



Assessing Household Water Availability, Accessibility, and Harnessing Strategies for Sustainable Water Security in Kwahu East Plateau, Ghana

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Abstract

The study evaluated household water supply, access, and harnessing methods in Abetifi, Kwahu East, Ghana, within a quantitative research framework, involving 400 respondents selected through stratified random sampling. It discussed seasonal changes in water supply, the primary factors affecting household access, and the efficiency of adaptation measures. During the dry season, 85 per cent of households lacked water, 70 per cent had no piped water, and people walking 3.5 km daily spent 4.8 hours a day collecting water. Contrastingly, the wet season had a minimum of 25 per cent scarcity, a 1.2 km travel distance, and an average collection time of 2.5 hours. More than 55 per cent of households spent more than 5 Ghana cedis per day on water, and 60 per cent of households experienced frequent breakdowns of the borehole or standpipe. During the wet season (70%), water was collected from rainwater; during the dry season (70%), came from boreholes, with the help of household storage systems (60%). The results of remote-sensing analysis indicated that the mean value of the NDWI (-0.582) during the wet season was larger than the mean value during the dry season (-0.461), and the results of the LULC analysis (2000-2025) demonstrated that vegetation cover and growth reduced by half and built-up areas expanded, which identified the fact of increased anthropogenic pressure on water resources. The study's originality lies in combining household survey information, NDWI, and LULC analysis within the Sustainable Livelihoods Framework to assess the interaction among seasonality in climatic conditions, human adaptation, and plateau hydrology. The results provide data-driven, practical recommendations for developing climate-resilient community-based water systems in Ghana's highlands.

Keywords: Household strategies, Kwahu East Plateau, Seasonal variability, Water accessibility, Water scarcity.

1. Introduction

Water scarcity, a global issue, worsens each year because it affects populations across regions worldwide. Even though water covers our planet, the available fresh drinking water is limited and distributed unevenly around the world (UNESCO, 2019). The combination of climate change, population growth, and inadequate water management has made secure access to clean water an urgent global issue. Access to drinking water, along with water for cooking and sanitation, has become elusive for about 80% of people across various

locations. The combination of dry climate conditions causes droughts in certain areas, prompting residents to manage water through rainwater collection systems and imported water supplies (WWAP, 2020).

National development increases water demand, which exceeds the fixed supply available to each nation. Operating innovative, sustainable water-collection methods is an immediate necessity in our current situation. The vast African continent needs substantial attention to water issues, as many regions experience long dry seasons and limited access

to groundwater. Numerous communities rely on surface water and seasonal rains to sustain their water supply, yet they remain at risk of running out (Boretta and Rosa, 2019).

Water distribution and storage systems remain inefficient in rural and semi-urban areas due to inadequate infrastructure. Several African nations address their water supply problems by using rainwater collection systems, along with well drilling and saltwater removal methods (Wiegand et al., 2021); however, these methods also pose challenges regarding cost and sustainability. People in dry areas who lack sufficient household income cannot reliably access the water supply through truck-delivery services. Residents must walk long distances to reach water supply points at remote locations because of the critical need for local water management systems.

The inconsistent water supply particularly affects all communities in Ghana throughout the dry season. Areas throughout northern Ghana traditionally experience water shortages, yet seasonal water scarcity also affects parts of the southern regions, according to Nezamoleslami and Hosseinian (2020). Ghana has formulated multiple water access policies over the years by installing boreholes, establishing small-town water systems, and installing public standpipes. The problems posed by rapid urban expansion and pollution, alongside climate change, continue to compromise access to dependable, high-quality water, according to Ribeiro et al. (2022). Products from mechanised borehole water sources become scarce as regional groundwater levels continue to decline, leading to dry wells. People from affected communities start buying water from private vendors, leading to increased household costs and a division of water resources by income.

The water crisis in Abetifi and its surrounding areas in the Kwahu East District is distinctive because the region lies on the Kwahu Plateau. Abrupt water infiltration in this region is challenging due to the dominant rock formations in the soil (Sikakwe, 2020). The low elevation of the local groundwater makes well-drilling attempts unsuccessful, as they yield negligible water. The dry season leads to the complete depletion of water resources, turning the limited supplies yellow

and raising safety concerns about their use. Distribution of water by small vehicles is one of the main observed trends, as these vehicles fetch water from different areas to supply homes. The widespread, though unreliable, water distribution method that relies on external suppliers and varies by customer requirements is costly to operate. 77% residents have attempted to harness rainwater, but due to limited storage capacity, they often run out of water before the dry season ends.

Research on water accessibility problems in Abetifi has primarily focused on describing deficits without establishing comprehensive solutions (Kumi, 2018). This research extends previous studies by evaluating both water resource availability and household adaptability to water situations, in addition to water accessibility. The current study does not follow previous investigations focused on water quality evaluations and accessibility hurdles, as it examines water system performance alongside new methods to enhance regional water security. The quantitative research methodology will enable this study to produce quantifiable results on household responses to water scarcity and to develop scalable solutions to maintain water availability. The study analyses water-retrieval strategies in Kwahu East District by examining resource availability and accessibility, as well as household-level adjustments to seasonal water stress.

The originality of the work lies in combining quantitative household surveys, geospatial analysis, and the Sustainable Livelihoods Framework (SLF) to understand intricate processes of interaction among hydrology, livelihoods, and adaptation in a plateau context. It implements an empirical-spatial model that merges remote sensing parameters (NDWI), statistical modelling, and field data to demonstrate spatial-temporal changes in water availability across seasons. Moreover, the study is the first to apply seasonal measures of water access to assess the impact of rainfall variability on household behaviour and infrastructure performance.

By connecting physical geography (plateau geology and hydrology) with the social aspects of household adaptation and cost implications, this work transcends the case-study approach to provide a comprehensive evidence base for

policy design and adaptive water management. The proposed study thus provides a new direction for analysing and enhancing water security in topographically constrained areas such as the Kwahu East Plateau.

Although various national interventions have enhanced water accessibility in Ghana, households in plateau areas such as Kwahu East still experience severe seasonal water insecurity. The high topography and rocky nature of the district inhibit groundwater storage and the effectiveness of conventional borehole systems.

During the extended dry season, the majority of households travel for many kilometres to fetch limited water, which is usually of inferior quality. High transport costs and inconsistent vendor availability compound households' vulnerability. These shortages have been predominantly described in previous studies without incorporating spatial evidence or using practical adaptation models responsive to the special plateau conditions.

For example, a study in the nearby Kwahu West Municipality found that constructed and bare land had significantly increased over 22 years, while vegetative cover decreased, potentially weakening hydrological recharge (Aninakwah et al., 2024). The absence of quantitative evaluation of the relationships among seasonal changes, domestic reactions, and spatial water movement has produced a significant gap in water-management studies. This research paper thus examines household water availability, access, and harnessing in Kwahu East through a combined analysis of survey data and remote sensing to provide evidence-based policy and community adaptation management for sustainable water policy.

The following research questions seek to guide the study.

1. How do seasonal changes affect water availability in Kwahu East?
2. What are the key factors influencing household accessibility to water, and what challenges do households face in water supply?
3. What water-harvesting strategies do households use, and how effective are they in ensuring water availability?

1.1. Theoretical framework

The Sustainable Livelihoods Framework serves as a robust academic framework for understanding community responses to water scarcity and environmental adaptation efforts. DFID (1999), as documented by Solesbury (2003), developed a framework that characterises how people maintain their well-being through the use of human, social, natural, physical, and financial assets, even in the face of external shocks (Scoones, 2015). According to the SLF, livelihood approaches to water resources availability depend on institutional elements, ecological environments, and economic frameworks (Chambers and Conway, 1992).

The framework enables understanding of adaptive processes by studying how resource-constrained people and households manage environmental barriers to maintain their well-being. The worldwide problem of water scarcity particularly affects communities in regions where environmental factors and poor water infrastructure create challenges.

