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Water insecurity and inequalities in access to safe drinking water in the municipality of Zagnanado (Benin)

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Abstract

Equal access to safe drinking water still poses a major challenge for public health and sustainable development in sub-Saharan Africa, where regional inequalities and inadequate infrastructure heighten communities' vulnerability. This study examines water insecurity and inequalities in access to safe drinking water in the municipality of Zagnanado, in central Benin, through an integrated approach based on exposure, sensitivity, and adaptive capacity.

The methodology relies on a mixed-methods approach combining an inventory of water and sanitation infrastructures, a household survey conducted among 250 households across all administrative districts, as well as semi-structured interviews and focus group discussions. Statistical and spatial analyses were applied to identify territorial disparities and key drivers of hydric vulnerability.

Findings show significant household dependence on unprotected water sources, used by nearly 70% of the population, as well as marked infrastructure failure, with over 40% out of service and very limited coverage of village water supply systems. Long distances to water sources, low rates of domestic treatment, and inadequate sanitation services increase exposure to health risks, mainly for women and children.

This study highlights structural water vulnerability resulting from technical, institutional, and social factors. It emphasizes the need for an inclusive approach involving infrastructure rehabilitation, enhanced maintenance and local governance, and the promotion of domestic water treatment, in order to sustainably reduce inequalities in access to drinking water in the municipality of Zagnanado.

Keywords: Water vulnerability; Access to drinking water; Territorial inequalities; Water infrastructure; Zagnanado; Benin

1. Introduction

Global access to safe water is a big deal for sustainable development in the 21st century. Even with international commitments, like Sustainable Development Goal (SDG) 6.1, a lot of people around the world, especially in rural areas of sub-Saharan Africa, still rely on unsafe water sources (WHO/UNICEF, 2021). This highlights the issue of unequal access to water, which is made worse by geographical, socioeconomic, and institutional factors that increase people's water vulnerability (Montgolfier & Bonneville, 2014). This makes spatial analysis of water supply disparities a key tool for breaking down territorial exclusion and guiding public policy toward targeted, equitable interventions (Howard & Bartram, 2003).

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There are still big differences in access to clean water in Benin. Though the national rate of access to improved water sources has gone up, there are disparities between different areas, urban and rural areas (Ministry of Health, 2022). For instance, population growth and the expansion of intensive agricultural activities in rural communities in the Zou department exert growing pressure on water infrastructure, thereby increasing the vulnerability of local populations (MAEP, 2023). Together with climate constraints, this creates a vicious cycle of water stress, especially in highlands and lowlands where access to groundwater is limited (Hounkonnou et al., 2019).

The municipality of Zagnanado, located on the plateau of the same name, is a good example of this dynamic. Although crossed by several waterways such as the Ouémé River and its tributary Zou (MAEP, 2023). It encounters significant challenges in supplying high-quality water. Its dependence on unprotected water sources, coupled with inadequate infrastructure generates significant health risks. This issue is often exacerbated by poor community management and inadequate preventive infrastructure maintenance. Two distinct rainy seasons, with heavy rainfall in June and September, also lead to risks of surface water contamination during floods, increasing people's vulnerability to waterborne diseases (Biaou, 2016).

This study therefore seeks to analyze the geographical factors determining water insecurity in the municipality of Zagnanado. It applies a comparative geographical approach to six districts in order to highlight inequalities in drinking water access and identify priority areas for action. The aim is to identify socio-spatial and institutional factors that influence access to water, while making recommendations to strengthen the resilience of water supply systems. This alines with the work of Cairncross & Valdmanis (2006), who highlight the importance of addressing geographical and behavioral dimensions in WASH service planning in order to effectively address inequalities in access to water in rural areas of Benin.

