

Research Article

Trends and challenges of borehole construction for sustainable water management in Buea, Cameroon

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ABSTRACT

Escalating populations, rapid urbanization, and the intensifying impacts of climate change are exacerbating water scarcity, pushing communities worldwide to seek alternative and often unregulated water sources. This has led to a significant increase in reliance on groundwater, particularly through borehole construction, especially in urban centers of developing nations. The development of boreholes has grown over the years to stabilize water demand in Buea despite its associated challenges. This study therefore aimed to assess the trends and challenges of borehole construction for sustainable water management in Buea. An observatory study design was adopted, utilizing a mixed-methods approach to collect both primary and secondary data. A preliminary field survey provided initial insights into construction trends and associated challenges. Quantitative data were gathered through questionnaires administered to 300 randomly selected households, while qualitative data were obtained via key informant interviews, and extensive field observations. Data analysis involved descriptive and inferential statistics for quantitative data, and thematic analysis for qualitative insights. Results indicated a significant increase in borehole construction, with over 500 boreholes identified in Buea, far exceeding past figures in the past three decades due to population increase and changing lifestyle. This uncontrolled proliferation has led to negative environmental consequences, notably groundwater contamination and damage to surrounding ecosystems, often attributed to improper site selection and a lack of necessary permits. Challenges encountered in borehole construction included difficulties in obtaining permits, the engagement of inexperienced engineers, and high construction costs. Statistical analysis (*Chi-square* value of 11.7, greater than the critical value of 5.99 at 6 degrees of freedom) confirmed that borehole construction has significant implications for the population in Buea. Regarding coping strategies, while a majority (50.5%) of households actively adopts water-saving practices and community-based initiatives like rainwater harvesting are emerging, there is high support for government subsidy programs (7.5%), public education campaigns (7%), and strengthening water conservation policies (6.5%). Addressing these issues necessitates comprehensive strategies covering infrastructure development, efficient management practices, equitable access to water resources, public health initiative promotion, education and sanitization, effective policy implementation and monitoring systems, subsidization, investment among others.

Keywords: Borehole construction, Socio-economic implications, Water management, Buea

INTRODUCTION

Access to reliable and safe water remains a fundamental global challenge, exacerbated by unprecedented rates of population growth, urbanization, and industrialization. As demand for water sources continues to escalate, borehole construction has emerged as an increasingly popular and often critical alternative or supplementary source of water supply, particularly in regions where surface water is scarce or unreliable (WHO, 2018).

Advancements in drilling technology and equipment have further enhanced the accessibility and cost-effectiveness of borehole construction globally. However, this growing reliance on groundwater also presents significant sustainability challenges, as evidenced by nations like Pakistan, which ranks fourth globally in annual groundwater exhaustion, abstracting quantities comparable to larger economies such as the U.S., China, and

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India. Pakistan's role as a major exporter of groundwater-intensive goods highlights the profound implications of unsustainable groundwater abstraction (Margrat et al., 2013; Dalin et al., 2018).

In Africa, groundwater has recently become the preferred means of water supply to meet the burgeoning demand of both dispersed rural communities and small urban towns across numerous Sub-Saharan African countries, including Angola, Benin, Botswana, Cape Verde, Cameroon, Malawi, and Niger (Adelina et al., 2008). It is estimated that approximately 100 million of the rural population throughout sub-Saharan Africa are serviced by groundwater for domestic supplies and livestock rearing. Groundwater development has particularly flourished in drier regions of Western, Eastern, and Southeastern Africa, where annual rainfall is less than 1000 mm (Foster et al., 2006). The increasing construction of boreholes across the continent is also recognized as a critical climate change adaptation strategy, driven by changing weather patterns and more frequent droughts that necessitate secure and reliable water sources (Adelina et al., 2008).

Consequently, many African governments, along with Non-Governmental Organizations (NGOs) and private sector companies, are actively investing in and supporting borehole construction as part of their water infrastructure development plans, providing crucial funding, technical expertise, and project implementation in underserved areas (Ibe, 2014; Bonsor et al., 2015). Noteworthy examples include Malawi, which witnessed a dramatic increase in boreholes from 9,600 in 1994 to 19,000 by 2001, a trend driven by a proliferation of drilling contractors (Pavelic et al., 2012). Similarly, in South Africa's Limpopo province, an estimated 35,000 boreholes exist, with 6 to 10 boreholes per village in rural areas, yet a significant portion (around 66%) are reportedly dry, highlighting challenges in sustainable operation and management (Pavelic et al., 2012; GRIP). The lifespan of boreholes, critical for long-term water security, varies significantly based on construction quality, pumping rates, and maintenance (Pavelic et al., 2012).