The research team uses the SLF extensively to understand human responses when developing methods to ensure resource security (Ellis, 2000). Regions experiencing inconsistent rainfall, along with deficient groundwater sources and limited infrastructure, prompt households to adopt alternative water-collection strategies to meet basic needs, as shown by Zhang et al. (2021). These adaptation methods combine rainwater collection techniques with borehole construction, with limited water distribution control and small-scale water sales, driven by resource opportunities and supportive external networks.

The Special Landscape Framework is an essential tool for studying household adjustments to Kwahu East's groundwater challenges, given its specific rocky terrain, which promotes rapid rainwater infiltration. Agent populations in this region must frequently adapt their water use and collection methods because it faces limited water reserves, changing seasonal water supplies, and divided water distribution networks.

The SLF's emphasis on livelihood assets and adaptation mechanisms helps explain how people secure water access, depending on their

available resources and external constraints (Scoones, 2015).

Through their study, the SLF researchers demonstrate that institutions, alongside policies with socio-economic elements, shape household processes related to water access and management. The way residents in Kwahu East maintain their water system does not account for the overall impact of elevation, rocky topography, and rainfall variability on household water behaviour and distribution system performance (Zhang et al., 2021). The research will evaluate household adaptation responses to seasonal water scarcity by applying the SLF and assessing the variables that affect these coping strategies. Through its essential theoretical framework, the SLF helps researchers study and understand various aspects of water access, availability, and adaptation strategies. The framework allows a comprehensive examination of household responses to water scarcity in Kwahu East by explaining how people use their available resources under restricted conditions, in contrast to the broader socio-economic and environmental context.

1.2. Empirical review

Seasonal variations in plateau areas subject water availability to severe fluctuations, driven by climatic variability and complex topographic features. The high terrain around the world experiences high wet and dry cycles, which significantly impact surface and groundwater levels. In rainy seasons, rainfall replenishes lakes, aquifers, and rivers, whereas in dry seasons, precipitation is scarce because rainfall becomes unpredictable and evaporation is high (Yoshioka et al., 2020). The cycles cause periodic cycles of plenty and famine that upset agricultural and domestic regimes worldwide, particularly in semi-arid highlands. According to the Intergovernmental Panel on Climate Change (IPCC, 2021), increases in temperature and altered rainfall patterns are intensifying those extremes, and water management systems in plateau and upland habitats are under pressure.

The same situation can be observed in some regions of Asia, where the shallow soils of the Deccan Plateau and the complex rock components do not allow sufficient runoff to

be collected and replenished during monsoons (Jana et al., 2020).

Similar pressure on upland communities is exerted by seasonal rainfall variability across Africa. Dry periods in the Ethiopian central highlands, e.g., have been associated with reduced yields from wells and stream flows, curtailing access to household and agricultural water (Zhang et al., 2021). Both in the Sahel and on the East African plateaus, long-term droughts are increasingly driving migration and changes in settlement patterns as households seek more reliable water sources (Adaawen et al., 2019). Some locations have also historically used traditional ways to regulate water, such as ancient stepwells and standard tanks in India, or hillside catchments in Ethiopia, suggesting that local hydrological knowledge remains long-term and beneficial (Narain et al., 2019).

However, contemporary water infrastructure indeed fails to integrate these adaptive traditions, leading to inefficiencies that further worsen scarcity during the extended dry season. This means that the issue of water management in plateau areas needs to be addressed through place-specific, unique strategies that integrate seasonal variations and social adaptation.

Household water availability remains a particular concern in water-stressed settings across sub-Saharan Africa. Water reliability is still threatened by limited rainfall, excessive evapotranspiration and old-fashioned infrastructure (UNICEF, 2020). This will leave women and children with several hours to collect water, especially from distant rivers or community wells, leaving little time for education or income generation. Substandard water quality is one of the causes of frequent waterborne illnesses, which, in turn, perpetuates the cycle of poverty (Bain et al., 2014).

A rapid rise in population and urbanisation also increases demand and pressure on available groundwater sources, leading to a decline in aquifer levels (Famiglietti, 2014). Even though groundwater is an important source, its extraction is unsustainable, posing a long-term threat to its availability. The same situation is reported by Wiegand et al. (2021), who note that the efficiency of piped systems decreases due to reductions in infrastructure

and, in particular cases, leakage in peri-urban settlements.

In response, households in Africa have adopted various coping strategies. Rainwater harvesting, solar-powered pumps, and mini purification plants have shown potential but are constrained by high installation costs and limited technical capacity (Adaawen et al., 2019).

In regions where governance systems facilitate community-based water management, cooperatives and user associations have enhanced equity and local control over resources, as in Kenya and Tanzania. Nonetheless, most of the current literature generalises the problem of water access and ignores the geomorphological variation which determines the water behaviour, especially in plateau environments where shallow aquifers and rocky landscapes obstruct groundwater recharge (Aninakwah et al., 2024; Ribeiro et al., 2022). The majority of African studies focus on institutional or engineering solutions, with minimal inclusion of quantitative household data and geospatial variables (e.g., Normalised Difference Water Index (NDWI) or Land Use/Land Cover (LULC) dynamics) to explain the location-specific forces behind scarcity (Nezamoleslami and Hosseinian, 2020). This is an analytical gap, as it limits understanding of how physical terrain and socio-economic variables interact to shape household access to water.

Similar dynamics are observed at the Ghanaian level, as recent studies show. Increased surface runoff and decreased infiltration in upland municipalities such as Kwahu West and Kwahu East, which tend to compromise groundwater recharge, are due to urban sprawl, deforestation, and agricultural encroachment (Aninakwah et al., 2024). Water insecurity in the country is not eliminated by government policies such as the Ghana Water Policy and the Community Water and Sanitation initiative, which lack a focus on the hydrogeological limitations of plateau communities. According to a study by Ribeiro et al. (2022), highland districts still rely on boreholes and rainwater systems that are prone to climate change and lack comprehensive monitoring of seasonal changes in water behaviour.

Strategies to harness water and adapt to household conditions have become a necessity. Through rainwater harvesting, rooftop rainwater catchment, and small-scale irrigation systems, these practices have become common in rural sub-Saharan Africa as affordable remedies for seasonal water scarcity (Masarirambi et al., 2009). The drip-irrigation technologies enhance agricultural productivity by reducing runoff and evaporation losses (Postel et al., 2001).

The combination of indigenous conservation techniques with the latest technology, including lined tanks and soil-water retention systems, will create a more resilient household and food security (Wiegand et al., 2021). However, its prevalence remains limited due to a lack of technical expertise, prohibitive initial costs, and cultural norms that limit women's involvement in decision-making. Such socio-cultural processes highlight that the adaptability of technology should be inclusive and gender-sensitive to supplement technological innovation.

Despite this, few studies have empirically tested the performance of these adaptation measures in the exclusive hydrological and socio-economic settings of plateau environments. The literature is primarily based on lowland systems and does not assess the overall impact of elevation, rocky topography, and rainfall variability on household water behaviour (Ribeiro et al., 2022). The gap thus filled in the present study is the combination of two household survey datasets with spatial indicators NDWI and LULC, to determine the influence of seasonal variation and land-use change on water availability, access, and adaptation in Kwahu East. The relationship between physical geography, socioeconomic processes, and policy relevance contributes to geographically specific knowledge of water security in highland Ghana. It provides a model of upland territories that can be replicated in other areas of Africa.

2. Materials and Methods

2.1. Research design

The research adopted a quantitative design utilising the principles of the positivist philosophical worldview. Positivism focused on objective research methods, which required

measurable evidence for statistical analysis to discover patterns together with relationships (Creswell and Creswell, 2017). The research approach was sufficient for the study goals because it provided a framework for collecting numerical data to draw generalised conclusions about Abetifi's water resources. The research's fundamental belief that water scarcity, along with accessibility, operated as observable phenomena, supported by positivism's philosophical premise that reality remains objective and observable (Saunders et al., 2009). The research applied a quantitative approach to generate concrete information about sustainable water management strategies for the Kwahu East Plateau.

