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Evaluating hydrological dynamics and water quality in agricultural landscapes in Ghana's Forest Transition Belt: A Citizen Science Approach

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SUMMARY

Food system transformation is intrinsically tied to effective land and water resource management, especially in the regions facing competition among various land uses. The Ahafo-Ano Southwest District in Ghana exemplifies this complexity, with agriculture, mining, and agroforestry practices competing against one another for arable land, impacting the local food system and contributing to water resource degradation. This study investigates the quantity and quality of water in the Mankran watershed, employing a participatory approach through citizen science to address the increasing challenges within the Ahafo-Ano Southwest district. To conduct this investigation, a team of seven citizen scientists, including four women, was carefully selected from the local community, and equipped with the training to monitor water resources effectively. The Mankran watershed, within the Ahafo-Ano District, was chosen for its strategic representation of different land-uses that affect water resources. The study focused on three distinct riparian communities: Mmrobem, representing the upstream with agroforestry as the predominant land use; Barniekrom, representing the midstream with agricultural activities prevailing; and Kunsu, representing the downstream with mining activities as the predominant land use.

Installation of staff gauges at midstream and downstream locations facilitated streamflow measurements, while manual rain gauges were deployed in each community for comprehensive rainfall measurements. Additionally, groundwater monitoring involved the selection of two wells in Mmrobem, three in Barniekrom, and two in Kunsu. Basic hydrological variables such as daily rainfall, streamflow rate, and groundwater level, along with water quality parameters (pH, turbidity, dissolved oxygen, nitrate, phosphate, chloride, and heavy metals), were diligently measured by the citizen scientists from June to October 2023. Monthly water samples were sent to a laboratory for further technical analysis, including the determination of heavy metals. The data revealed rainfall variations impacting six-month streamflow, notably in mid-stream and downstream areas. Downstream, influenced by mining, experienced twice as more streamflow rate, indicating potential mining runoff. Water quality assessments showed pH, turbidity, dissolved oxygen, nitrate, and phosphate variations, influenced by community land use. Nitrate concentrations peaked in the rivers in June, while wells in agricultural lands showed consistently high concentrations, likely due to leaching. Phosphate concentrations increased as the rainy period progressed in streams mirroring well concentrations, signifying subsurface flow dominance. Mercury concentrations were low in surface water but four times higher in groundwater.

Despite the challenges posed by mining activities, the citizen scientists demonstrated their capacity to provide reliable semi-technical measurements comparable to standard laboratory analyses. This not only confirmed the efficacy of citizen science in environmental monitoring but also empowered these individuals to become environmental stewards within their communities. The study further emphasized the dominance of subsurface flow in the landscape, with implications for potential transport mechanisms for water quality in the landscape. The water quality index indicated poor conditions across all study sites, emphasizing the urgent need for a comprehensive integrated landscape management plan. This plan must consider the role of subsurface flow to safeguard environmental resources, enhance water quality, and protect human health. The commitment of all stakeholders is also paramount to successfully implementing such a plan and ensuring the sustainable development of the Ahafo-Ano Southwest district.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

The incorporation of citizen science (CS) research into contemporary advanced scientific methodologies for diagnosing, investigating, and analyzing intricate issues, generating real-time evidence-based information to inform decision-making, has progressively expanded over the years (von Gönner et al. 2023). Particularly in hydrological monitoring programs, citizen science has gained prominence, addressing challenges related to continuous in-situ hydrological parameter observation across extensive temporal scales, financial constraints, and limited accessibility to targeted areas (Weeser et al. 2018). When combined with technology, the citizen science approach offers a convenient avenue for community-based participatory research, and precise data collection. Numerous citizen science approaches for water resource data monitoring have emerged globally, with a notable focus on North America and Europe (Njue et al. 2019). In these regions, community-based monitoring and citizen science play a crucial role in providing reliable data to bridge gaps and address water and development challenges (Paul and Buytaert 2018). This underscores the significance of supporting and implementing citizen science approaches in Sub-Saharan Africa.