Regionally, while trying to meet SDG 6, emphasis in borehole construction is the on sustainability and environmental conservation. Water resources have become increasingly scarce due to climate change and over exploitation such as deforestation and land use change, pollution of water resources, damming and diversion of rivers just to name a few. There is a growing demand for borehole construction that minimize environmental impact and promote long term water resource management. Borehole construction has become popular due principally to; water scarcity, population growth and urbanization, need of water for agriculture among others.

This has led to the adoption of eco-friendly drilling practices such as mud rotary drilling, which reduces the use of chemicals and water during the processes as stated by (Blowes et al., 2016). With the use of modern drilling technology with advancement in drilling equipment and techniques, boreholes can now be constructed more efficiently and cost effectively for example, the use of rotary drilling rigs has become a popular choice for

borehole construction due to their ability to drill deeper and access ground water resources in a variety of geological formations (Banks, 2014).

One of the key trend is the increased use of mechanized drilling techniques to improve efficiency and productivity in borehole construction (Chin, 2016). Another trend in the construction of borehole in Cameroon is the growing use of sustainable and environmentally-friendly drilling practices which includes the use of biodegradable drilling fluids and the adoption of geophysical methods to locate suitable drilling sites with minimal environmental impact (Feumbe, 2108).

These practices help to reduce the ecological footprint of borehole construction and ensure the long-term sustainability of ground water resources. Furthermore, there is a trend towards the use of community-based approaches in borehole construction project in Cameroon which includes involving local communities in the planning and implementation of water supply projects which can help to ensure the long-term success and sustainability of the boreholes (Tonye et al., 2019). By empowering local communities to take ownership of water supply projects, borehole construction efforts in Cameroon can be more responsive to the needs and priorities of the people they serve.

Within Cameroon, despite boasting substantial groundwater resources estimated at 120 billion cubic meters, their distribution is highly erratic across the country's diverse geological settings (Keleko et al., 2013; Wirmvem et al., 2013). Boreholes are constructed both to augment public water networks and for direct industrial abstraction from aquifers (Ako et al., 2012). However, national water demand is projected to increase drastically in the coming decades due to population growth and expanding irrigation needs (GWPAFTA, in full first 2010). In the Fako Division of the Southwest Region, over 60% of the rural and peri-urban populations in areas like Buea and Tiko still rely on untreated water from community sources and hand-dug wells (Dzekewong et al., 2016).

The unprecedented rise in population, urbanization, and agricultural activities in fast-growing towns such as Buea, Tiko, and Mutengene has led to the severe depletion and deterioration of existing water sources. Faced with these difficulties, both public and private entities have increasingly resorted to constructing boreholes as primary sources of water supply for drinking and various domestic activities. Disturbingly, water from some of these privately constructed boreholes, often of questionable quality, is sold to the public without adherence to requisite quality standards set by the WHO (Masse et al., 2016). Within Buea, and specifically in neighbourhoods like Bomaka, Muea, Molyko, households face persistent water shortages, with existing research indicating that 100% of households source their water from alternative means like boreholes and wells (Awudu et al., 2023).

Buea, a rapidly urbanizing center within Cameroon, is characterized by a unique volcanic geological setting, which significantly influences groundwater movement and presents specific challenges for borehole construction and management. A

study by Jato et al., (2016) showed that the construction of borehole has become a common practice in the region as it provides a reliable and sustainable source of water for communities. Nkeng et al., (2018) also highlights the importance of borehole construction in Buea citing the need for improved water infrastructure to meet the growing populations demands. Despite the presence of specialized expertise for drilling in such conditions, the community has grappled with severe water scarcity for many years. This persistent scarcity has driven residents to increasingly invest in borehole and well construction, viewing it as a vital solution that has, to some extent, alleviated the burden of water fetching, particularly for women and children, and potentially reduced the risk of water-related diseases.

This study therefore sought to analyze the trends and underlying drivers of borehole construction, assess the environmental impacts and socio-economic implications of borehole construction on the population, identify the challenges and barriers associated with the construction and management of boreholes and propose sustainable management measures and

policy recommendations for borehole construction and water resource utilization in Buea.

MATERIALS AND METHODS

Study area

Buea is located in South Western Region of Cameroon between Latitude $04^{\circ}08.036'$ and $04^{\circ}12.627'N$ of the Equator and Longitude $009^{\circ}13.104'$ and $009^{\circ}18.675'E$ of the Greenwich Meridian (Figure 1). Buea host Mount Cameroon which is the most prominent of all West African volcanic mountains. The mountain is a heap of piled lava reaching a height of 4,096 meters above sea level (masl). It is very immense with a length of about 50 km and a width of about 35 km, covering an area of 1,750 km². It starts from the sea and rises into a small peak of 1,713 meters, which bears the name Etinde or Small Mount Cameroon. From this small peak, the mountain slopes down to a height of about 900 m before rising again continuously until the submittal plateau of 4,070 masl (Ndeh et al., 2022).