Figure 2 indicates that the research area comprised Abetifi, the district capital of Kwahu East in Ghana's Eastern Region. It is located between 6deg35'-6deg45' N and 0deg40'-0deg50 W at an average elevation of approximately 600-700 m above sea level. It is part of the Kwahu Plateau, the highest inland insular plateau in the country. The topography is rough and hilly, with Precambrian Birimian and Tarkwaian rocks composed mainly of quartzites and schists, which limit the soil's ability to reabsorb and retain groundwater.

Such rocky lithologies result in low aquifer yields and compel excessive reliance on seasonal rainfall and surface runoff to supply domestic water (Ghana Geological Survey Authority, 2015).

Abetifi has a tropical savannah climate with wet and dry seasons (April-October and November-March, respectively). The average rainfall per annum is between 1,200 mm and 1,500 mm, with higher amounts in May-June and September, but the average monthly temperature is 22 °C- 30 °C. The region experiences high potential evaporation rates exceeding 1,700 mm/year, and surface water is lost rapidly during the dry months (Djibo et al., 2015).

Abetifi has a population of approximately 10,000 people, with a socio-economic profile, and is the administrative and commercial centre of the rural areas of Ofraamase, Pepeese, Suminakese and Hweehwee. The occupations are mostly farming, trading, and public service, although water scarcity imposes seasonal limitations on these activities. Its high plateau level, rocky base, and urban population surge make it a perfect site to study available household water supplies and adjustment measures in topographically constrained areas.

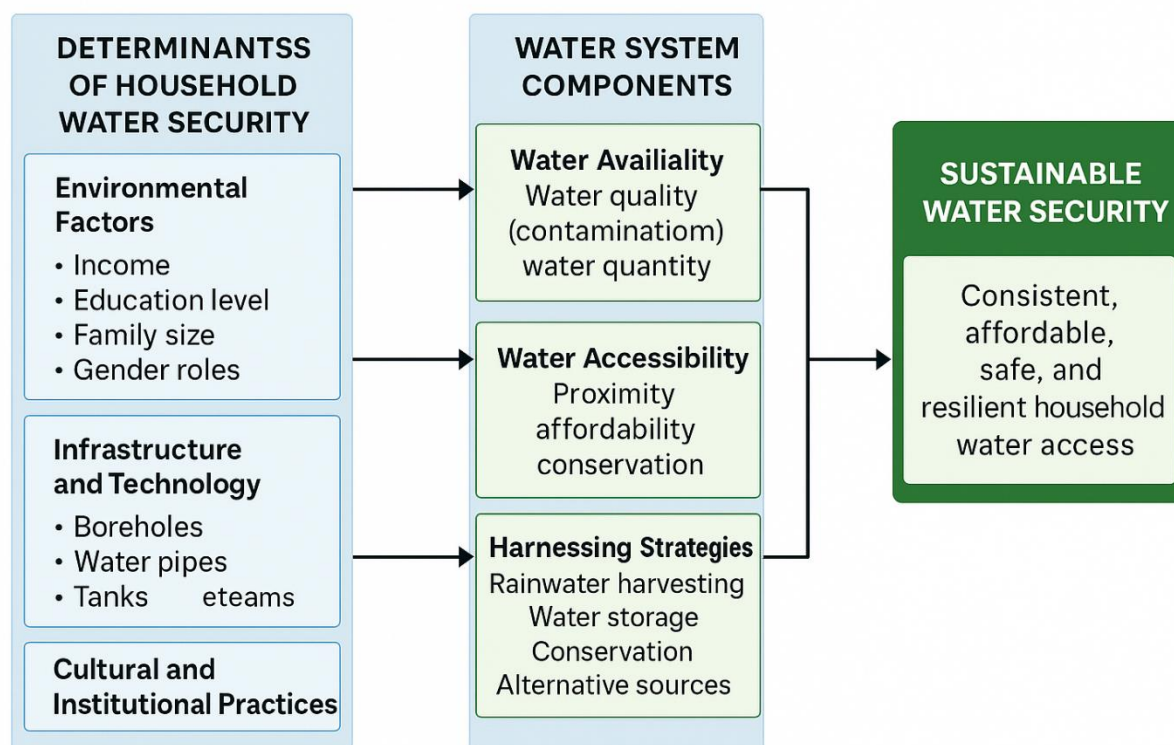


Fig. 1. Conceptual Framework



Abetifi had an estimated population of 10,000 residents, based on the 2010 Population and Housing Census, adjusted for population growth over the past decade (Ghana Statistical Service, 2010). To determine the sample size for this study, the following formula was used:

where:

- Plugging in the values, $n = 400$

random participant groups from each stratum in proportion to their population proportions. The research method used to represent all important sub-populations proved effective in increasing the accuracy and generalizability of the study results, according to Nilsson and Lövgren Hallberg (2023)

It used a structured questionnaire designed to collect quantitative data on water availability, accessibility, and household adaptation strategies. The instrument had four broad sections that encompassed demographic and socio-economic factors; household water sources; seasonal variability, accessibility determinants of distance, time, and cost; and harnessing and adapting household water practices. All questions were closed-ended and scored on a five-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree).

Categorical variables such as gender, water source, and season were coded numerically to facilitate statistical analysis. The hierarchical form improved data input reliability, and combining it with spatial indicators derived

from remote sensing further improved reliability. The data coding was conducted according to a pretested scheme, which ensured the clarity of the variables, their internal reliability, and compatibility with both descriptive and inferential data analysis (SPSS and STATA).

2.4. Data analysis procedures

The researchers used SPSS (Version 26) and STATA (Version 17) to analyse survey data acquired from structured questionnaires. Descriptive statistics, including frequencies, means, and standard deviations, were generated to summarise household characteristics and water-related variables. Inferential analysis involved correlation tests and multiple linear regression models to examine relationships between household water availability, accessibility, and adaptation responses. The regression approach was applied to quantify the predictive influence of distance, cost, and seasonal variation on household water stress while ensuring statistical significance at the 95% confidence level ($p < 0.05$). This analytical design provided a robust understanding of interrelated factors shaping water accessibility in Abetifi and established an empirical foundation for evidence-based policy decisions (Field, 2024).

2.5. Validity and reliability

The research used established surveys from previous water studies, which were modified to apply them to the Abetifi local environment. A preliminary survey was conducted to refine the questionnaire and assess its ability to measure the study objectives. Cronbach's alpha was used to assess reliability and determine survey item consistency, with a threshold of 0.7 or higher (Tavakol and Dennick, 2011). Standardised data collection approaches, together with stratified random sampling, reduced research bias and improved the reliability of the study results.

2.6. Uncertainty and limitations

Even though the current study used quantum and spatial approaches and was rigorously conducted, some doubts remain about the research process. The 400 respondents in the household survey constitute a large sample, but it might not be sufficient to

reflect intra-community differences in water-use behaviour across all settlements. Data collection might be programmed seasonally, which could affect the answers given, as the house may have different views on water scarcity depending on how it has been raining recently. The spatial resolution of the Sentinel-2 NDWI composites used in the remote sensing analysis is 10m, which can blur small transient water bodies and introduce minor spatial aggregation errors. Also, recall and response biases may affect self-reported household data, especially when estimating daily water consumption and expenditure. Despite these limitations, cross-validation of field data and satellite-based observations reduced uncertainty and ensured high reliability in the results.

2.7. Influence of dynamic seasonal conditions on results

The weather changes between wet and dry seasons on the Kwahu East Plateau also introduce temporal variability in the study of the resulting outcomes. The distribution of rainfall and the rate of water evaporation vary significantly from year to year, which affects the reliability of water sources, the use of NDWI to estimate water surface moisture, and even household preferences as reflected in polls. Even though the mean values were taken to reflect standard seasonal conditions, interannual anomalies, such as unusually long droughts or heavy rains, could lead to variations in the mean values.

The same issues have been reported by Yoshioka et al. (2020) and IPCC (2021), who note that climate variability alters hydrological responses and socio-economic behaviours in the short run. As a consequence, the findings represent an overall seasonal effect rather than an exact annual extreme. To improve this, the study has synchronised field data collection with satellite data and cross-validated observations across different data sources to ensure consistency while allowing the natural dynamism of the plateau climate system.