The municipality of Zagnanado is positioned on Zagnanado highlands, the smallest of northern highlands in the Lama depression, between 7° and 7°30 North latitude and 2°15 and 2°30 East longitude. It covers an area of 780 km² and is bordered to the north by the municipality of Dassa-Zoumè, to the south by the municipalities of Ouinhi and Zogbodomey, to the east by the municipalities of Kétou and Adja-Ouèrè, and to the west by the municipalities of Covè, Za-kpota, and Djidja (Figure 1).
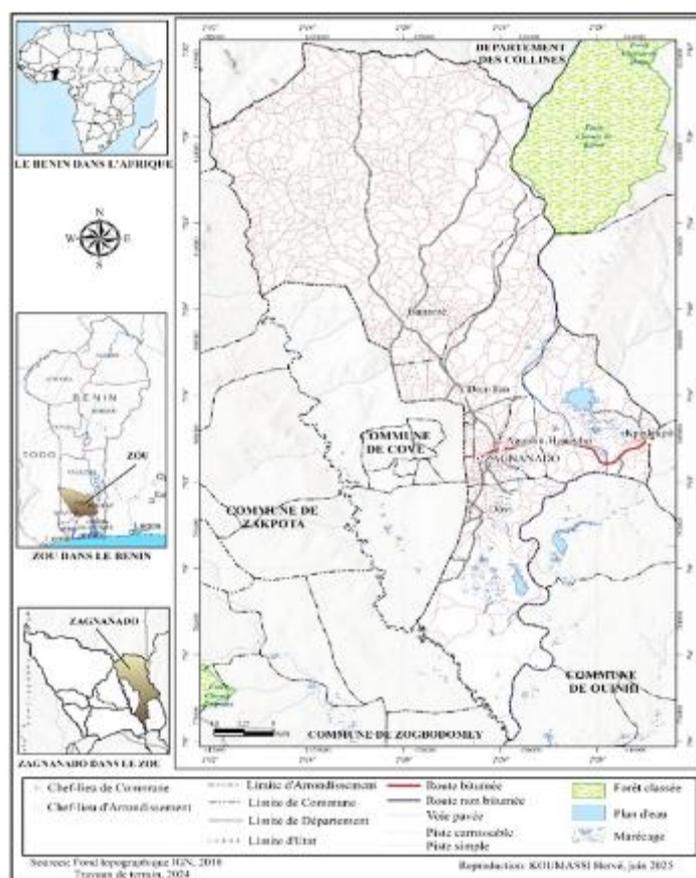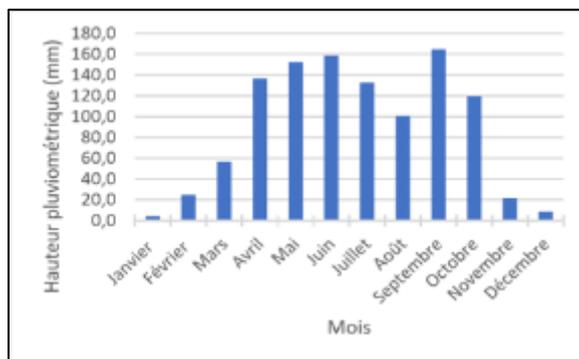

Figure 1 Location of the Municipality of Zagnanado

Landforms in the municipality are characterized by peneplains and plateaus, creating an elevation difference of approximately 270 m between the highest point in the northern part of the municipality and the lowest point in the southern tip. Slopes are generally less than 5%, but nearly 4% of the land is characterized by slopes with a gradient greater than 15%.

The municipality of Zagnanado has a sub-equatorial climate of four seasons (Adam and Boko, 1993). Figure 2 shows the municipality's rainfall pattern.

Source: Meteo Benin, 2024

Figure 2 Rainfall pattern in Zagnanado

The rainfall pattern in the municipality of Zagnanado is bimodal, with peaks in June and September.

Average monthly temperatures range from 29.3°C to 25.8°C, with the maximum recorded in March and the minimum in August (Figure 3); with often high relative humidity, which can increase the heat index.

The long rainy season lasts about four months (March to July), with maximum rainfall occurring in June, amounting to 346.5 mm. Precipitation becomes scarce in August. This is the short dry season when rainfall is below ETP but still above ETP/2. Rainfall returns in September and October, with a second peak in September (154.7 mm) although not as high as in June. This is the short rainy season.

2. Research methodology

The research methodology for this study aims to provide a thorough and reliable analysis of the challenges related to access to drinking water and sanitation in the municipality of Zagnanado. It combines qualitative and quantitative techniques, which allows for an overall understanding of the issues and suggests appropriate solutions. The study consisted of several key steps: collecting documentary data, conducting field research (both quantitative and qualitative), analyzing the data, and confirming the results.