Across sub-Saharan Africa, citizen science (CS) approaches have emerged as powerful tools for community engagement and data collection across various fields. These grassroots efforts involve local community residents actively participating in scientific research, contributing valuable insights and data that might otherwise not be readily accessible through traditional scientific channels. Some examples include the Giraff population in Kenya (O'connor et al. 2019), Malaria control in Rwanda (Asingizwe et al. 2018), and gully erosion control in Ethiopia (Buytaert et al. 2014). In each of these cases, citizen scientists collaborated with scientists to document and track local biophysical challenges. In the regions facing water quality challenges, citizen scientists have played pivotal roles in collecting water quality data to inform the water suitability for irrigation (Babiso et al. 2023). These approaches not only empower local communities but also foster a sense of ownership and environmental stewardship. By bridging the gap between scientific research and local knowledge, citizen science approaches in sub-Saharan Africa are promoting inclusive, community-driven solutions to address urgent environmental, livelihood and societal issues.

There are critiques and reservations about the reliability of data gathered by citizen scientists which are identified as significant hurdles impeding the integration of such data into decision-making processes and gradual acceptance within the scientific community (Wilson et al. 2018). There are however effective resolutions for these challenges that can be addressed through means such as the implementation of robust training programs, the incorporation of citizen science data with remote sensing data, the establishment of a clear data collection protocol, and the implementation of a rigorous verification process (Fritz et al. 2022). Moreover, in the field of hydrology, the growing accessibility of remotely sensed (RS) data faces limitations such as low temporal resolution and significant uncertainties, posing challenges to hydrological assessments (Ochoa-Tocachi et al. 2018). And citizen science can play a crucial role in mitigating such limitations and in addressing significant uncertainties.

The CGIAR Initiative on Transforming Agrifood Systems in West and Central Africa (TAFS-WCA) is improving nutrition and food security within the context of climate change in West and Central Africa through nutritious, climate-adapted, and market-driven food systems. And the initiative investigated how a locally grounded, transparent monitoring of landscape through a citizen science approach supports evidence-based management of water resources and explored the potential of citizen science in hydrological monitoring in the southern part of Ghana. In this part of the country, many river bodies and basin landscapes are severely impacted by the expansion of illegal mining activities (called *galamsey*), resulting in a direct threat to national food security (Gilbert and Albert 2016). However, the challenge of data deficiencies and limited inclusion of stakeholders from the grassroots continue to be a major concern for resource managers in alleviating the problem.

In this study, the CS approach was adopted to monitor water quantity and quality while empowering communities to address local environmental issues and promote the successful implementation of a sustainable landscape management plan. It emphasized a collaborative, inclusive model for sustainable governance, fostering community responsibility for the environment, and enhancing data collection. The hydrological monitoring program by the citizen scientists (CSs) is a comprehensive approach aimed at unraveling the differences among hydrological variables within the watershed by focusing on the key drivers that affect these variables; such as mining, agricultural expansion, and deforestation. The objective of the monitoring program is to identify and understand the variations in hydrological variables and water quality within the watershed because of the competing land uses.

Overview of the monitoring program

The citizen science (CS) approach in this landscape aims to engage citizen scientists (CSs) in a one-year intensive hydrological monitoring program for three distinct land use characteristics: forested landscape, agrarian landscape, and galamsey watershed. To investigate the extent of environmental challenges from competing land-uses on the status of water quality and quantity, seven CSs were initially selected from the district. A kick-off meeting was conducted from May 22 – 26, 2023, to initiate the program, recruit local volunteers, co-identify monitoring stations, train volunteers on local monitoring equipment, and co-install field equipment. This was followed by a comprehensive citizen science training program on June 15 and 16, 2023. Before the training, an assessment of the perception of the seven citizen scientists were performed. The majority of participants volunteered at least four times a year, with 47% volunteering at least once every month. They possessed experience in agricultural, economic, and population research, but have never been part of water research projects before. Knowledge acquisition was the driving force for participation, with 14% being driven by financial or unemployment reasons. Perceptions towards the importance of the environment and citizen science were rated high, with most agreeing that they would be personally affected if the quality of the environment declined.