2.8. Ethical issues

This study was conducted in accordance with the ethical principles of the Declaration of Helsinki. Participants were fully informed about the research purpose, assured of their

confidentiality, and provided written consent before participating. An institutional ethics committee reviewed and approved the study

protocol to ensure compliance with ethical standards.

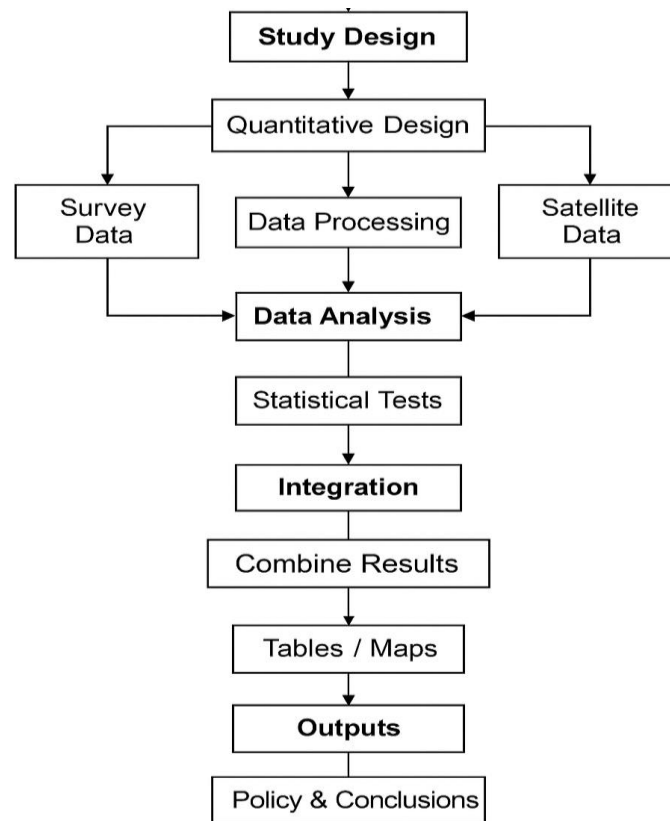


Fig. 3. Stepwise Flowchart of the Research Methodology Showing Key Data Collection and Analysis)

3. Results and Discussion

Table 1 depicts the demographic characteristics of respondents. There were equal numbers of males and females among the 400 participants since each group contained 200 people. A total of 120 respondents (30%) were 18 to 30 years old, while 160 participants (40%) were 31 to 45 years old. The 80-person group (20%) consisted of those aged 46 to 60, and the older population consisted of 40 participants (10%). The participants had diverse educational levels: 10% had no formal education, 20% had primary education, 40% had secondary education, and 30% had tertiary education.

The workforce consisted of 120 farmers (30% of the group), 100 traders (25%), 80 civil servants (20%), 60 people out of work (15%), and 40 diverse occupations (10%). The survey revealed that 25 per cent of households had 1-3 individuals, 50 per cent had 4-6, and 25 per cent had seven or more. The duration of residence in Abetifi indicated that 160 participants (40%) had lived there for 5–10 years, 160 (40%) for 11–20 years, and 80

(20%) for more than 20 years. The study participants had lived in Abetifi for at least 5 years to meet the requirement of residing there for that period.

3.1. How do seasonal changes affect water availability in Kwahu East

The Abetifi water sources, as indicated in Figure 4, reach their annual rainfall peaks in May (150 millimetres) and in June (140 millimetres) during the rainy season. The water source at this location reaches a maximum height of 3.0 meters in June, whereas the river level drops to 1.8 meters in February. The dry season reveals lower groundwater levels, reaching a minimum of 3.5 meters in August before rising slightly to 4.4 meters in November. Three water sources demonstrate seasonal variations in this data because each responds differently to changes during its specific season.

Table 2 shows significant differences concerning water accessibility between rainy and dry seasons in Abetifi. The. In contrast, rural households need to spend twice as long,

2.5 hours in the wet season as in the dry season to get water, highlighting heightened water access challenges.

Table 1. Demographic Characteristics of Respondents

Category	Subgroup	Number of Respondents	Percentage (%)
Gender	Male	200	50%
	Female	200	50%
Age Group	18–30 years	120	30%
	31–45 years	160	40%
	46–60 years	80	20%
	Above 60 years	40	10%
Education Level	No formal education	40	10%
	Primary education	80	20%
	Secondary education	160	40%
	Tertiary education	120	30%
Occupation	Farming	120	30%
	Trading/Business	100	25%
	Public/Civil Service	80	20%
	Unemployed	60	15%
Household Size	Others (e.g., artisans)	40	10%
	1–3 members	100	25%
	4–6 members	200	50%
	7+ members	100	25%
Years of Residence	5–10 years	160	40%
	11–20 years	160	40%
	Above 20 years	80	20%
Total		400	100

Households experience water scarcity at 25% during the wet season, yet this rate expands to 85% during the dry season. Water access distances lengthen during the dry season, with sources available only at an average of 3.5 km, while they are accessible at 1.2 km in the wet season. Boreholes serve as the primary water source during the dry season, accounting for 70% of dependency. In contrast, rivers serve as the primary water source during the wet season, accounting for 60% of dependency. This evidence shows that water accessibility changes markedly from season to season throughout the study zone.

Remote sensing outcomes using the Normalised Difference Water Index (NDWI) were analysed to confirm the seasonal analysis of water access patterns: wet (May–July 2024) and dry (January 2025) seasons. The quantitative survey results, which indicate a significant seasonal variation in water availability in Kwahu East, are corroborated by the comparative NDWI statistics and spatial maps (Figures 5 and 6).

Table 2. Seasonal Variation in Water Availability Indicators (Distance, Time, and Cost)

Metric	Wet Season	Dry Season
Average Daily Water Access (Hours)	2.5	4.8
Percentage of Households Facing Water Scarcity	25%	85%
Average Distance to Water Source (km)	1.2	3.5
Primary Water Sources	Rivers (60%), Boreholes (30%), Rainwater (10%)	Boreholes (70%), Rivers (20%), Rainwater (10%)

The mean value of NDWI between the wet and dry seasons was statistically higher at -0.582 in the wet season than at -0.461 in the dry season, which means that more surface water existed in the environment in the wet season than in the dry season. There was also a slight increase in the maximum NDWI values (0.238 to 0.246) and the minimum values (-0.822 in wet and -0.770 in dry), and low standard deviations (0.140 and 0.118) indicate relative stability of the surface conditions across most of the plateau. Spatially, the NDWI maps show that during the wet season, there are strong water signatures (cyan and light colours) in the northern and central upland areas, indicating temporary ponds, saturated soils, and increased moisture in vegetation.

Conversely, in the dry-season map, the NDWI values show general deterioration, with large areas of yellow to magenta, indicating that surface water bodies are drying out and that the soil is losing moisture, especially in the south escarpment and the built-up areas. These spatial patterns confirm the field evidence: households with better reports of longer water-collection times and greater scarcity during the dry months highlight the direct roles of rainfall seasonality and plateau hydrology in household water access.

According to the land use and land cover (LULC) maps of 2000 and 2025 (Figure 7), substantial spatial change is occurring in the Kwahu East Plateau.

Vegetation cover predominated across most of the landscape in 2000, indicating high levels of natural infiltration and a relatively stable hydrological environment. The urban and bareland areas had grown tremendously,

replacing vegetated areas, especially around Abetifi, Nkwatia and Oframase. This transition represents additional anthropogenic change to the land surface, driven by building, agricultural land use, and urban population growth. The growth of impervious built-up areas has decreased soil permeability, altered

runoff processes, and reduced the likelihood of groundwater recharge. The change pattern aligns with NDWI signals of decreased surface water availability, suggesting that human-induced land conversion has exacerbated water scarcity on the plateau.