2.1. Documentary data collection and infrastructure assessment

The first step in the field survey is to collect data from existing documents to get an overview of the infrastructure in Zagnanado. This includes data on the number of water access facilities, the geographic distribution of water supply infrastructure, drinking water access rates, and details on sanitation, hygiene, and waste management. These data were supplemented by a physical inventory of the municipality's WASH infrastructure, including 179 boreholes, 4 village water supply systems (AEV), 219 school latrines, 67 latrines in health centers, and 15 latrines in markets. Every piece of infrastructure is mapped and evaluated based on criteria such as usability and accessibility.

2.1.1. Collection tools

Data collection tools are designed to comprehensively document conditions of access to water, sanitation, hygiene, and waste management, in accordance with the guidelines of the PHAC guide (2016 version). They include structured questionnaires, semi-structured interview guides, and focus group guides to cover the technical, institutional, and behavioral aspects of the WASH sector. The questionnaires allow for standardized data collection on sanitation and socio-sanitary facilities, as well as analysis of hygiene practices in households, schools, health centers, and public places. The interview guides target key institutional and technical actors (local authorities, decentralized services, operators, NGOs) in order to gather qualitative information on the governance and management of services. Finally, all the tools

are digitized using the KoboCollect application, which ensures data reliability, facilitates data processing, and enables continuous and rigorous oversight by the ad hoc committee.

2.1.2. Fieldwork

Field data collection is a crucial step in analyzing water resilience and inequalities in access to drinking water, as results depend heavily on the methodological approach used. Following the guidelines in the Community Hygiene and Sanitation Plan Development Guide (PHAC, 2016), the survey covered all WASH subsectors to capture the structural, territorial, and social dimensions of access to drinking water services in the municipality of Zagnanado.

Quantitative data have been collected through structured questionnaires administered to households, schools, health facilities, and key public places (markets, bus stations, places of worship, and accommodation facilities) across the 43 villages and neighborhoods of the municipality. The questionnaires documented conditions of access to drinking water (distance to water points, frequency of supply, cost, and domestic treatment), sanitation practices, hygiene behaviors, and methods of solid waste and wastewater management, all of which are recognized as factors contributing to water vulnerability.

Households are the basic statistical unit of the study, as they are relevant for analyzing domestic access to drinking water and situations of water vulnerability. The sampling strategy is based on a mixed approach combining purposive sampling to identify key informants and local authorities, and simple random sampling to select the households surveyed, ensuring both the qualitative relevance and statistical representativeness of the data.

The sample size (n) is determined using Schwartz's formula (1995), based on a confidence level of 95% and a margin of error of ±5%:

$$n = \frac{Z^2 \times p \times (1-p)}{e^2}$$

where Z=1.96 corresponds to the 95% confidence threshold, p represents the estimated proportion of households affected by the variable studied, 1-p (noted q) is its complement, and e=0.05 is the acceptable margin of error. The value of p is estimated based on the ratio between the number of households per village (n_i) and the total number of households in the district (N), i.e. $p = n_i/N$.

To account for spatial and social disparities with regard to access to drinking water, the sample is distributed proportionally among the villages and neighborhoods in the municipality. A sampling rate of 5% has been applied to each spatial unit, making it possible to determine the actual number of households to be surveyed per locality and to ensure balanced representation of territorial inequalities in access to drinking water.

Table 1 Distribution of respondent households

Villages	Sample Size
Agonli-Houegbo	31
Baname	76
Don-Tan	27
Dovi	35
Kpedekpo	38
Zagnanado	43
Total	250

The survey sampled 250 households in accordance with PHAC methodological recommendations (2016). The proportional distribution of this sample according to household size and the spatial distribution of villages and neighborhoods aims to ensure social and territorial representativeness, enabling a thorough analysis of disparities and inequalities in access to drinking water within the municipality.

Fieldwork made it possible to carry out a physical inventory of sanitation infrastructure, water points, and waste management facilities in order to assess existing provision and identify structural factors contributing to water vulnerability in the municipality of Zagnanado. The collected data covers the existence, type, functional status, and accessibility of public and family latrines, water points (boreholes, standpipes, wells), and community facilities in schools, health centers, and markets. The absence of sewage sludge treatment plants and the predominance of rudimentary waste management systems have also been documented, highlighting marked territorial inequalities in sanitation.

Meanwhile, qualitative data have been collected to assess the societal perceptions, institutional constraints, and community dynamics that affect access to clean water and sanitation services. This approach is based on 85 semi-structured interviews conducted with institutional, technical, and community actors, supplemented by 12 focus groups bringing together different social groups (female household heads, young people, students, older people, and people living with disabilities). The combination of these methods provides a clear understanding of inequalities in access to drinking water and the social mechanisms that reinforce water vulnerability at the local level.