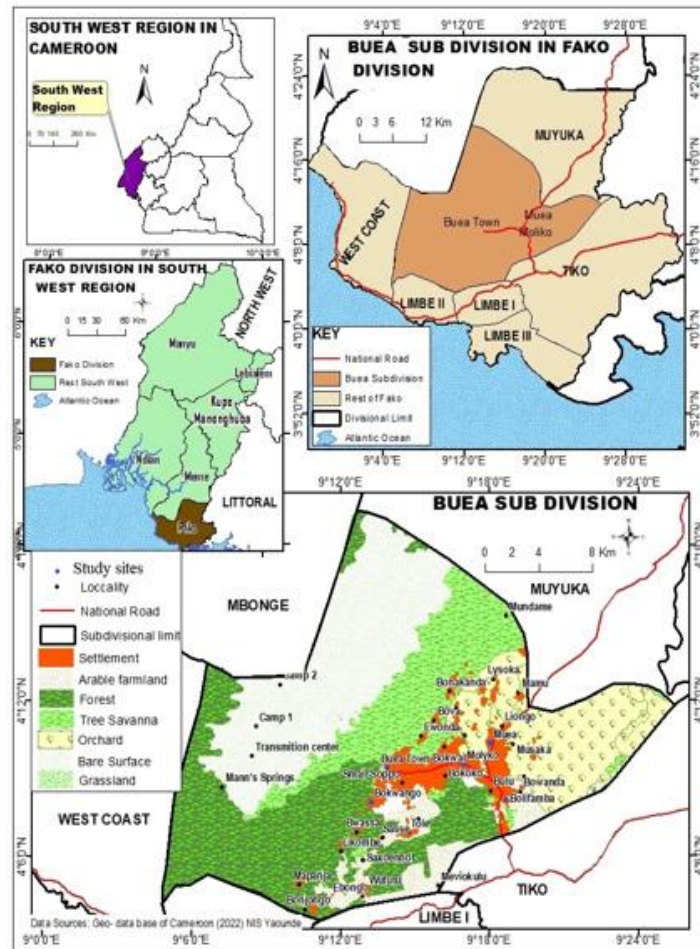


Figure 1. Location of Buea in Fakö Division, South West Region of Cameroon

The climate of the study area is of the tropical monsoon type and characterized by two main seasons; the wet season with heavy rains (mid-March-October) and the dry season (November to

mid- March). The rainy season is characterized by changeable weather with storms and high rainfall variability from mid-March to June and steady rains from mid-June to September. The

changing weather with storms and squalls from October to November marks the transition period between the rainy and dry season. Buea records high rainfall amount with an annual total of over 3500 mm, distributed evenly almost throughout the year (Balgah, 2005). The area is composed mainly of volcanic rocks which range from massive basaltic lava flows to pyroclastic materials (ash and cindery materials) (Endeley et al., 2001).

The soils are rich volcanic (Andosols) derived from the decomposed lava (Yerima et al., 2013). Andosols usually have a bulk density of less than or equal to 0.9 g/cm³, resulting from a combination of amorphous volcanic material and organic matter (Ndeh et al., 2022). They have a relatively high water holding capacity and resist erosion by water and notorious for their highly variable exchange capacity. The natural vegetation at the foot of the mountain has been cleared down for settlements and farming.

Plant recovery on the different lava flow has resulted in a rich and mosaic type of vegetation on the mountain slopes (Ndeh et al., 2022). From about 915 m above Buea town, is a thick slope covered by thick and evergreen forest. The forest extends up to an altitude of 1700 m and gives up way to typical savanna vegetation. At an altitude of 3000 to 3500 m, the slope is covered by grass, which is much shorter than the proceeding savanna. Between 3600 and 4000 m, the typical vegetation is comprised of

lichens and mosses (Neba, 1999 cited in Ndeh et al., 2022). Several institutional establishments are found within region and due to the rich volcanic soils, farming is the predominant economic activity practiced characterised by the use of agrochemicals. A lot of construction works are carried out to cater for the increasing population as a result of the creation of many new institutions.

This study used the survey and quantitative research designs to collect the needed data. Stratified random sampling procedure was used whereby in the study area was divided into two based on special classification or rural-urban classification of the Municipality. Primary data were gotten from the field through observations, interview and questionnaire administration. The secondary data were gotten from the University of Buea library, internet sources, council and CAMWATER.

The sampled households constituted those using boreholes because the sources of their water abstractions were from the immediate environment and not from the water catchments. Households views were ranked on a five (5) points likert scale (5-strongly agreed, 4-agree, 3-neutral/uncertain, 2-disagree, 1-strongly disagree). The target population of the study was drawn from the total population according to the 2005 population census which stood at 131325 (Table 1).