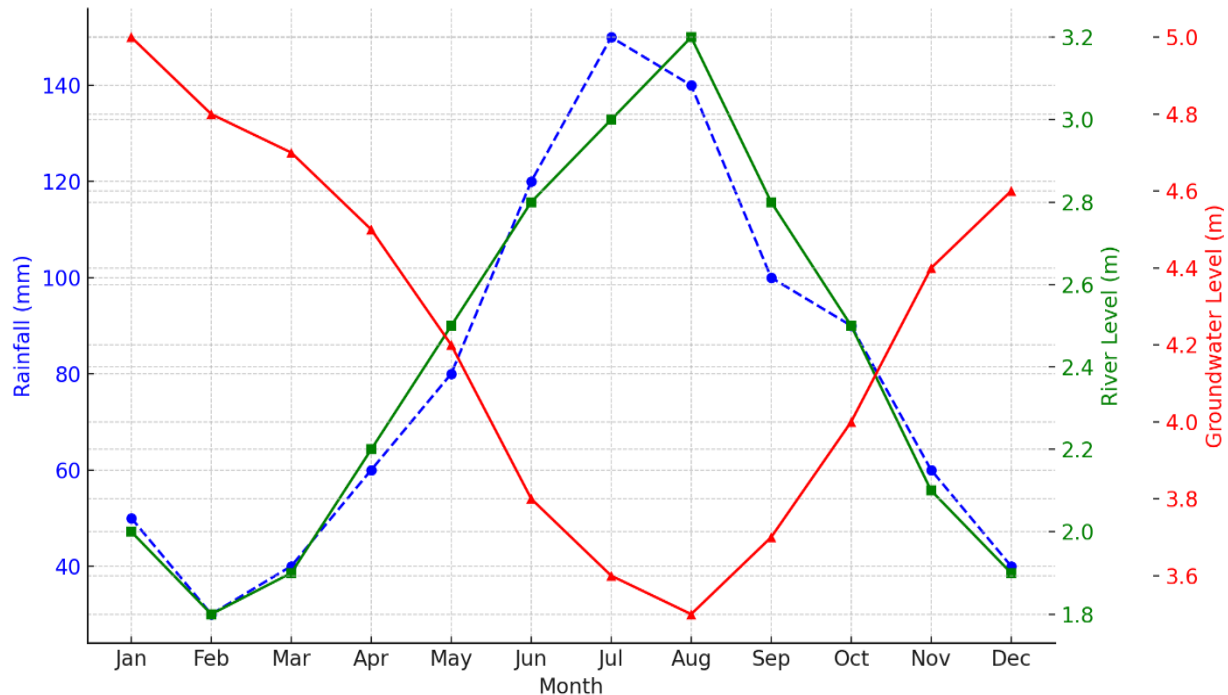


Fig. 4. Seasonal trends in water sources for Abetifi (Water Resources Commission of Ghana, 2019)

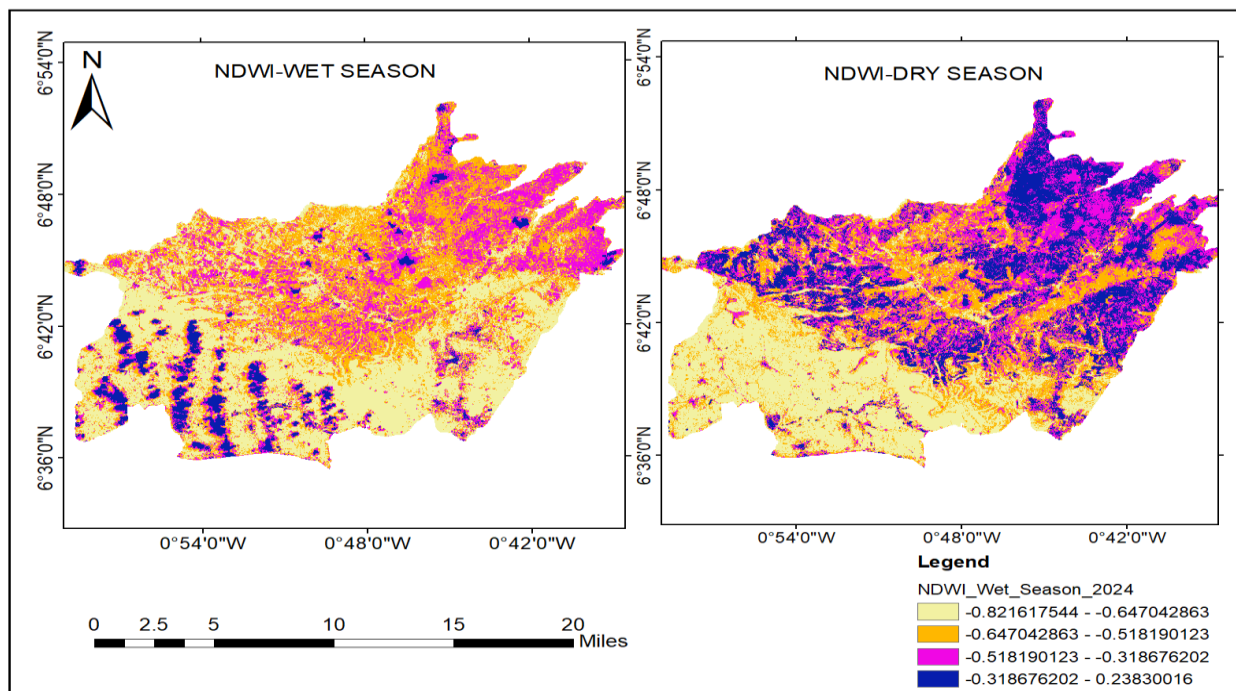


Fig. 5. Spatial Distribution of NDWI during Wet and Dry Seasons across Kwahu East Plateau

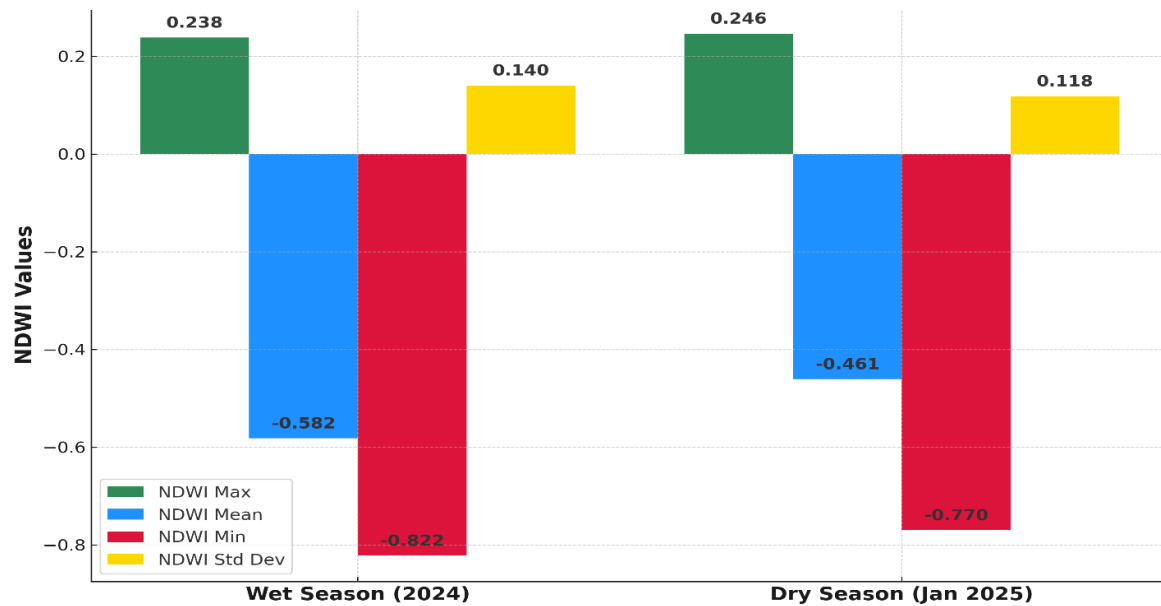


Fig. 6. Comparative NDWI Statistics for Wet and Dry Seasons (2024–2025) in Kwahu East Plateau