Since June 2023, CSs have collected rainfall, groundwater, and surface water readings in the three study communities of Mmrobem, Barniekrom, and Kunsu. Physicochemical parameters being monitored daily by CSs included pH, turbidity, dissolved oxygen, streamflow stage, streamflow velocity, rainfall depth, temperature, and groundwater level. The results were recorded in a data logging book, and a screenshot was transmitted each day for verification and storage. Furthermore, surface water, groundwater, and rainwater samples are taken each month for extensive standard laboratory analysis, such as pH, temperature, nitrate, phosphate, chloride, turbidity, total suspended solids, mercury, and arsenic. The raw data is presented in the attached metadata Excel sheet. The CSs were also equipped with correlation charts and maximum contaminate levels or acceptable thresholds to provide basic results interpretation and predict quality. For detail information about the training of the citizens, readers can refer Adusei-Gyamfi et al., (2023).

2.0 METHODOLOGY

2.1 Study area

The target landscape for this study was the Mankran watershed in the Upper Offin Sub-basin of the Pra Basin (Figure 1). The Upper Offin watershed covers an area of 3070 km^2, draining directly to the Offin River, while the Mankran watershed covers 122 km^2. The study sites for this monitoring program were chosen to represent the different drivers of change within the micro-watershed. This includes Kunsu, which represented the impact of illegal mining drivers; Barniekrom, which represented drivers associated with agricultural expansion; and Mmrobem, which represented agricultural expansion, extensive logging, and deforestation. These competing land uses have distinct impacts on the water system, that need to be assessed to guarantee sustainable landscape management in the target district for socio-economic and ecological benefits.

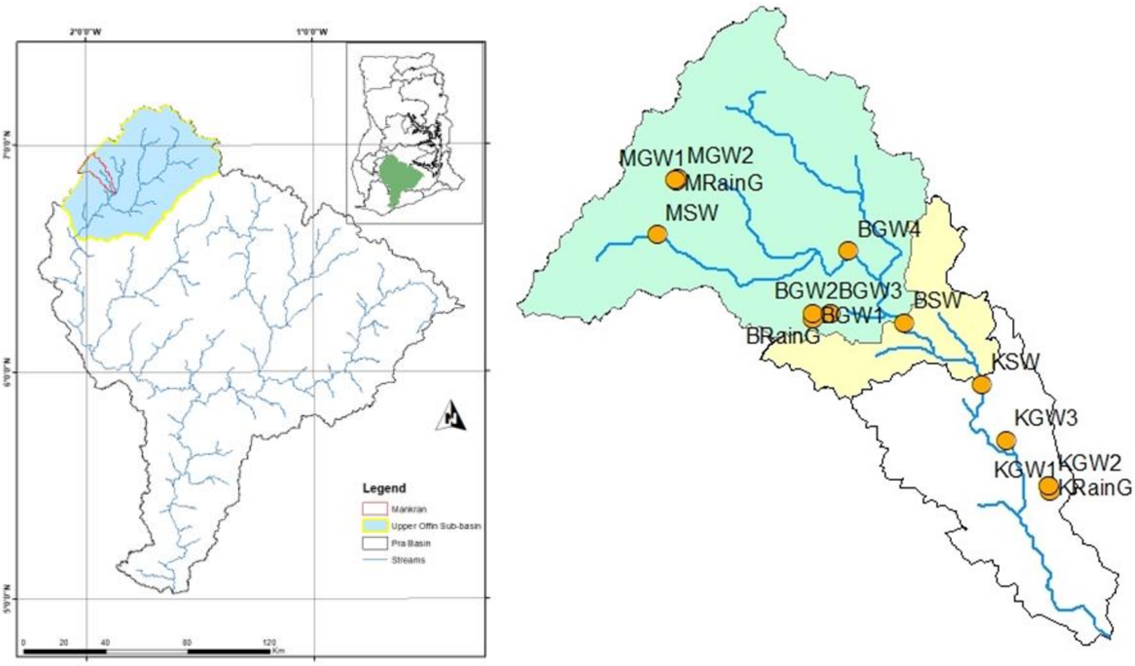


FIGURE 1. A map showing the study area and sampling points in the Mankranso watershed