Table 1. Sample population from communities in Buea Cameroon.

Questionnaire distribution				Interviews
Communities	Quadrants	Target population	Sampled households	
Federal quarters	Urban	2308	25	3
Small Soppo		6367	41	
Molyko		13831	55	
Clerk's quarters		2623	27	
Government Residential Area (GRA)		777	15	
Koke	Rural	1451	20	2
Mile 18- Muea		27329	52	
Mile 16		1459	20	
Bokwai		2258	25	
Bwiteva		1677	20	
Total	2	70402	300	5

From these strata, a total of 300 households were randomly selected for questionnaire administration and 5 interviews were done in a proportionate manner as the sampled population for the study, so as to avoid representation bias. Thus, a total of 305 respondents constituted this study gotten from the Fishers formula. Thematic data analysis was used to analyze the data gotten from the interviews. The study used both qualitative and quantitative methods of data analysis. Data obtained from the field were cleaned, coded into a computer and analyzed using Statistical Package for the Social Sciences, (SPSS) version 21 and presented on tables, pie charts and histogram.

Thematic data analysis was used to analyze the data gotten from the interviews. It analyses the topics, ideas, and patterns of meaning that come up repeatedly. The thematic analyzes followed a six-step process: familiarization, coding, generating themes, reviewing themes, defining themes, and writing up. The interviews were design respecting the participant's privacy and also focused just on the research topic. Pictorial depictions of boreholes were taken from the field.

RESULTS

This section presents the key findings from the assessment of

borehole construction trends, their associated impacts, and the various measures to ensure sustainability.

Socio-economic and demographic information of respondents

The demographic characteristics of this study presented are, age, academic level, level of income. The respondents making a percentage of 39% were female. For ages, 41% were between 21-35 years of age, 29% were 36-55 years of age and 7% were 55 years of age and above. As far as education is concerned, 7% of respondents had not completed primary school, 10% had completed primary school, 20% have completed their secondary education while 53% had completed one or more University levels of education.

Water supply sources and ownership

The assessment of water supply sources revealed a dominant reliance on boreholes within Buea. An overwhelming number of respondents (71%) affirmed their use of borehole water, obtained

either from personal, communal or institutional boreholes. This was followed by those who opined the use of pipe borne water (20%). Other sources constituted a minimal proportion, with 3% of the population using streams, and 4% using wells, or harnessed springs 2%. Results indicated that of the boreholes in the municipality, 96% of the boreholes identified were individually owned, 1% own community as identified in Bokwango and Bova. Respondents cited several key reasons for opting for personal borehole ownership. These water sources were identified either in Buea urban or Buea rural.

The study also considers the level of agreement or disagreement. It is noted that an overwhelming majority of urban respondents with mean value of 4.42 representing a strongly affirmed their use of borehole water while 3.55 (agreed) to using boreholes in the rural strata of Buea. Other sources constituted a minimal proportion, with 4.03% urban population using piped water and 3.22% rural households using streams. Other sources equally included community managed water schemes, wells, and rain water harvesting. This is summarized in Figure 2.

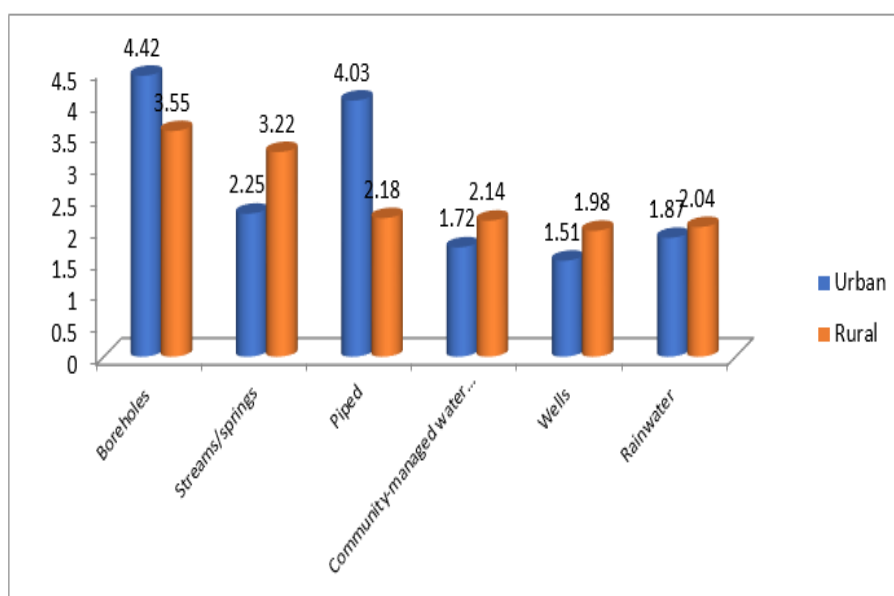


Figure 2. Water sources used by households in Buea.

