ADDRESSING WATER SCARCITY IN THE MAGDALENA DEPARTMENT, COLOMBIA: A COMPREHENSIVE ANALYSIS USING SYSTEM DYNAMICS AND BOURDIEU'S THEORY

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ABSTRACT

Water scarcity is a critical issue affecting millions globally and the Magdalena department in Colombia is no exception. This study employs an integrated approach using system dynamics modelling and Pierre Bourdieu's social theory to explore the underlying causes of water scarcity and unavailability in this region. Causal loop diagrams (CLDs) were developed through participatory workshops with local stakeholders, revealing complex interdependencies and reinforcing feedback loops that exacerbate water scarcity. Key factors identified include climate change, deforestation, poor water quality, high agricultural and livestock water demand, infrastructure deficiencies and governance challenges. Bourdieu's theoretical framework further elucidates how economic, cultural and social capital, as well as power dynamics within the field of water management, influence these factors. The study highlights the critical role of governance and environmental education in addressing water scarcity. Improving infrastructure, enhancing governance and increasing educational initiatives are identified as essential strategies for mitigating water scarcity in the region. The findings underscore the importance of a holistic approach that considers both systemic and social factors in water management. By integrating system dynamics with social theory, this research provides a robust framework for understanding and addressing the complex challenges of water scarcity in the Magdalena department. The proposed interventions aim to empower local communities and promote sustainable water management practices, ultimately contributing to the resilience and sustainability of water resources in the region.

Keywords: Magdalena (Colombia), Bourdieu's theory, system dynamics, water management, water scarcity.

1 INTRODUCTION

Water is crucial for all life and yet it is becoming a dwindling and deteriorating resource for millions worldwide [1], [2]. Providing enough water to meet the diverse needs of a growing population has become a significant challenge in recent times. Water scarcity has emerged as a global issue [3], resulting from physical, economic, and environmental factors. Physical water scarcity arises when there are insufficient freshwater resources to meet demand, often occurring in arid or semi-arid regions [3], [4]. Environmental water scarcity occurs when the surrounding conditions hinder efficient use of the resource; processes such as erosion, infiltration, and evaporation can significantly contribute to environmental scarcity [5], [6]. Economic water scarcity arises from underinvestment in water infrastructure or inadequate management of water resources, despite the presence of sufficient water [4], [7]. It can lead to severe consequences such as food insecurity, limited access to safe drinking water, conflicts, and harm to ecosystems. This issue is compounded by population growth, rising water consumption, pollution, and climate change [6], [8], [9]. Effectively addressing this problem demands a comprehensive approach that encompasses conservation efforts,

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infrastructure development, sustainable agricultural practices, and enhanced water governance systems [3], [4], [10]. Without concerted global action, water scarcity is expected to become an even more pressing challenge in the coming decades.

Worldwide, frameworks have been developed to comprehensively address issues in water management, such as integrated water resource management (IWRM). IWRM has been used since the 1990s as an approach to gain a better understanding of water and its usage [11]. It aims for a more thorough analysis by encompassing various non-conflicting aspects of the system. However, analysis by Biswas [11] indicates that publications often use IWRM as a concept without delving into real-world context and interactions with stakeholders within the system. A decade later, Woodhouse and Muller [12] reinforced this notion, highlighting that most research results remain conceptual and lack emphasis on people's lived experiences. Woodhouse concluded that there needs to be greater community dialogue about their governance over resources while seeking adaptive solutions from within.

Colombia has been affected by the phenomena discussed by Woodhouse and Biswas. According to Blanco [13], the government aims to achieve three main points: maximising water resources efficiently, allocating water across different social and economic groups equitably, and protecting the water resources base for environmental sustainability. However, it was concluded that Colombia is failing to meet these requirements due to a lack of synergy between theoretical planning and execution. Furthermore, recent research focusing on social and contextual interactions has emerged as an attempt to address previous issues [14]–[16]. Bocarejo [15], details how certain infrastructure for controlling and regulating rivers have had a detrimental effect on local communities, leading them to lose governance over their land and resources. The argument is made for community management given Colombia's diverse history and culture.

To better understand the complex interactions underlying water scarcity, it is useful to draw on Pierre Bourdieu's theory, which offers a valuable framework for analysing human practice within socio-ecological systems (SES). According to Bourdieu [17], the practices of individuals or social classes are structured and enabled by their habitus and the capital resources they can control or have access across different fields. These capital resources include equipment, property, credit, or money (economic capital); skills, knowledge, ways of seeing, understanding, and doing (cultural capital); and means of accessing additional resources through social networks (social capital). People use and deploy these capital assets according to their dispositions, perceptions, and appreciations (habitus) in competitive contexts (field) defined by stratified positions of prestige and explicit and implicit rules, boundaries, and objectives for the use and valuation of capitals. Bourdieu's theory provides an understanding of how human practices can affect system dynamics, especially in the context of water resources. Dynamical systems modelling is an interdisciplinary approach used to study causal interactions within social-ecological systems and their dynamics at the system level. It incorporates elements from both the system dynamics and mathematical dynamical systems traditions, promoting a 'systems view' that sees elements of an SES as causally interconnected and interdependent; this approach allows mapping the structure of causal relationships within a system and understanding how system-level dynamics result from causal relationships [18].