2.2. Data processing and analysis

The collected data undergoes systematic processing to enable in-depth analysis of water vulnerability and inequalities in access to drinking water. Quantitative data is imported, organized, and cleaned using Microsoft Excel, which is also used to produce statistical tables and descriptive graphs. Text processing and structuring of results have been carried out within Microsoft Word.

Spatial analysis of data related to the distribution of water points and sanitation infrastructure has been carried out by means of QGIS software, enabling the production of thematic maps illustrating territorial disparities in access to drinking water services. Visual aids (field photographs) are processed and harmonized with Microsoft Office Picture Manager. All of these tools enable clear, consistent, and reproducible presentation of results, in accordance with international scientific publication standards.

3. Results

3.1. Water supply status in the municipality

The municipality of Zagnanado has a wide range of water sources, the use of which varies according to the spatial context (rural or semi-urban), seasonality, and the availability of infrastructure. Field data has identified six main (Figure 3) categories of sources, characterized by varying levels of access and use. These are boreholes equipped with human-powered pumps (PMH), the SONEB network, protected and unprotected wells, village water supply systems (AEV) feeding standpipes, surface water, and collected rainwater. These varying sources strongly influence territorial and social disparities of access to drinking water in the municipality.
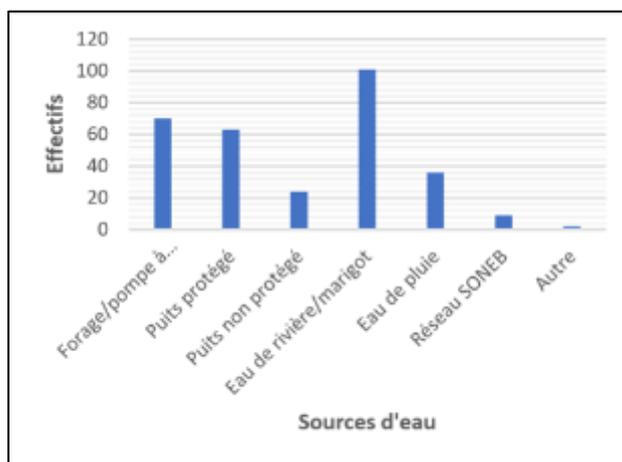
Source : Data collection, may 2025

Figure 3 Water sources available in the municipality

A review of water supply patterns reveals significant disparities in access to various sources within the municipality of Zagnanado. The findings reveal surface water (rivers and backwaters) as the primary source for 44.3% of households, followed by boreholes equipped with hand pumps (30.7%) and protected wells (27.6%). Other sources include collected rainwater (15.8%), unprotected wells (10.5%), and the SONEB network (3.9%), reflecting a forced diversification of uses depending on the local availability of infrastructure.

These results show that more than 70% of households depend mainly on unclean water sources, including surface water, rainwater, and unprotected wells, which heightens their exposure to health risks. These sources are extremely vulnerable to microbiological contamination and chemical pollution caused by human activity. Conversely, improved sources, such as protected wells and the SONEB network, remain marginal (31.5%), while village water supply systems (AEV), due to their dysfunction, fail to mitigate the overall vulnerability of the water supply system.

Figure 4 Water supply facility

An analysis of the current state of drinking water supply highlights a particularly worrying situation in the municipality of Zagnanado. In accordance with World Health Organization (WHO) standards and Benin's national guidelines, particularly the National Strategy for Universal Access to Drinking Water, a source is considered "improved" when it provides effective protection against external contamination, especially of fecal origin. The analysis focuses on the availability and accessibility of drinking water sources identified in the municipality (Table 2).