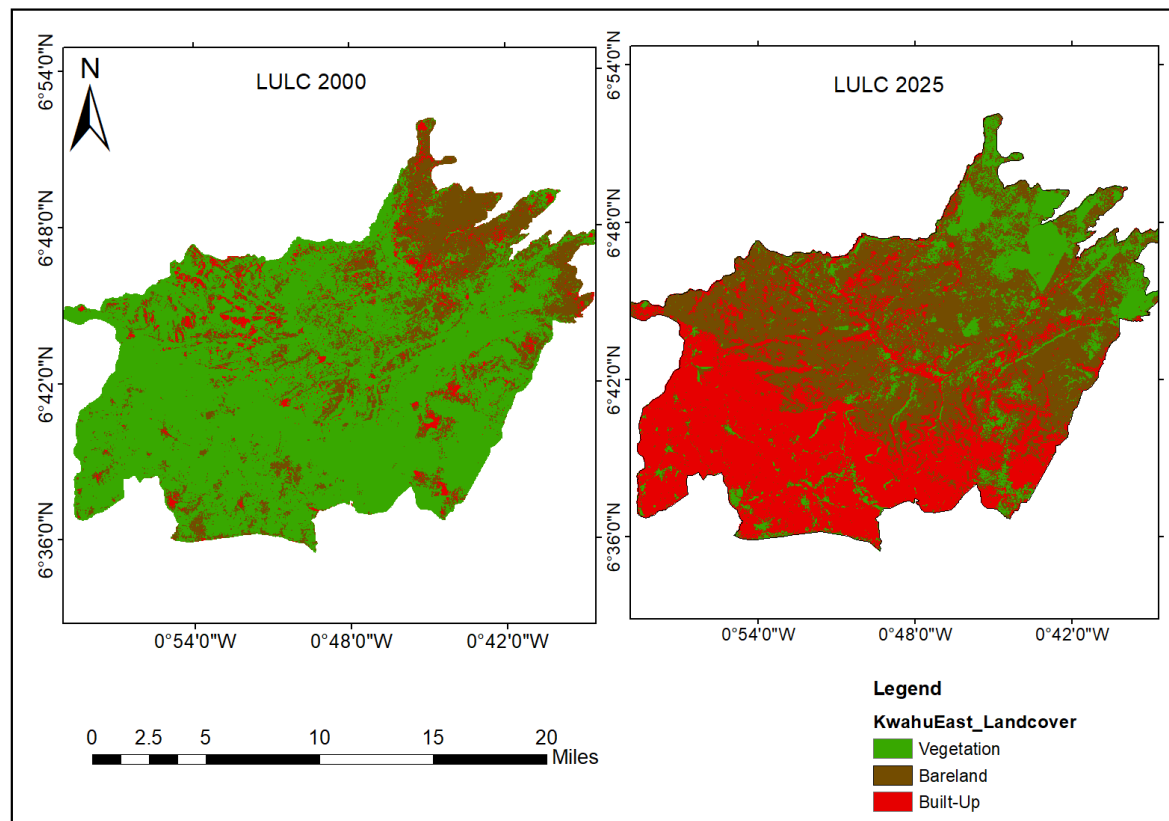


Fig. 7. LULC Maps of Kwahu East (2000 and 2025) Depicting Anthropogenic Impacts on Water Availability.

Spatially, the transition analysis reveals that vegetation cover has decreased. In contrast, water-harvesting cover has increased by over twice as much, while barelands and built-up surfaces have increased by more than twice as much, indicating the magnitude of human influence on the plateau environment.

These trends can be compared with recent discoveries in Ghana's semi-urban highlands, where agricultural growth, road development,

and deforestation altered the role of watersheds (Sikakwe, 2020; Nezamoleslami and Hosseinian, 2020). The overlays of NDWI and LULC indicate that decreases in vegetative cover are significantly associated with low NDWI areas, demonstrating that environmental disturbance from anthropogenic activities alters local hydrology and reduces seasonal water resilience.

3.2. What are the key factors influencing household accessibility to water, and what challenges do households face in water supply?

As shown in Table 3, water access problems differ significantly between seasons within the Abetifi community, according to the collected data. Households must walk 2 kilometres or more to find water in the dry season, whereas only 40% do so in the wet season. Households experience increased financial pressure during the dry season, as 55% spend 5 GHS or more per day on water, compared with 30% in the wet season. The constant presence of infrastructure problems affects 2 out of 3 homes that lack piped water year-round. Water source reliability deteriorates during the dry season, as 60% of sources experience breakdowns, compared with 40% in the wet season. Household water collection time exceeds 1 hour during the dry season for 50% of residents, but declines to 30% during the rainy season, indicating people have more time available for other tasks in the wet season.

Table 4 shows that water scarcity is the foremost issue among respondents, with 85% agreeing and an average score of 4.5. The assessment shows that inadequate infrastructure ranks below poor water quality, but both issues pose substantial challenges to household welfare (mean = 3.7, 60% agreement). The high cost of water produces moderate challenges (mean = 3.5, 50% agreement).

Table 3. Determinants of Household Water Accessibility in Dry and Wet Seasons

Factor	Dry Season (n = 400)	Wet Season (n = 400)
Distance to Water Source	260 respondents (65% travel $\geq$ 2 km)	160 respondents (40% travel $\geq$ 2 km)
Cost of Water	220 respondents (55% pay $\geq$ 5 GHS/day)	120 respondents (30% pay $\geq$ 5 GHS/day)
Infrastructure Availability	280 respondents (70% lack piped water)	280 respondents (70% lack piped water)
Water Source Reliability	240 respondents (60% report breakdowns)	160 respondents (40% report breakdowns)
Time Spent Collecting Water	200 respondents (50% spend $\geq$ 1 hour)	120 respondents (30% spend $\geq$ 1 hour)

Table 4. Challenges in Water Supply (Likert Scale Analysis)

Challenge	Mean Score	Median Score	Standard Deviation	Percentage Agreeing
Water Scarcity	4.5	5.0	0.6	85%
Poor Water Quality	3.8	4.0	0.9	65%
Seasonal Shortages	4.2	4.0	0.7	75%
High Cost of Water	3.5	3.0	1.1	50%
Long Distance to Sources	4.0	4.0	0.8	70%
Inadequate Infrastructure	3.7	4.0	1.0	60%

3.3. What water-harvesting strategies do households use, and how effective are they in ensuring water availability?

Household water-harvesting methods in Abetifi exhibit different trends throughout the year, as shown in Table 5.

Table 5. Household Water Harnessing Strategies (Wet vs. Dry Season)

Strategy	Wet Season Usage (%)	Dry Season Usage (%)
Rainwater Harvesting	70%	20%
Surface Water Collection	60%	30%
Dug Wells	50%	40%
Boreholes	30%	70%
Water Storage (Tanks/Jars)	40%	60%
Greywater Recycling	0%	0%
Modern Filtration Systems	5%	5%

70% of households in Abetifi collect rainwater using Rainwater harvesting during the wet season, along with Surface water collection (60%). Additionally, they use Dug wells (50%) and Water storage methods (40%) for their water needs. The dry season sees substantial decreases in rainwater harvesting to 20% of households and in surface water collection to 30%. In comparison, boreholes supply 70% of households and water storage services 60% of families during this water-scarce period. Traditional methods continue to prevail, as evidence shows that graywater recycling (0%) and filtration systems (5%) remain uncommon year-round.

Households show flexibility through their seasonal adjustments, and they most heavily depend on basic traditional water sources that are easily accessible.

3.4. Effectiveness of the water-harvesting strategies

As shown in Figure 8, rainwater harvesting, along with boreholes, was identified by the respondents as the most efficient approach for water harvesting during periods of water

scarcity (90 at level 5, 80 at level 4, and 50 at level 5).

Surface water collection leads to mixed outcomes among participants, with 60 responses at level 1 and 50 at level 2. A total of 60 respondents rated dug well effectiveness at level 2, and 50 at level 3, but their views were inconsistent. The effectiveness ratings for water storage tanks and jars are levels 3 and 4, with 60 responses each.