Concerning respondents cited several key reasons for opting for personal borehole ownership. A significant majority (27%) of respondents strongly affirmed avoiding the problem of over-utilization of water followed by 25% of respondents aimed to avoid conflict over water usage, 16% of respondents sought to avoid inconveniences and 12% of respondents who attributed it to the high demand for water. Only 3% preferred personal ownership due to concerns about poor maintenance of community-owned boreholes. This pursuit of individual ownership can, however, contribute to social tensions and conflicts over water rights, usage, and maintenance, as highlighted in contexts with declining water levels and drying wells (Mabhaudhi et al., 2016; Vengosh et al., 2014).

Trends of borehole construction in Buea

Field observations revealed a significant and notable increase in borehole construction within neighborhoods in Buea. Currently, there are more than 500 boreholes operating in the studied neighborhood, a substantial increase compared to historical figures. This proliferation is a direct response to the persistent water crisis, compounded by rapid population growth and urbanization process current experience in Buea. However, respondents' opinion varies significantly with estimations of borehole numbers varied widely (Figure 3) as 27% of the respondents indicated approximately 1-10 boreholes, 21% others estimated 11-20 boreholes and only 14% estimated 11-30 boreholes. This finding indicated a significant underestimation by the survey population, likely due to a lack of comprehensive awareness beyond their immediate vicinity.

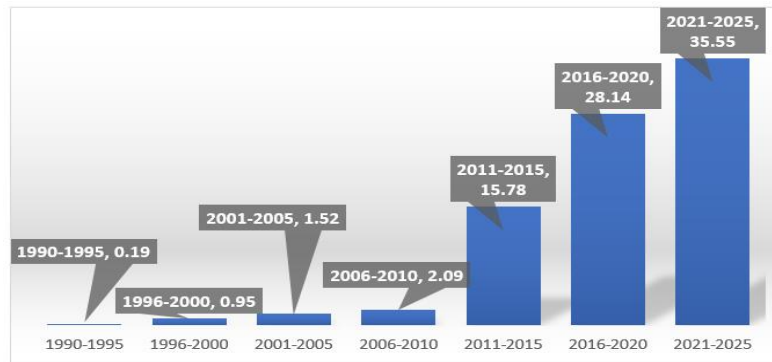


Figure 3. Trends and drivers of borehole construction

Analysis of construction trends over time (Figure 4) revealed a clear acceleration as an overwhelming majority of respondents (39%) strongly affirmed that more boreholes were constructed

between 2021 and 2024 followed by 35% of the respondents who indicated that more were constructed between 2016 and 2020 and only 8% reported construction within the 2006-2010 period.

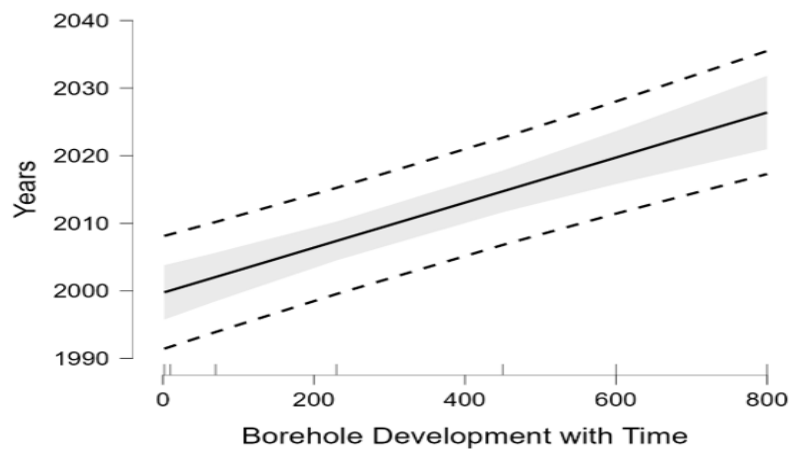


Figure 4. Trend of borehole development with time.

Reasons for rapid increase in the trends of boreholes in Buea

The reasons for the rapid increase in the number of boreholes were also assessed. From this, a high proportion of sampled population (30%) noted that this is due to increase in the number of Cameroon who have travelled (Bushfallers) which confirmed to the study that over 40% of individual houses with boreholes

are owned by “Bushfallers”. This was followed by those who opined that the Anglophone crisis (21%) has favoured the rapid increase in boreholes in Buea. The others such as frequent water shortage from CAMWATER (14%), rapid construction boom (10%) business opportunity (6%), change in behaviour of Landlord and tenants and Perceived water quality. This is summarized in Figure 5.