Table 2 FPM status by district in 2024

Districts	Total number of FPM	Number of active FPMs	Number of FPMs to be renovated	Functionality rate in %	Failure rate in %
Zagnanado-centre	43	24	19	55,81	44,19
Don-Tan	21	06	15	28 ,57	71,42
Dovi	12	06	06	50	50
Kpédékpo	35	27	08	77,14	22,86
Agonlin-Houégbo	22	15	07	68,18	31,82
Banamè	46	23	23	50	50
TOTAL	179	101	78	56,42	43,58

Source : Strategic diagnostic report, 2024

There are significant spatial disparities in access to drinking water between the districts of the municipality of Zagnanado. The district of Kpedekpo stands out for its relatively satisfactory coverage, characterized by the presence of a functional village water supply system (AEV) and a 77.14% functionality rate for boreholes equipped with human-powered pumps (FPM). Conversely, Don-Tan appears to be the most vulnerable district, with a broken AEV and a low FPM functionality rate (28.57%). The districts of Banamè and Dovi occupy an intermediate position, with FPM functionality rates of around 50%.

3.2. Critical disparities and massive over-reliance on unprotected sources, high vulnerability

The analysis highlights a strong dependence on FPMs, with few AEVs and a high failure rate (four AEVs identified, only one of which is operating). The 179 FPMs are therefore the municipality's main source of drinking water, although 43.58% of them are out of service, significantly limiting effective access to water. Furthermore, the urban districts of Zagnanado-centre and Agonlin-Houegbo have no AEVs, leaving them highly vulnerable in the event of further FPM failures.

These results highlight significant inequalities in access to drinking water and structural water vulnerability. They underscore urgent need to strengthen water infrastructure in a sustainable manner by improving failing public water facilities and water supply systems, prioritizing the most underserved districts, and extending water supply systems to uncovered areas. Strengthening maintenance systems, raising public awareness of health risks, and integrating these issues into municipal hygiene and sanitation policies are essential to sustainably reducing inequalities in access to drinking water.

3.3. Critical breakdown of drinking water infrastructure

The assessment of hydrological infrastructure reveals a worrisome situation in the municipality of Zagnanado. Of the 179 boreholes equipped with human-powered pumps (FPM) identified, 43.58% are out of service, representing 78 non-functional structures, which strongly compromises people's access to drinking water. Significant spatial disparities are observed between districts, with failure rates ranging from 28.57% in Don-Tan, relatively better served, to 71.42% in Banamè, reflecting differentiated territorial vulnerability.

Furthermore, village water supply systems (AEV) are still very limited and largely inadequate, with only one functioning out of the four identified. This exacerbates the population's dependence on FPM, which are frequently out of service. The urban districts of Zagnanado-centre and Agonlin-Houégbo have no AEVs, further increasing their water vulnerability and the risk of supply disruption in case of additional FPM failures.

3.4. Water source location distance

Water source distance is key to access and is central to people's water security. According to the WHO, a distance of less than 500 m is crucial to ensure appropriate use, preserve health, strengthen gender equality, and achieve the Sustainable Development Goals (SDG 6) relating to clean water and sanitation. Figure 5 summarizes access distances to water sources in the municipality.
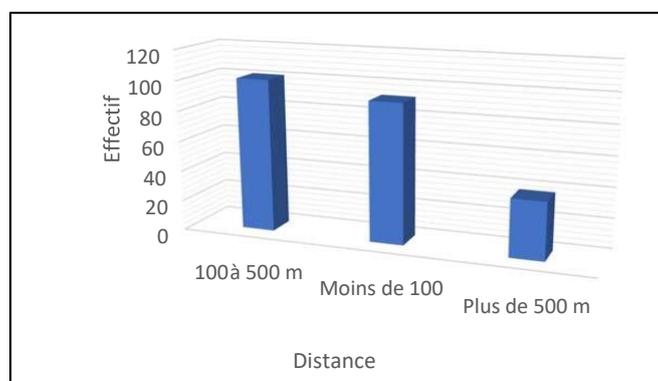

Figure 5 Distance from household to water source

An analysis of accessibility to the main water source shows that 44.3% of households collect water from a distance of between 100 and 500 meters. This meets the minimum standards of the World Health Organization (WHO), which recommends a maximum radius of 500 meters for an improved water source in rural areas (WHO, Guidelines for

Drinking-Water Quality, 2017), as well as the objectives of Benin's National Strategy for Universal Access to Drinking Water, which aims to provide access within 500 meters for all households by 2030.

However, only 40.4% of households have access within 100 meters, which is deemed optimal according to worldwide standards. Previous studies have shown that access to water located less than 100 meters away, or less than 30 minutes round trip, promotes higher water collection volumes and improved domestic hygiene practices (Howard & Bartram, 2003), while reducing the physical burden borne mainly by women and children.