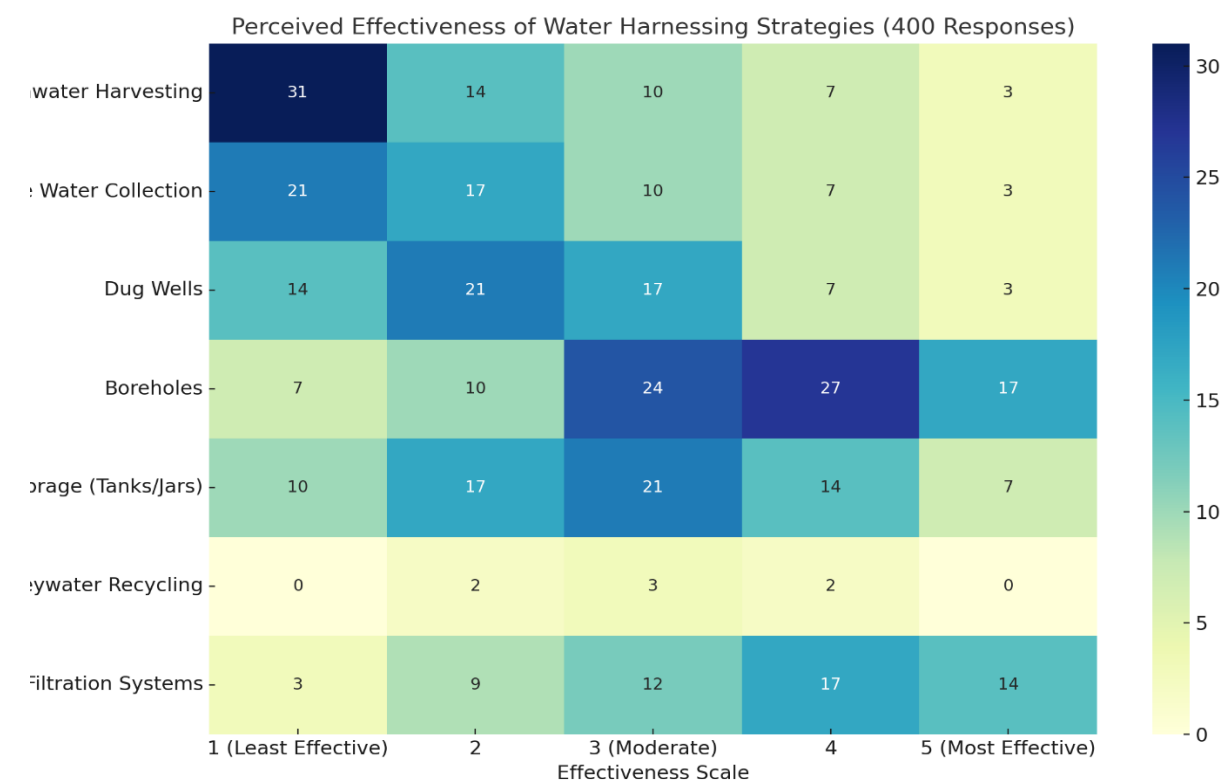


Fig. 8. Effectiveness of the water harnessing strategies

The survey participants considered greywater recycling to have the lowest impact, with only five responses rating it at levels 2 and 4. The evaluation of modern filtration systems shows balanced use: 50 respondents use them at level 4, and 40 use them at level 5. Rainwater harvesting, together with boreholes, is the primary solution to water scarcity for people worldwide.

4. Discussion

4.1. Seasonal changes and water availability in Kwahu East

The research indicates that seasonal variations influence water resources in the Kwahu East District, most notably in Abetifi. River and groundwater levels reach their peak

during May and June during the year's wet season. The seasonal river water levels drop to 1.8 meters, while groundwater reaches its lowest point in August during the dry season. Yoshioka et al., (2020) found that the Kwahu East plateau exhibits considerable seasonal water variation due to its rocky surface and limited water-sequestration capacity. Water shortages result from seasonal rivers and groundwater dependence, so households must travel farther and spend more time obtaining water during dry seasons.

During wet seasons, the traditional rainwater harvesting methods and dug wells serve as essential water management systems, according to the research findings. The usage of rainwater harvesting declined significantly

(to 20%) during the dry season when these systems become less effective. Traditional methods prove inadequate for handling prolonged dry spells in plateau regions, as stated by Jana et al., (2020). This research stands out by quantitatively examining seasonal water trends to directly assess household access, thereby establishing evidence-based strategies to improve water supply.

Households use their natural assets, including groundwater, along with rainfall measurements to maintain their way of life, as the Sustainable Livelihoods Framework (SLF) describes in its analysis. This research shows that external factors, such as poor infrastructure and climate change, limit the effective use of household natural resources. The long-term threat to water security stems from declining groundwater levels, as people heavily depend on boreholes during the dry seasons. According to Ellis (2000), sustainable management of limited resources requires blending traditional water management methods with contemporary solutions in resource-scarce regions. The noted hydrological variability is similar to experiences in broader sub-Saharan regions, where declining aquifer recharge and rising evapotranspiration lead to dry-season water stress (Abdi, 2023). These results confirm the claim that topographic uplift and meagre lithology within plateau studies augment seasonality lack, in contrast to lowland areas, which have the advantage of greater aquifer retention (Sikakwe, 2020).

4.2. Remote sensing evidence of seasonal water variability

The NDWI analysis provides numerical evidence of the significant seasonal variation in water availability on the Kwahu East Plateau. Figures 5 and 6 indicate that the average NDWI values in the wet season (-0.582) were significantly higher than in the dry season (-0.461), reflecting the different hydrological conditions. This is consistent with the field data in Table 2, which shows that 85% of households report water scarcity during the dry season, whereas only 25% report it during the wet season. The maps of spatial distribution indicate increased desiccation of the southern and central plateau

areas during the dry season, with NDWI values decreasing below -0.70, indicating that soil moisture is exhausted and temporary ponds are lost. These remarks confirm the seasonal oscillations outlined by Yoshioka et al., (2020), who noted that rocky plateau structures are characterised by shallow soil depths that do not allow substantial infiltration and moisture storage, resulting in severe moisture shortages after rainfall ends.

These environmental differences are considered external stressors under the Sustainable Livelihoods Framework (SLF), limiting households' access to natural and physical resources and affecting their adaptive mechanisms. For example, the decrease in NDWI during the dry season is associated with greater household reliance on boreholes (70 vs. 30) and a longer collection duration (4.8 vs. 2.5 hours), demonstrating how physical scarcity can translate into livelihood vulnerability. These types of correlations between the satellite-based surface moisture and household water stress were observed in semi-arid Ethiopian and Kenyan districts (Zhang et al., 2021; Wiegand et al., 2021).

The NDWI evidence thus supports the study's strength, as it combines spatial analysis with household-level observation, finding that a definite biophysical-social connection exists between hydrological seasonality and human adaptation on the Kwahu Plateau. Such overlap between field and remote-sensing data provides evidence of the soundness of the results. It is consistent with Aninakwah et al. (2024), who reported similar NDWI-household correlations in the Kwahu West Municipality in Ghana. It also highlights the importance of using remote sensing in community-level water research to identify temporal hotspots of scarcity.

4.3. Anthropogenic land cover changes and water stress

The LULC analysis (Figure 7) shows that human-induced changes in the Kwahu East Plateau landscape have become a leading cause of water shortages. The vegetation cover dwindled by over half between 2000 and 2025, while bareland and built-up areas increased in size around Abetifi, Nkwatia and Oframase. The change implies increased urbanisation, deforestation, and agricultural encroachment,

all of which have broken the natural hydrological balance (Aninakwah and Aninakwah, 2025). Reduced vegetation cover reduces infiltration and the evapotranspiration buffering capacity, thereby reducing groundwater recharge and increasing surface runoff. The changes are similar to those reported by Nezamoleslami and Hosseinian (2020) and Sikakwe, (2020), who noted that human land conversion in the Ghanaian highlands exacerbates seasonal droughts and sedimentation in surface channels. The trend also aligns with that of Ribeiro et al. (2022), who found that rapid settlement growth, but not corresponding water infrastructure development, increases reliance on boreholes and supplier systems, thereby contributing to the further development of socio-economic disparities in water access.