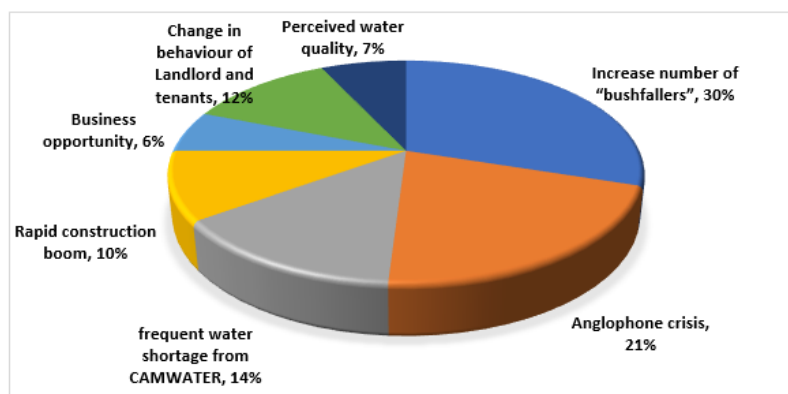


Figure 5. Reasons for increased trends of boreholes in Buea.

During the construction process, engineers reported difficulties such as wall collapse, slow progress in sticky ground conditions,

and delays in areas with high rock concentration (Figure 6).



Figure 6. Sample boreholes in Buea. A) Borehole construction; B) Already constructed Borehole (MissBright Bomaka) with a tank (Kawah-Bomaka))

Challenges in borehole construction and management

Buea is at the foot of Mount Cameroon, so borehole drilling here is very different from other parts of Cameroon due to the

volcanic nature, high rainfall, rapid urbanization, cost of construction, electrical blackouts, and uneven ground water distribution amongst others as presented on Table 2.

Table 2. Challenges in borehole construction.

Challenges		Respondents
Geological/hydrological challenges	Volcanic and rocky terrain	4.62
	Uneven ground water distribution	3.55
	Low water table in dry season	4.53
Technical and cost challenges	High drilling cost	4.02
	Lack of proper hydrological surveys	3.51
	Power to run pumps	1.87
Water quality challenges	Natural contamination	3.54
	Surface pollution by infiltration	4.21
	Challenges of treatment after drilling	3.75
Environmental and social challenges	Siltation and low recharge	3.2
	Over-abstraction risk	2.55
	Poor maintenance	2.41
	Land access	2.1
Institutional challenges	Weak regulation	3.55
	Difficulties in obtaining drilling permits	4.55

From Table 2, it can be said that the challenges in borehole construction runs from geological to technical. Geologically, the hard volcanic rocks, fracture aquifers as affirmed by 4.6 mean value representing a strongly agreed perception. This has resulted in high cost of construction and uncertain yield of boreholes. Hydrologically, seasonal drop in water table has resulted in drop in water table and unreliability of borehole water in some areas in Buea especially those locations at higher altitude like Buea town and Bwitingi as well as Bokwango. This was affirmed with a mean value of 4.53. The cost of drilling boreholes is also high in

Buea constituting a serious technical and cost challenges as affirmed with a mean value of 4.02. Other pertinent challenges included institutional lapses such as difficulty in obtaining drilling permit with a mean value of 4.55.

Respondents and field observations highlighted several challenges hindering effective borehole construction and sustainable management including hiring inexperienced engineers, high cost of construction of boreholes, electricity bill as well as water pumping frequency, awareness of contamination

and treatment. construction permits, compliance, permit procedure effectiveness and costs of permit and construction are bore by the company constructing the borehole not the owners. Companies already have the permit to drill and so seek for permits only if there are obstacles in drilling in someone's compound in which the drill is to be done in an empty land. This therefore requires permit from the Buea council. From finding, a significant proportion of the population (86%) had no knowledge that borehole construction requires a permit. Among the 14% who were aware, not all applied for a permit, because their boreholes were within their compound.

Based the level of awareness on electricity cost and water pumping frequency for borehole usage, 36% of the sample respondents reported their monthly electricity costs between 11,000 and 15,000 FCFA, and 35% between 5,000 to 10,000 FCFA respectively. Due to prevailing circumstances where many respondents in Buea do not pay electricity bills, they often pump water multiple times, with 42% pumping more than 11 times per week and some distributing water to neighbors for free.

Based on awareness of contamination and treatment, findings revealed a critical lack of awareness regarding water quality and safety. 54% of respondents were unaware that boreholes could be contaminated if not properly constructed (i.e., not following environmental and legal procedures). Even higher proportions, 72%, were unaware of the need to periodically treat their boreholes or wash their tanks. Among those who did treat their boreholes, chlorine was used, but in assumed, rather than measured, quantities.