Conversely, 16.7% of households walk more than 500 meters to access their main water source, exceeding the thresholds recommended by the WHO and national policies. This indicates water vulnerability, which might lead to reduced water use, increased tiredness, and significant socioeconomic impacts, including lost productive time and children dropping out of school, especially girls.

3.5. Pre-consumption water treatment

Domestic water treatment is a key health barrier, mainly in contexts where water sources are not always safe. Figure 6 shows households' opinions on water treatment.
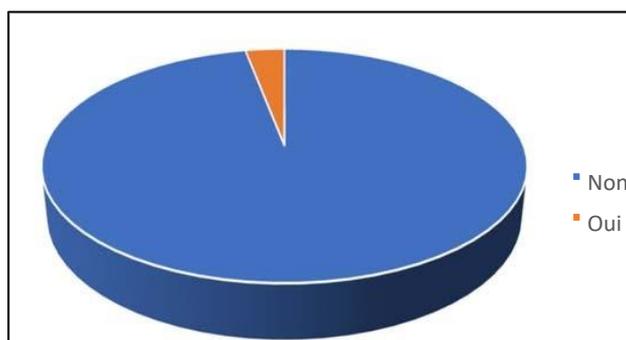

Figure 6 Pre-consumption water treatment

A key water vulnerability is the extremely low rate of domestic water treatment (3.1%) in the municipality of Zagnanado. This reflects households' high exposure to health risks, with nearly 70% of them relying on unimproved or potentially contaminated water sources. This increases the population's susceptibility to waterborne diseases, with the most vulnerable groups such as children and the elderly.

Moreover, this limited use of water treatment practices reflects a limited capacity for adaptation, despite recommendations from the World Health Organization and Benin's national guidelines promoting simple and accessible techniques (boiling, filtration, chlorination). The widespread lack of treatment of drinking water thus highlights combined shortcomings in terms of awareness, risk perception, and effective access to means of purification, contributing to increased overall households' vulnerability to water-related risks.

3.6. Water treatment strategy

Inadequate sanitation infrastructure, poor management of human waste, wastewater runoff into living spaces, and ongoing open defecation favor surface water and shallow groundwater contamination. These factors increase households' exposure to microbiological risks and heighten their vulnerability to disease, mainly in areas without centralized water supply and treatment systems. This is why home water filtration is a key preventive sanitation measure, as it can improve water quality at the point of use and help households deal with water-related risks (Figure 7).
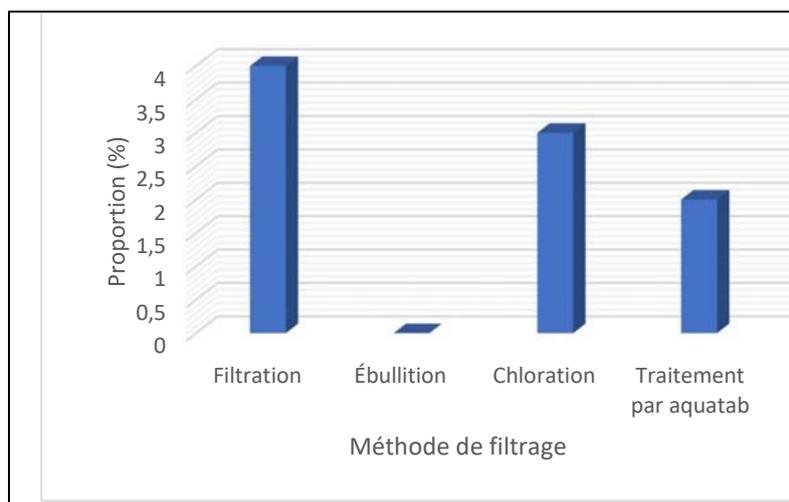
Source : data collection, may 2025

Figure 7 Water treatment strategy

The analysis indicates that boiling is rarely used as a method of treating water from unsafe sources. This limited use raises particular concern, as boiling is recognized by the World Health Organization as one of the most effective, accessible, and reliable methods for destroying pathogens. This finding reflects households' limited ability to adapt, possibly due to a lack of information, material constraints (availability and cost of fuel), or the time required to implement this practice.

Furthermore, little use of chlorination and aquatabs suggests additional barriers, including supply difficulties, perceived high costs, or mistrust of chemicals. This increases people's exposure to microbiological risks and heightens their health sensitivity, in a context where WHO standards identify these methods as key barriers against waterborne diseases such as diarrhea, cholera, and dysentery. The inadequacy of these practices is therefore another factor increasing water-related risks at the local level.