Note:(MGW – Observation wells at Mmrobem; MrainG – Rain gauge at Mmrobem; MSW –streamflow gauge at Mmrobem; BGW – Observation wells at Barniekrom, BrainG – Rain gauge at Barniekrom; BSW – Streamflow gauge at Barniekrom; KGW – Observation wells at Kunsu; KrainG – Rain gauge at Kunsu; and KSW – Streamflow gauge at Kunsu).

Mmrobem – Upstream

The micro landscape of Mmrobem was primarily characterized by the presence of two significant drivers of change: agricultural expansion and deforestation. These two forces had far-reaching consequences on both the environment and the local communities. Agricultural expansion often involves the conversion of natural forest landscapes into farmland, which can lead to deforestation, soil erosion, and changes in land use. The monitoring program in the community covered two observation wells (MGW1 and MGW2 in Figure 1), one surface water location for water quality (MSW in Figure 1), and one rain gauge (MrainG in Figure 1). The observation well MGW2 was assessed for water quality, while MGW1 was assessed both water quality and groundwater level.

Barniekrom area - Midstream

The primary driver of variations in hydrological quality and quantity was agricultural expansion. The monitoring program covered one surface water location for both streamflow and water quality monitoring (BSW in Figure 1), one rain gauge (BrainG in Figure 1), and four observation wells. Three of the observation wells (BGW1, BGW2, and BGW3 in Figure 1) were sited within the community, while one (BGW4 in Figure 1) was located in the farming enclave to capture changes occurring in areas significantly affected by agricultural activities. The area of the micro-watershed outlet at Barniekrom was 74.2 km^2. The observation well BGW4 was assessed for only water quality, while BGW1, BGW2, and BGW3 were assessed for both water quality and groundwater levels.

Kunsu area - Downstream

Kunsu sampling location represented the impact of illegal mining on hydrological variables. The monitoring program covered one surface water location for both streamflow and water quality monitoring (KSW in Figure 1), one rain gauge station (KrainG in Figure 1), and three observation wells. Two of the observation wells (KGW 1 and KGW2 in Figure 1) were located within the community, while one (KGW3 in Figure 1) was in the mining enclave. These sites were strategically selected to capture the changes occurring in areas significantly impacted by illegal mining activities. The area of the Kunsu micro-watershed outlet was 90.3 Km^2.

2.2 Monitoring activities and data collection approach

This study employed a multifaceted approach that combined daily on-site analysis and data collection along with monthly sampling for expanded laboratory analyses. Daily, CSs conducted on-site environmental analysis that encompassed the use of basic field instruments to measure parameters such as streamflow stage, streamflow velocity, and water quality indicators. Samples were collected each month using plastic containers with screw caps and transported in an ice chest to the laboratory for analysis within 24 hours. Each measurement was repeated thrice, and the average of the two closest values was recorded.

Rainfall: Rainfall was monitored manually at 6 am and 6 pm from manual rain gauges installed at each of the three study locations. A 1.5L plastic bottle was stripped off its label and laterally cut into two halves. Permanent graduation marks (cm) were made on the bottom half. The top half was inverted and inserted into the bottom half and fixed to a pole installed in an open space to serve as a manual rain gauge. An automated rain gauge is being installed at Barniekrom to validate manual rain depth results. Each month, rain samples are also sent to the laboratory for chloride analysis.