Environmental and management impacts of borehole construction

The study identified several critical environmental and management impacts stemming from the proliferation of boreholes. A primary concern is the negative environmental consequences arising from improper location selection for boreholes. This often leads to adverse effects such as groundwater contamination and damage to surrounding ecosystems. These findings underscore the critical importance of obtaining proper construction permits and conducting thorough site assessments prior to commencing any borehole construction.

While boreholes provide an alternative water source, observations indicated that not all households with boreholes treat their water, and storage tanks used for preservation are often not regularly cleaned. This practice introduces potential risks, negating some of the health benefits associated with improved access. A substantial majority of households, 119 (59.5%), strongly agreed or agreed that unreliable and poorly managed and maintained water significantly impacts health in Buea. Key reasons cited included increased strain on healthcare services and a higher incidence of waterborne diseases. Observations by the District Medical Officer corroborated this, noting alarming rates of water-related illnesses linked to old, rusted iron pipes connecting households in Buea, leading to disconnections and assisted repairs. The study quantitatively demonstrated a significant impact of poorly constructed and maintained

boreholes on the population. A calculated *Chi-square* value of 11.7, which exceeds the critical value of 5.99 at 6 degrees of freedom, statistically indicated that borehole construction and its associated unreliability have significant implications for the population in Buea.

DISCUSSION

This study aimed to assess the trends and impacts of borehole construction for sustainable water management in Bomaka, Buea, structured around three core objectives. The findings illuminate the complex interplay between water scarcity, unplanned urbanization, and the proliferation of private water sources, offering critical insights into the challenges and opportunities for sustainable water governance in peri-urban African contexts.

Based on the trends and drivers of borehole construction in the study area, the study's findings unequivocally indicate a dramatic increase in borehole construction within the neighborhoods of Buea, with field observations revealing over 500 operational boreholes in Buea with a majority of the boreholes located between Mile 17, Bomaka Muea axis and Molyko as well as major street. This surge, while providing immediate relief from water scarcity, signifies a significant departure from past trends and aligns with broader global and African patterns of increasing reliance on groundwater due to population growth, urbanization, and water demand (WHO, 2018; Adelina et al., 2008). While survey respondents provided varying estimates of borehole numbers (e.g., 27% indicating 1-10, 21% indicating 11-20), the stark discrepancy with field observations (over 120 boreholes) suggests a potential underestimation by residents, likely due to limited awareness of boreholes beyond their immediate vicinity or those not directly serving their households. This highlights the challenge in accurately quantifying such informal or semi-formal infrastructure, a common issue in rapidly developing areas.

The overwhelming majority of respondents (35.5% strong affirmation, indicating more construction between 2021 and 2025 confirmed a recent acceleration in borehole drilling, during this period. This rapid trend is primarily driven by the number of Cameroon who have travelled (bushfallers) which confirmed to the study that over 40% of individual houses with boreholes are owned by "bushfallers". This was followed by those who opined that the Anglophone crisis (21%) has favoured the rapid increase in boreholes in Buea. The others such as frequent water shortage from CAMWATER (14%), rapid construction boom (10%) business opportunity (6%), change in behaviour of landlord and tenants and perceived water. Between 2016 and 2026, there has been a rapid increase in the number of Cameroon who have travelled and are actively involved in construction work in Buea. Most of the boreholes identified are owned by Cameroonians who are residing in foreign countries. The Anglophone crisis that is 10 years old today has led to the increase in boreholes in Buea. Many Cameroonians displaced from their divisions found peace in Buea and decided to invest in Buea. Most of those who were hoping to invest in their villages or divisions have made up their minds to remain in Buea and so permanently investing in Buea and so increased in the number of boreholes. These drivers resonate with the broader challenges faced across sub-Saharan

Africa, where groundwater development is flourishing to meet growing demands that conventional water supply systems struggle to match (Foster et al., 2006; Dzekewong et al., 2016). The minimal influence of "self-preference" (2%) underscores the reactive, necessity-driven nature of borehole proliferation in Buea, rather than a preference for private sources. This aligns with the documented increase in borehole drilling observed in other African countries like Malawi, driven by government, NGOs, and private contractors to address water deficits (Pavelic et al., 2012).

Field observations supported this, showing displays of poor water quality attributed to improper location selection or insufficient treatment. This aligns with reports emphasizing that improper location can lead to groundwater contamination and ecosystem damage (World Bank, 2019). Perceptions regarding the quality of borehole water in Buea were mixed. An overwhelming majority (45%) strongly affirmed that their borehole water was good while 4% of the sampled respondents indicated it was very good. Conversely, 16% perceived the water as "poor," and 17% as "very poor." The variability in perceived quality points to underlying issues such as improper borehole siting, which can lead to contamination.