4. Discussion

The survey results highlight high structural water vulnerability in the municipality of Zagnanado, with significant regional differences in access to safe drinking water, ongoing reliance on unimproved sources, and limited household resilience. These findings echo the analyses of the WHO/UNICEF Joint Monitoring Program, according to which effective access to drinking water depends not only on infrastructure availability, but also on its functionality, accessibility, and sustainability over time (WHO/UNICEF, 2021, pp. 12–18).

4.1. Regional inequalities and inefficiency of water infrastructure

These disparities among Zagnanado's districts confirm that the mere presence of waterworks does not guarantee equal access to drinking water. The high proportion of boreholes equipped with man-powered pumps (MPPs) in disrepair is consistent with the dynamics described by Harvey and Reed (2007, pp. 370–372), who show that inoperable water points are one of the main factors behind the failure of water supply policies in rural Africa.

Likewise, Lockwood and Smits (2011, pp. 45–52) emphasize that the absence of robust institutional mechanisms for managing and maintaining water systems exacerbates spatial inequalities and transforms existing facilities into water vulnerability sources rather than resilience drivers.

4.2. Reliance on unimproved water sources and exposure to health risks

Households' heavy reliance on surface water and unprotected wells significantly increases their exposure to microbiological risks. According to the World Health Organization, unimproved sources are highly vulnerable to fecal contamination, especially in contexts characterized by inadequate sanitation and poor excreta management (WHO, 2017, pp. 22–27).

Studies by Prüss-Ustün et al. (2019, pp. 1190–1192) show that unsafe water use remains one of the main determinants of the global burden of waterborne diseases, particularly diarrhea and cholera. These findings align with the analyses

of Montgomery and Elimelech (2007, pp. 26–28), which link water source quality, sanitation, and water vulnerability directly.

4.3. Social burden and distance to water sources

The long distances covered by some households to access water are the main factor driving unequal access. Howard and Bartram (2003, pp. 11–15) show that the volumes of water collected decrease significantly for distances greater than 500 meters or 30 minutes round trip, leading to a deterioration in domestic hygiene practices.

Furthermore, Sorenson, Morssink, and Campos (2011, pp. 152–156) highlight that water collection disproportionately affects women and children, with significant social consequences such as loss of productive time and girls dropping out of school. These factors confirm that physical accessibility is a key factor in water vulnerability.

4.4. Slow uptake of home treatment and limited adaptability

Low rates of domestic water treatment reflect households' limited ability to adapt to water quality risks. The WHO explicitly recommends boiling, filtration, and chlorination as effective barriers against pathogens when sources are unimproved (WHO, 2017, pp. 38–41).

However, studies by Clasen et al. (2015, pp. 839–841) show that such practices remain uncommon in many rural settings due to economic constraints, negative perceptions, and a lack of awareness. Likewise, Fewtrell and Colford (2004, pp. 55–58) use a meta-analysis to argue that the lack of domestic treatment is the main reason for poor water safety and the risk of diarrheal diseases.

4.5. Local water governance implications

Findings confirm that an overall approach to reducing water vulnerability is needed, combining infrastructure upgrades, better maintenance, and effective local governance. Smits et al. (2011, pp. 9–14) point out that safe water service sustainability is closely tied to local communities' ability to manage, monitor, and fund infrastructure. Finally, WHO/UNICEF (2021, pp. 30–34) recommends clearly integrating water vulnerability into local WASH policies to sustainably reduce inequalities in access to drinking water.

5. Conclusion

This study highlights high water vulnerability in the municipality of Zagnanado, characterized by significant territorial inequalities in access to drinking water, significant deficiencies in water infrastructure, and ongoing dependence on unimproved sources. Inadequate infrastructure facilities, long distances to access water, and very low use of domestic water treatment increase households' exposure to health risks and reflect limited adaptive capacity.

Achieving a lasting reduction is a challenge that requires a comprehensive approach. This approach should combine the rehabilitation and expansion of infrastructure, the strengthening of maintenance and local governance, and the promotion of domestic water treatment. Addressing water vulnerability in municipal sanitation and hygiene policies is essential to reducing inequalities in access to drinking water and strengthening community resilience.

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