Surface water: The stream stage and velocity were measured at two locations (Kunsu and Barniekrom) using manual staff gauges. Metallic poles with graduation markings (cm) on them were cemented in the rivers of two communities to serve as manual staff gauges. The surface velocity (m/s) was determined by dropping a leaf upstream of the staff gauges over a distance of 10m. The time required for the floating leave to reach the staff gauge was recorded by the CSs. The average velocity was considered to be 0.85 times the surface velocity (Costa et al. 2006). The discharge was calculated by multiplying the average velocity with the cross-sectional flow area, which was once measured, except for Kunsu, where the measurement was retaken due to the alteration of the river channel by illegal small-scale mining activities. The stage-discharge relationship was developed, checked again, and recorded at least once after major flow events. The measurement was done once daily, except after a stormy event, when at least one additional measurement was performed.

Groundwater level: This parameter was measured daily with the help of a graduated electrical cable connected to an AC clamp meter at one end and opened at the other end. The working principle was that once the exposed cable touched the water, ions in the water served as a bridge and caused current flow, which was recorded by the voltmeter. The open exposed cable (0 cm mark) was lowered gradually into the observation well until there were readings on the voltmeter. The water level was measured by noting the readings on the meter at the ground level. The cable was pulled out gradually until the voltage dropped significantly. The two readings were averaged to represent the groundwater level. Two Heron Skinny Dipper, water level meters were used twice a week to validate the manual water level measurements at Kunsu and Barniekrom.

Turbidity: The turbidity of the surface water was measured with the help of a home-built Secchi disk by the citizens every day (Appendix A). The turbidity of surface waters was also measured in the laboratory each month using a calibrated turbidimeter. This device measures the suspended particles in a sample with a beam of light and a light detector set at 90° from the original beam. The amount of light reflected for a given density of suspended particles depends on its properties, such as shape, color, and reflectivity.

A 20 cm diameter white circular disk was divided into four quadrants using a masking tape. Two opposite quadrants were colored black, and a hole was drilled at the center of the disk. A graduated rope was attached to the disk at the center while a stone was tied at the end of the rope that emerged at the back of the disk to increase its density. The turbidity measurement was done daily, with the CSs positioned at or close to the center of the stream. The disk was slowly lowered into the stream until it disappeared. The depth of the cord that was immersed in the water was noted before the disk was slowly pulled up until it was seen again. The new depth on the cord was noted, and the average was recorded.

Dissolved oxygen: The dissolved oxygen concentration of the water was determined by the Winkler method (Pomeroy and Kirschman 1945; Carvalho et al. 2021). A sample bottle was filled with water with no headspace. The dissolved oxygen in the sample was then "fixed" by adding a series of reagents that form an acid compound that was then titrated with a base. A color change at the endpoint signified neutralization. A detailed step-by-step procedure for this method and any other measuring parameters was provided to the CSs.

Temperature and pH: The temperature and pH of surface waters are recorded daily by CSs using handheld multiparameter water quality meters. The tip of the electrode of the calibrated (verified periodically) device was uncapped and rinsed with deionized water. The parameter to be measured was selected before the electrode was fully immersed in the sample (but did not touch the contain walls) to begin measurement. The electrode was rinsed after reading, and the data was recorded. The water quality parameters were taken daily at the same time to nullify the impact of temperature variations on measurements. An online platform was created where CSs uploaded their recorded data daily for verification and backup.

FIGURE 2. Different monitoring activities carried out by citizen scientists

In addition to the measurements performed by CSs, rainwater, observation wells, and surface water samples were sent monthly to the Environmental Laboratory at KNUST for extended analysis, such as pH, temperature, nitrate, phosphate, turbidity, total suspended solids, chloride, mercury, and arsenic. These measurements were done using more sensitive instruments than the field ones used by CSs.

Total suspended solids: A known volume of the homogenized sample was filtered through pre-weighed filter papers of 0.45µm size. Depending on the turbidity of the sample, more than one filter paper was used. After filtration, the filter paper was kept in an airtight desiccator until dried. The mass of the blank filter paper was then subtracted from the mass of the desiccated filter paper to obtain the mass of the suspended solids. The mass of the suspended solids was then divided by the volume of filtered water to obtain the total suspended solids in mg/L.