Causal diagrams, provide a powerful yet intuitive device for deducing the statistical association implied by causal relations. These diagrams serve nonmathematicians aiming to represent significant relations between two or more variables [19]. This attribute aligns well with the intents of SES research, allowing participation across different disciplines and actors to offer input on the topic. However, it does come with complications such as definitions, biases, and concepts that require a thorough and systematic approach [20]. A review [21]

observed that 119 out of 120 articles use social variables and mostly integrate them with environmental ones using rich description and causal loop diagrams as methods, demonstrating the usefulness of this linkage method.

This paper aims to explore the underlying causes of water scarcity and unavailability in Colombia's Magdalena department. It will utilise the SES framework and causal diagram methodology, as this region is grappling with issues stemming from technicalities and bureaucratic processes that prioritise information over practical solutions. Additionally, Bourdieu's theory will be incorporated to understand how human practices and social, economic, and cultural capitals influence water management.

2 MATERIALS AND METHODS

2.1 Study area

The department of Magdalena is in Colombia's Caribbean region (Fig. 1). This area's diverse geography, including coastal areas, river valleys, wetlands and mountainous regions, presents water management challenges. Principal water bodies in this area comprise the Magdalena River and the Ciénaga Grande de Santa Marta. The region's economy relies on agriculture, livestock, fishing, and tourism but faces significant water scarcity, including pollution and conflicts.

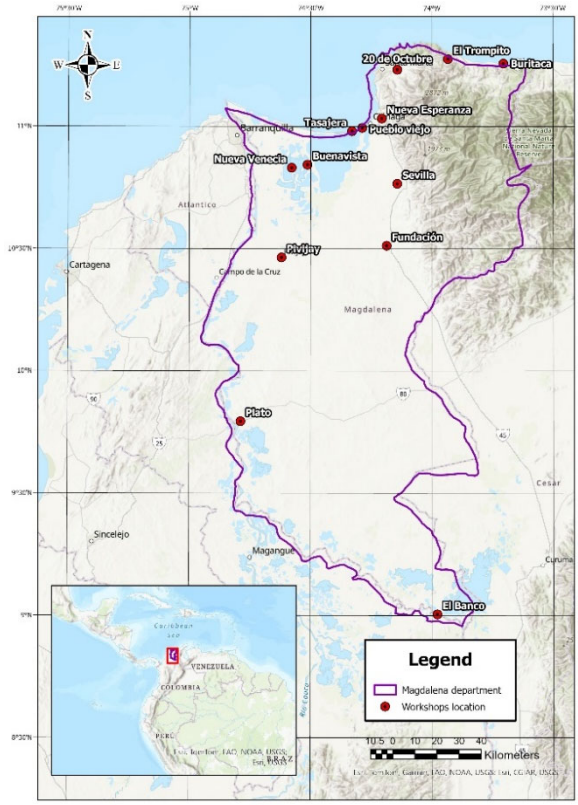

Figure 1: Study area.

This intentional geographical distribution captures the region's diversity, including variations in water availability and socio-economic conditions. We initially contacted community leaders through word-of-mouth referrals and smaller WhatsApp groups, commonly used for communication in these areas. After establishing contact, we assessed the feasibility of conducting workshops in each community by estimating the potential number of participants and identifying the necessary materials and supplies.

During our discussions with community leaders, it became clear that providing food would significantly increase participation. In cases where communities were impoverished, offering groceries proved to be an even more effective incentive (Fig. 2). This approach was crucial in ensuring community engagement by addressing immediate needs while encouraging workshop participation.

Figure 2: Grocery donation.

With these preparations and incentives in place, we anticipated a minimum of ten participants per community. However, the workshops were designed to proceed even if the actual number of attendees fell below this threshold. This flexibility ensured that the workshops could be conducted regardless of participation levels, maximising our outreach and impact across the diverse communities of the Magdalena department.

Finally, 13 workshops were developed: five in the urban area of Pivijay, Plato, Pueblo Viejo, Fundación and El Banco; three in the rural area of Santa Marta (El Trompito, Buritaca and 20 de Octubre); one in the rural area of Pueblo Viejo (Tasajera), one in the rural area of Ciénaga (Nueva Esperanza), one in the rural area of Zona Bananera (Sevilla); and two in the stilt towns of Buenavista and Nueva Venecia (Fig. 1).