Based on the various implications of borehole construction on the population of Buea, the evaluation of borehole construction implications revealed critical knowledge gaps among Buea population, which directly contribute to negative socio-environmental consequences. A significant 54% of respondents were unaware that boreholes could become contaminated if not properly constructed, and an even higher 72% were unaware of the necessity of treating their boreholes or storage tanks. This profound lack of awareness is deeply concerning; as it directly undermines the potential health benefits of accessing groundwater and, conversely, exacerbates public health risks.

This finding aligns with previous research in Cameroon, which has highlighted the sale of "questionable quality" water from informal sources (Masse et al., 2016) and the high percentage of populations relying on untreated community water (Dzekewong et al., 2016). The practice of using assumed quantities of chlorine for treatment by those who do treat their water further indicates a lack of standardized practices and adequate guidance. Improper location selection, as noted in the results, directly contributes to environmental degradation, including groundwater contamination and ecosystem damage (World Bank, 2019; Holman et al., 2019). The volcanic geological setting of Buea (as noted in the problem statement) further complicates groundwater movement and necessitates specialized construction and management, making this lack of awareness particularly perilous (Ako et al., 2012; Mazor et al., 2009). The statistical significance of borehole construction's implications ($X^2=11.7$) confirms that these issues are not isolated incidents but exert a substantial impact on the community's overall well-being, contributing to educational challenges, social strain, and most critically, health impacts, including increased waterborne diseases.

Based on the challenges and sustainable management strategies of borehole construction, the study identified significant

challenges associated with borehole construction and management that hinder efforts towards sustainable water provision in Buea. A striking 86% of the population demonstrated no knowledge regarding the requirement for a construction permit, highlighting a pervasive lack of regulatory awareness. Even among the 14% who were aware, many did not apply for permits due to perceived "cumbersome procedures or cost." This perception is reinforced by 81% of respondents finding the permit procedure ineffective, with only a small, affluent proportion (4%) indicating otherwise. This suggests a disconnect between regulatory intent and practical implementation, creating an environment ripe for uncontrolled development. The issue of hiring inexperienced engineers further compounds the problem, jeopardizing borehole longevity and water quality (Pavelic et al., 2012). The high cost of borehole construction was also a major deterrent, although findings indicated a recent reduction in costs, making them more accessible. This cost factor, combined with the complexities of permits and expertise, pushes communities towards informal or poorly regulated options.

CONCLUSION AND RECOMMENDATIONS

Conclusively, the study demonstrates a clear increasing trend in borehole construction within Buea, primarily driven by persistent water scarcity attributed to population growth, urbanization, and industrialization. While this proliferation has served as a vital alternative or supplementary source, significantly helping to provide a more reliable water supply, it comes with considerable socioeconomic and environmental implications. The findings indicate that the uncontrolled nature of this development, particularly due to improper construction practices, has led to the contamination of water sources. Furthermore, the high initial cost of borehole construction poses a significant financial burden on low-income earners in Buea. Critically, a substantial portion of community members and borehole owners lack awareness regarding proper water treatment and tank cleaning, contributing to potential waterborne diseases. There is also a widespread unawareness or disregard for the necessity of obtaining permits from the council, which is crucial for proper site selection and mitigating future environmental risks and hazards. Based on the findings and conclusions of this study, the following recommendations are put forth to various stakeholders to foster sustainable borehole construction and water management in Buea.

The government, through relevant ministries and agencies, should invest in comprehensive training and capacity building programs for borehole construction technicians. This will ensure adherence to high-quality standards and promote the development of sustainable water supply systems in Buea. Government and local councils should implement and rigorously enforce strict regulations and monitoring mechanisms for all borehole construction activities. This is essential to ensure compliance with environmental and safety standards, preventing issues like improper siting and contamination. The government should promote the use of sustainable and cost-effective borehole construction techniques, such as manual drilling methods, especially in underserved areas of Buea, to improve equitable

access to safe and clean water. It is imperative that the government enacts and strictly enforces laws requiring all community members to obtain permits from the council before commencing borehole construction. This measure will ensure proper site location, thereby mitigating future environmental risks and hazards. The government should consider building public taps in strategic centers within Buea. This initiative would help to alleviate the prevalent water scarcity and reduce over-reliance on individual boreholes. Community members should be made fully aware of the importance of proper maintenance and regular upkeep of boreholes. This knowledge is crucial for ensuring their long-term functionality, usability, and the safety of the water supply. They should also take collective ownership of boreholes, whether publicly provided or individually owned but shared. This includes shared responsibility for their maintenance and upkeep once construction is completed. Borehole owners in Buea are strongly advised to consult with local authorities and community leaders before beginning any borehole construction. This ensures compliance with all necessary permits and regulations and promotes community awareness. Owners should also inform the community about the construction process, including any potential disruptions like noise or dust. In addition, they should ensure that the construction site and the borehole itself are properly secured and safe, especially to prevent accidents involving children and other vulnerable populations within the community.

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