Nitrate: Nitrate concentration in samples was analysed in the laboratory using an Agilent Cary 60 Ultraviolet Spectrophotometer following standard method 4500-NO_3^- (Rice and Bridgewater, 2012). Two wavelengths at 220 nm and 275 nm were measured to obtain NO_3^- concentration and eliminate the interference due to dissolved organic matter (Causse et al. 2017). Distilled water was used to prepare calibration standards from dried potassium nitrate. The NO_3^- calibration curve followed Beer Lambert's law up to 11 mg N/L. Absorbance was read against distilled water set at zero absorbance, while sample concentrations were obtained directly from a standard curve.

Phosphate: Phosphate concentration in samples was also analyzed in the laboratory using the Ultraviolet Spectrophotometric method following the standard method 4500-P Phosphorus (Rice and Bridgewater, 2012). Samples with pH above 10 are conditioned to reduce the pH by the addition of HCl. A 4 ml molybdate reagent and 0.5ml stannous chloride reagent were thoroughly mixed to develop a color which was measured photometrically at 690 nm and compared with a calibration curve using distilled blank water.

Heavy metals: Arsenic and Mercury were measured with an Agilent 4210 MP-AES G8007A Microwave Plasma Atomic Emission Spectroscopy (MP-AES), an atomic emission technique that identified an analyte by its electromagnetic spectrum (Li et al. 2013). Once an atom of a specific element was excited using microwave energy from an industrial magnetron, it emitted light in a characteristic pattern of wavelengths as it returned to the ground state. The temperature of the nitrogen-fueled microwave plasma equipment can reach 5,000 K, where atomic emission is strong, producing excellent detection limits and linear dynamic range for most elements. Emission from the plasma was directed into a fast-scanning monochromator. The selected wavelength range was imaged onto the high-efficiency Charged Coupled Device detector, which simultaneously measured spectra and background for optimum precision. The MP-AES quantified the concentration of an element in a sample by comparing its emission to that of known concentrations of the element, plotted on a calibration curve.

Water Quality Index: In this study, the water quality index (WQI) endorsed by the Canadian Council of Ministers of the Environment was adopted because of its wide usage and reliability (Cash and Wright 2001). This index was calculated based on the frequency and extent to which parameters measured for surface water and observation wells exceeded their respective guidelines set by the World Health Organization. The Canadian Water Quality Index (CWQI) equation was calculated using three factors: scope, frequency, and amplitude.

$$WQI = \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right) \qquad \text{Equation 1}$$

Where 'WQI' represents Water Quality Index, 'F_1' represents Scope, 'F_2' represents Frequency and 'F_3' represents Amplitude.

A number within the range of 1 to 100 was generated, with 1 being the poorest and 100 indicating the best water quality. In addition, there were breakdown ranges with the designation to classify water quality as poor, marginal, fair, good, or excellent.

3.0 RESULTS

The parameters being measured were selected based on their importance in understanding the hydrology and water health from the computing land uses in the landscape. The parameters to be measured by CSs were less technical, cost-effective, and did not require sophisticated equipment, making it possible for CSs to measure with little training. This ensured the sustainability of the monitoring program as local communities would not be financially and technically burdened to continue after the project's lifespan.

3.1 Hydrological data

Rainfall depth: Figure 3 shows the daily rainfall amount over the six-month period from June to October 2023, in the three landscapes. From the given data, it can be observed that the highest rainfalls were recorded between June/July and September/October, which corresponds respectively with the major and minor rainy seasons in southern Ghana.