2.2 Causal loop diagrams workshop

Upon reaching the local areas, we collaborated with the leaders to confirm the arrangements for food distribution and workshop scheduling. Once everything was prepared, we began conducting workshops, each of which had a duration of around 90 minutes.

We started by presenting our identities and the organisations we were affiliated with. It was crucial to articulate the intended use of the data obtained during the workshop and underscore our research objective: comprehending the community's connection with water and their struggles with water scarcity. Building trust and openness was essential, hence we also established specific guidelines to guarantee that the session would be productive and beneficial for all involved.

Following the introductions, we explained the concept of the causal loop diagram (CLD), our primary methodology for the workshop. It is a tool used to visualise and analyse feedback loops within a system, helping identify and understand relationships between different variables. We provided a thorough explanation, allowing community members to ask questions. This interactive segment encouraged dialogue and ensured all participants comprehended the activity. Next, we divided the attendees into smaller groups of two or three, depending on the total number of participants. Each group received a large sheet of white paper along with sticky notes and markers. They were instructed to write 'water scarcity' in the centre of the sheet. The task was for each participant to jot down different causes of water scarcity and its impacts on their daily lives onto the sticky notes, creating a visual map reflecting their perceptions and experiences related to water scarcity.

This collaborative exercise promoted teamwork and dialogue, enabling individuals to exchange their viewpoints and collaboratively examine the elements that lead to a shortage of water in their locality. It also supported them in visualising how various issues are interconnected and understanding the larger implications of water scarcity on their daily experiences (Fig. 3).

Figure 3: Causal loop diagrams workshop.

3 RESULTS

3.1 Magdalena department water scarcity CLD

The CLD was created using Vensim software (version 10.0.1) [22]. Vensim is a simulation software for system dynamics, used to analyse and structure dynamic feedback models. In Vensim, causal loop diagrams are built by adding variables and establishing causal connections between them. The merged model included all diverging perspectives of the 13 stakeholders (Fig. 4.). The causal loop diagram provides a comprehensive visualisation of the factors contributing to water scarcity in the Magdalena department. At the centre of the diagram is water scarcity, which is influenced by numerous interconnected factors. Climate change and El Niño phenomenon plays a significant role by increasing the frequency and intensity of the droughts. Deforestation further exacerbates this issue by reducing the soil's water-retaining capacity, also contributing to droughts. These droughts, in turn, directly increase water scarcity by reducing the availability of surface and groundwater resources. Poor water quality is another critical factor, reducing the amount of water available for human consumption and agricultural use. This degradation in water quality often results from poor agricultural practices and solid waste pollution, both of which are exacerbated by a lack of environmental education in the community. The demand for water in agriculture and livestock significantly contributes to water scarcity. Poor agricultural practices not only degrade water quality but also increase the demand for irrigation water. Similarly, livestock requires substantial amounts of water, further straining the available resources. Infrastructure deficiencies are highlighted as a major contributor to water scarcity. The lack of adequate infrastructure limits the efficient storage and distribution of water, making it difficult to manage the available resources effectively. This issue is closely tied to poor local government

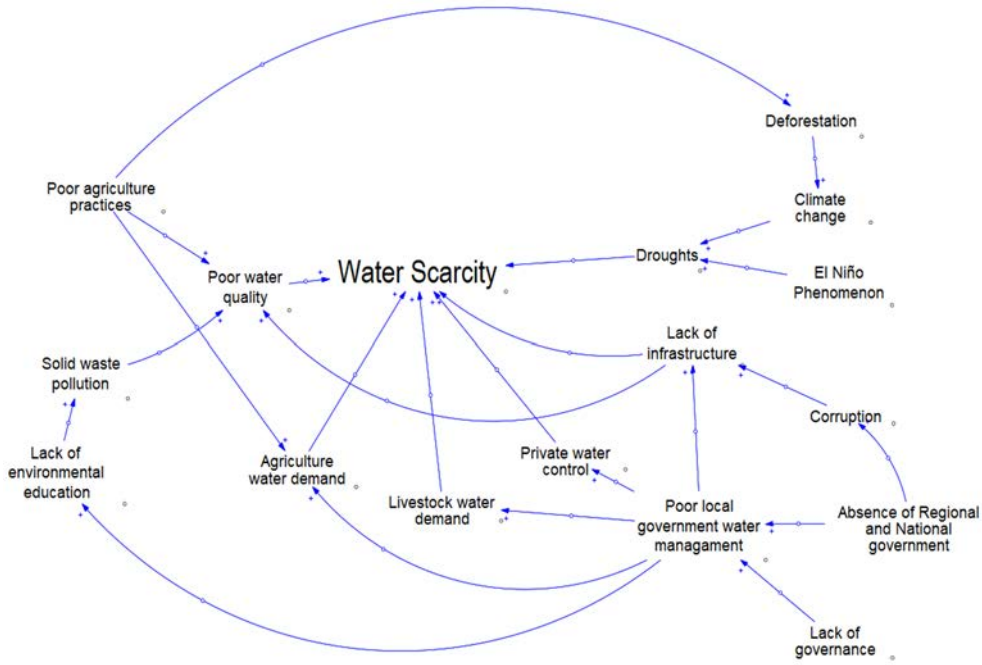

Figure 4: Magdalena department water scarcity CLD.

