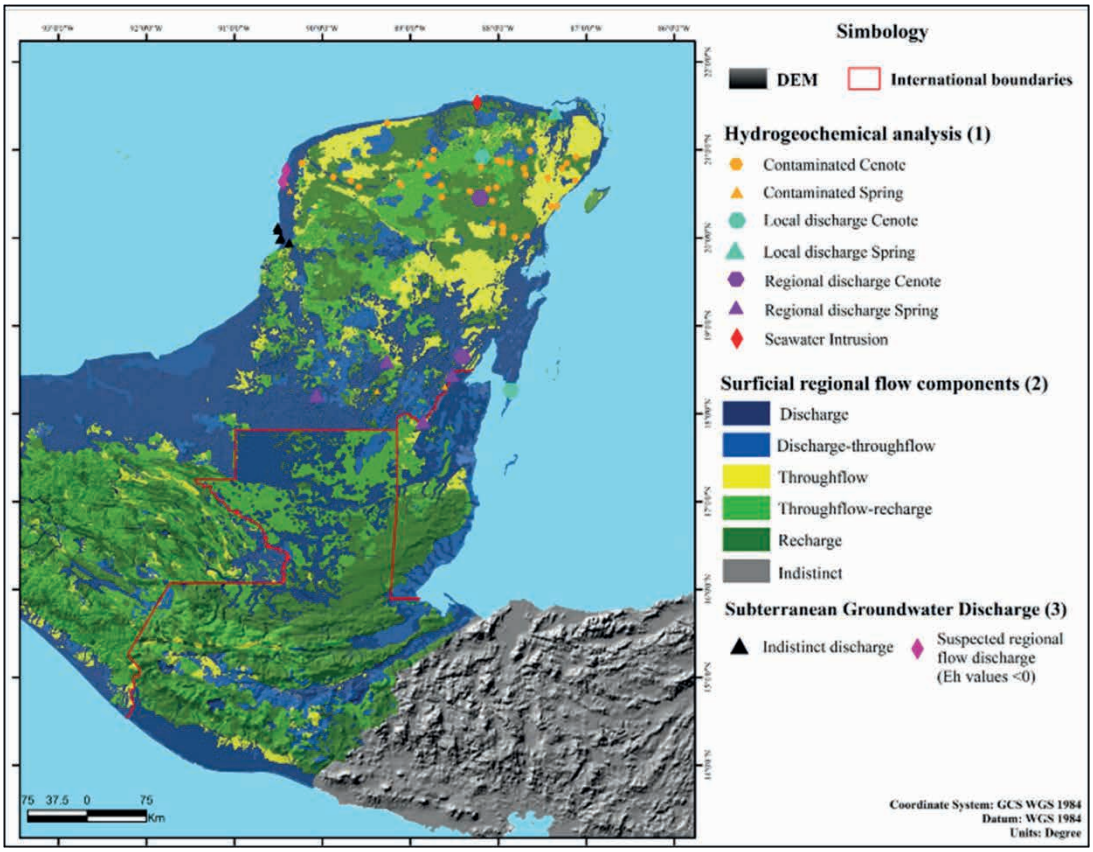

Figure 1. Regional groundwater discharge and recharge zones shared between Mexico, Guatemala and Belize

Source. Own elaboration. Note. SGD stands for evidence of groundwater discharges under the sea. This evidence was found in fieldwork in the town of Isla Arena, Calkiní, Campeche, Mexico in January 2022.

Figure 1 shows the distribution and proportion of environmental polygons near the border between Mexico, Guatemala and Belize that could be subject to environmental improvement policies, since this methodology is developed based on the interaction of various natural variables. Note that the hydrogeochemical results of Abud-Russell, et al. (2021) were integrated into the cartography, based on which it can be noted that there are discharge points of regional hierarchy flow systems discharging in the south of the Yucatan Peninsula, specifically in the municipalities of Calakmul, Campeche and Othón P. Blanco, Quintana Roo; both border with Guatemala and Belize.

These results aim to be subject to the methodological guidelines established by UNECE (2000) by integrating data collection and storage methods, analysis of the interaction between groundwater and surface water, and effects on groundwater quantity and quality in the context of abstraction and other potential environmental impacts. Such data shall serve as a scientific basis for the identification of indicators, including those related to socio-political and environmental variables that have an impact on groundwater, with the aim of defining integrated groundwater and land use management plans.

CONCLUSIONS

In Mexico, there is limited information and data regarding the systemic functioning of groundwater flows in the Yucatan Peninsula. The circulation of these groundwater flow systems is known to extend between the basins of these countries, flowing to and from Belize, Guatemala, and Mexico. However, to date, there is no approved scientific framework among these countries for the study of groundwater. The change of land use due to national public policies can generate adverse environmental implications that affect the proper functioning of these groundwater flow systems and, consequently, do not comply with environmental justice for the inhabitants and ecosystems of these three countries.

If we consider that Abud-Russell (2019a) identified important asymmetries in groundwater management schemes in Mexico, Guatemala and Belize, the context of international relations between these countries presents political challenges for these countries to comply with the Escazú Agreement, as well as the environmental conservation of shared natural elements and dignified conditions for their environment and inhabitants.

The results of this work are framed in the findings of Hatch-Kuri (2018) and Hatch-Kuri and Carrillo-Rivera (2021), who conclude that the lack of common scientific criteria on groundwater assessment prevents the identification of groundwater flows at inter-basin scale and the study of their systemic functioning.

Finally, based on the analysis of the data resulting from the above, it seeks to contribute to the scientific knowledge of the border environmental conditions, based on the methodology of Flow Systems, between Mexico, Guatemala, and Belize. This system of scientific knowledge can become the approved basis from which these countries build a common political scheme for groundwater management and provide clear attributions, based on modern scientific criteria and parameters, that provide conditions for the study, protection, legislation and shared management of environmental zones and groundwater.

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