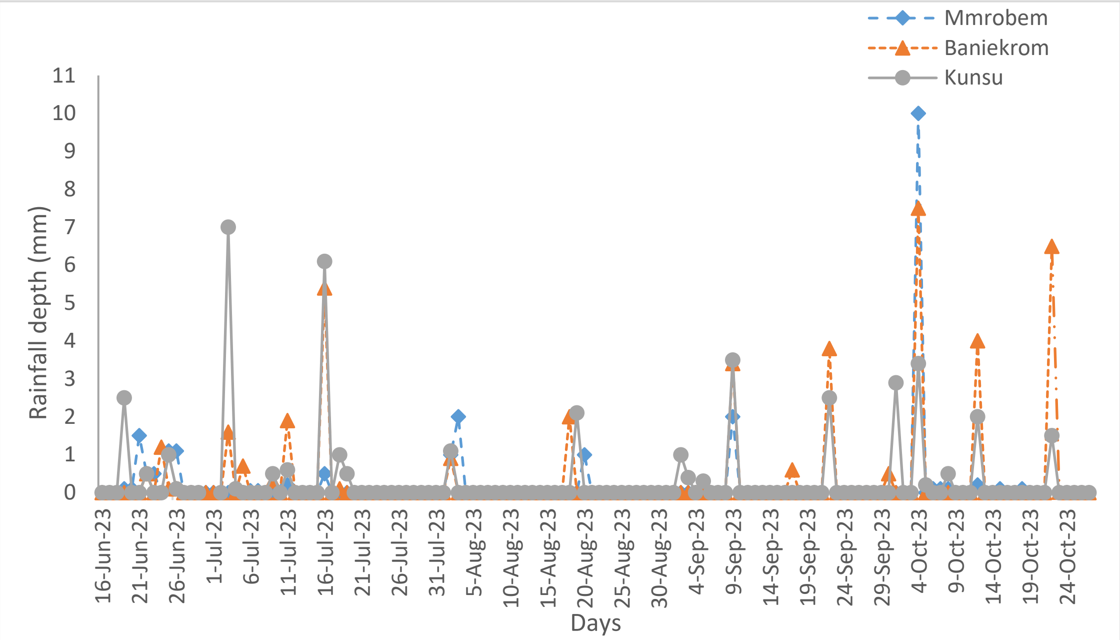


FIGURE 3. Rainfall depth recorded at each landscape location during the six-month period

During the major rainy season, the highest rainfall depth was recorded on July 3, while the highest rainfall depth for the minor rainy season was recorded on October 4. Kunsu recorded the highest amount of rainfall in a single day during the major rainy season, while Mmrobem recorded the highest rainfall in a single day during the minor rainy season. Cumulatively, Kunsu recorded the highest rainfall during the major rainy window, while Barniekrom recorded the highest rainfall in the minor rainy season. Considering the entire period under review (June – October), the total rainfall depth recorded at Barniekrom was comparable to that recorded at Kunsu, 665 mm and 720 mm, respectively. Mmrobem recorded 480 mm, the least rainfall depth, about 30% less than what was recorded in the other study communities.

Daily streamflow and rainfall: The stage-discharge relationship for the two outlets at Bainiekrom and Kunsu was established by simultaneously measuring the stage and discharge through velocity measurements (refer to Appendix A). These relationships at each of the two sites were used to compute the streamflow rate (Figure 4). Considering the daily rainfall depth recorded at Kunsu and Barniekrom and the streamflow through the respective outlets, it can be observed that, with the same amount of rainfall, the flow at Kunsu was higher than at Barniekrom. Whereas the highest flow recorded for Barniekrom was 1.3 mm/day, that recorded for Kunsu at the same time was 10 mm/day, representing an over seven-fold increase (Figure 4). These high flows were experienced in October, when the highest daily and monthly rainfall was recorded for the entire study period at 212 mm. In the major rainy season, the highest monthly rainfall was recorded in July at 153 mm. The Kunsu outlet had the highest monthly flow in the minor rainy season, recording 20.2 and 73 mm for September and October, respectively, compared to 22.0 and 55.7 mm recorded at Barniekrom for the same months.