water management, often hindered by corruption and a lack of support from regional and national government levels. Corruption within local government exacerbates the problem by diverting resources away from necessary infrastructure projects and effective water management practices. Additionally, the absence of governance at higher levels of government means there is insufficient coordination and support for local initiatives, further complicating efforts to manage water resources effectively. The lack of environmental education is a significant factor contributing to poor water management practices and increased pollution. Without adequate education on sustainable practices, communities are more likely to engage in activities that degrade water quality, such as improper solid waste disposal. The causal loop diagram reveals multiple reinforcing feedback loops, where issues like poor water quality, high agricultural demand, and frequent droughts mutually exacerbate water scarcity. For instance, poor water quality increases the demand for clean water, which is already limited due to droughts, further straining the available resources.

3.2 Bourdieu's theoretical framework analysis

To further understand these dynamics through Bourdieu's theoretical framework, we can analyse how habitus, capital, and field influence water management practices in the region. Bourdieu's theory emphasises that individuals' practices are shaped by their habitus (dispositions, perceptions and appreciations), capital (economic, cultural and social), and the field (social space where interactions occur). Economic capital, which includes access to financial resources, significantly affects infrastructure development and maintenance. Corruption and poor governance divert economic capital away from necessary investments in water infrastructure, exacerbating scarcity. Cultural capital, which encompasses knowledge and skills related to sustainable water use and management, is crucial. The lack of environmental education indicates a deficiency in cultural capital, leading to poor agricultural practices and pollution that degrade water quality. Social capital, defined as relationships and networks, plays a critical role in influencing water governance. Effective management requires collaboration among various stakeholders, including government agencies and local communities. Poor local governance and lack of support from higher-level authorities highlight deficiencies in social capital, limiting coordinated efforts to address water scarcity. The field, or the social space where interactions occur, is shaped by power dynamics and the distribution of capital. Actors with more economic and social capital, such as private water controllers, often dominate decision-making processes, marginalising communities with less capital. This imbalance affects resource allocation and management practices, perpetuating water scarcity. By applying Bourdieu's theory, it becomes clear that interventions must address the distribution and use of various forms of capital within the field of water management. Enhancing economic, cultural, and social capital among marginalised communities can empower them to participate more effectively in governance processes, leading to more equitable and sustainable water management practices. This integrated analysis underscores the importance of considering both systemic and social factors in addressing water scarcity, providing a comprehensive approach to improving water management in the Magdalena department.

4 CONCLUSIONS

This study provides a comprehensive analysis of the factors contributing to water scarcity in the Magdalena department through the use of causal loop diagrams and Bourdieu's theoretical framework. The integration of these methodologies offers significant insights into the complex dynamics and social structures that influence water management in the region.

The causal loop diagram revealed that water scarcity in the Magdalena department is the result of multiple interconnected factors, including climate change, deforestation, poor water quality, high water demand from agriculture and livestock, infrastructure deficiencies, and governance issues. These factors create reinforcing feedback loops that perpetuate and exacerbate water scarcity. Key intervention points identified include improving infrastructure, enhancing governance, and increasing environmental education to mitigate these issues.

Applying Bourdieu's theory further elucidates how economic, cultural, and social capital, as well as power dynamics within the field of water management, influence these factors. Economic capital affects infrastructure development and maintenance, with corruption and poor governance diverting resources away from necessary investments. Cultural capital, reflected in the knowledge and skills related to sustainable water use, is lacking due to insufficient environmental education, leading to practices that degrade water quality. Social capital, comprising relationships and networks, is crucial for effective water governance but is currently undermined by poor local management and insufficient support from higher government levels.

The analysis underscores the need for a holistic approach that addresses both systemic and social factors. Enhancing economic, cultural, and social capital among marginalised communities can empower them to participate more effectively in governance processes, leading to more equitable and sustainable water management practices. Specifically, targeted interventions should focus on infrastructure development, governance improvement and environmental education.

In conclusion, the combined use of causal loop diagrams and Bourdieu's theory provides a robust framework for understanding and addressing water scarcity. This integrated approach highlights the importance of considering the interplay between systemic issues and social structures in developing effective water management strategies. By focusing on the identified intervention points, it is possible to mitigate the factors contributing to water scarcity and promote the sustainable management of water resources in the Magdalena department.

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