From the perspective of the Sustainable Livelihoods Framework (SLF), such anthropogenic pressures undermine both natural and physical capital, leaving the household reliant on external or temporary water sources. The greater built-up area (in red) indicates areas of population concentration where impervious surfaces prevent water infiltration, thereby increasing water demand. The combination of supply and demand pressures creates a vicious cycle of worsening water insecurity, especially during the dry months when NDWI values are lower. Similar trends have been observed in the highland plateaus of Ethiopia (Zhang et al., 2021), where agricultural infiltration and deforestation altered the catchment hydrology, leading to decreased groundwater recharge. This study thus shows that anthropogenic landscape change augments natural climatic stress on plateau hydrology, using NDWI and LULC evidence. The physical infrastructure alone is not sufficient to control such interactions; land-use and watershed restoration measures are needed to maintain the ecological balance required for sustainable water availability.

4.4. Key factors influencing household water accessibility and challenges

The research study identifies distance to water sources and water costs, alongside infrastructure availability, as the main determinants of water accessibility in Kwahu

East. Households need to walk over 2 kilometres during the dry season to get water, whereas the distance falls to 2 kilometres in the wet season. Long distances to water resources make it difficult for women and children to access education or earn income, according to UNICEF (2020). Households in the dry season pay at least 5 Ghanaian cedis (GHS) per day for water, a substantial financial burden that mainly affects families with limited income.

The nationwide shortage of pipeline infrastructure contributes to water access problems, as 70 per cent of households receive no regular piped water supply. Wiegand et al. (2021) found that insufficient infrastructure prevents rural and semi-urban areas from accessing water. Research shows that Abetifi faces distinctive water problems due to its distributed water system, with water source failures occurring in 60% of cases during dry periods. The data disproves the notion that boreholes provide reliable water solutions in plateau areas, as groundwater levels decrease and equipment frequently fails.

Within the SLF framework, physical and financial assets function as critical factors which control water accessibility. Research indicates that households with greater financial capacity can obtain substitute water sources by purchasing it, whereas those with limited resources face significant difficulties. Scoones (2015) argues that people construct their livelihood strategies based on the resources they have and the environmental constraints they face. The research results demonstrate that institutions must develop solutions to address essential barriers, such as insufficient water infrastructure and unreliable water supply systems. The present finding is consistent with the article by Appiah, (2020), which stated that socio-economic disparities in Ghanaian upland communities mediate household resilience to seasonal water crises. It also complements the findings of Van Der Geest, (2004), who argue that the household's persistent vulnerability in semi-urban Ghana is not solely due to climatic variability.

4.5. Household water harnessing strategies and their effectiveness

Traditional water sources, such as rainwater collection and borehole extraction, provide the primary water supply for homes in Abetifi

town during both the wet (70%) and dry (70%) seasons. 90% of respondents view rainwater harvesting as effective, as evidenced by participants who rated it five on the effectiveness scale. Masarirambi et al. (2009) found that rainwater harvesting provides affordable, sustainable water solutions in regions with impaired water resources. The study reveals that rainwater harvesting use decreases to 20% during the dry season, when households primarily rely on boreholes and water storage as alternative water sources.

Modern approaches to recycling greywater and installing filtration systems are underused, as only 5% of households use them. Postel et al. (2001) found that drip irrigation and filtration systems enhance water-use efficiency, whereas this study reached the opposite conclusion. The scarcity of technology acceptance in Abetifi stems from high costs, insufficient technical knowledge, and cultural barriers, according to Wiegand et al. (2021). This research adds originality through its practical assessment of adaptive strategies in plateau conditions, which explains why conventional practices continue to dominate despite their stated limitations.

The findings support the Social Learning Framework, which explains how human and social factors determine which adaptation strategies become prominent. Families with technical expertise and community support networks tend to use efficient water-collection methods. The research investigation demonstrates how external factors, including environmental and structural weaknesses, create substantial barriers to these successful adaptation activities. The authors support the position established by Zhang et al., (2021) that sustainable water management depends on combining both traditional viewpoints and new technological advances. Another factor contributing to the high acceptance of rainwater harvesting is a report from Kenya and South Africa (Luwesi et al., 2025), which emphasises familiarity among the population and ease of maintenance as success factors. Nevertheless, the low adoption of modern systems indicates a critical policy gap in technical training and subsidies, and Aninakwah et al. (2024) also corroborate this in their paper on household adaptation behaviour in the plateau districts of Ghana.

The paper has established a distinct relationship among seasonal change, family adaptation, and policy orientation in the Kwahu East Plateau. All these are caused by seasonal changes in hydrology, as demonstrated by NDWI and LULC, which reduce household access to water and force them to adopt behavioural changes, including rainwater harvesting, water storage, and reliance on vendors. Such adaptive responses, while effective locally, are short-term and unevenly distributed due to financial and infrastructural constraints. This relationship highlights that the problem of water scarcity in a plateau setting is not only climate-driven but also structurally underpinned by a dysfunctional governance system and disorganised land use. To build adaptive capacity, it is recommended that policies focus on increasing decentralised water system development, encouraging rooftop and communal rainwater collection, and strengthening land-use controls to protect against excessive vegetation loss. Drought early warning and infrastructure planning can be enhanced by integrating geospatial monitoring into local water governance. This research can provide practical policy recommendations at the district level by proposing adaptation strategies within the context of seasonal variability to achieve equitable, climate-resilient water security in highland Ghana.

4.6. Conclusions and recommendations

The research investigates multiple essential issues related to water resources and collection systems in Abetifi town, Kwahu East district. Seasonal variations worsen water shortages because households must rely on more challenging sources, pay more, and walk farther in the dry season. Boreholes and rainwater-harvesting methods control the water supply landscape throughout Abetifi, even though contemporary water solutions are used sparingly. Research outcomes demand strategies that combine different water security initiatives to enhance water security in plateau regions.

Based on the analysis of research outcomes and findings, several actions should be implemented.

1. Local Government and District Assemblies need to invest money in creating piped water systems combined with storage facilities to provide steady water delivery. Maintaining boreholes and water sources regularly is a priority because it helps reduce breakdowns.

2. Non-governmental organisations, along with development partners, should provide financial support and training for affordable modern irrigation technologies while improving water filtration systems so they work alongside traditional methods.

3. Water User Associations, together with local leaders, should develop community-led water distribution systems which provide fair water access while stopping conflicts.

4. The Ministry of Sanitation and Water Resources must create policies to safeguard water security for plateau territories by developing necessary infrastructure while creating climate adaptation approaches.

5. Academic research institutions together with universities should carry out advanced research on water extraction methods that match plateau ecological characteristics while assisting their practical deployment.

6. Private Sector and Water Vendors should unite with local authorities for improving water distribution networks and supporting cost-effective water prices throughout dry periods.

4.7. Practical implications and policy gaps

The research presents a pragmatic mixed-methods design that integrates household survey data with satellite-based NDWI and LULC analyses to estimate seasonal water stress and human adaptation in plateau settings. This method demonstrates that spatial evidence can supplement social data to guide targeted water interventions. The results demonstrate significant policy gaps in Ghana's current Water Policy and Community Water and Sanitation Strategy, as the country fails to distinguish between plateau and lowland communities. The lack of local hydrogeological planning, unregulated borehole drilling, and weak implementation of rainwater harvesting continue to undermine household resilience. Policymakers and

district assemblies can utilise the synthetic framework used in this study to develop monitoring approaches for seasonal water changes, encourage cost-effective rainwater reservoirs, and focus specific water infrastructure projects on plateaus to manage supply sustainably.

5. Disclosure statement

No potential conflict of interest was reported by the authors

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