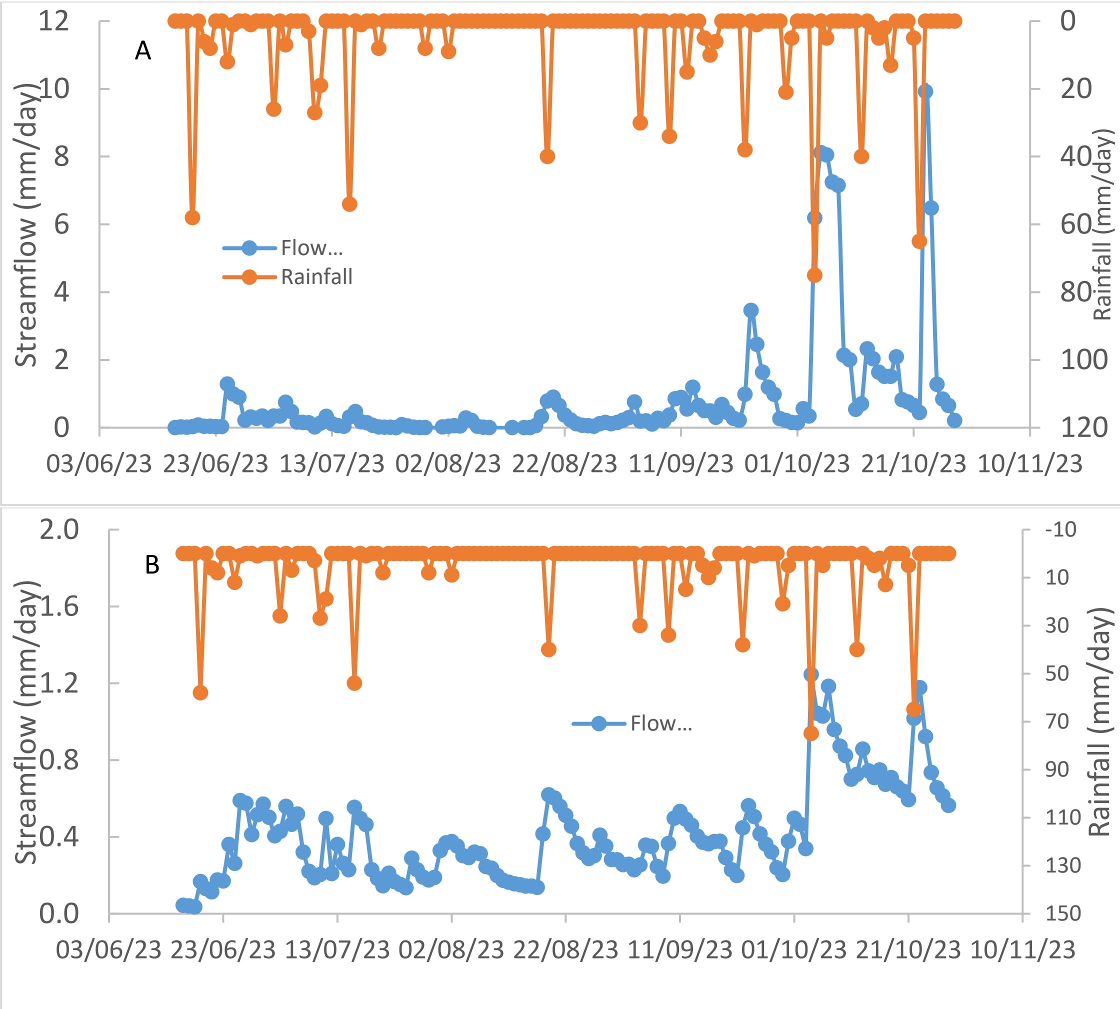


FIGURE 4. Daily streamflow and rainfall relationship at (a) Kunsu outlet and (b) Barniekrom outlet

The monthly runoff coefficient of the studied watersheds is presented in Figure 4. In this calculation, runoff refers to both surface and subsurface runoff, and the coefficient is the proportion of the monthly runoff with its corresponding rainfall. The average monthly runoff in June in both landscapes was the same, at 5%. The runoff coefficient for Barniekrom increased from June (5%) to October (10%), and for August, a 20% increase was observed. For

Kunsu, it showed the same trend, increasing from 5% in June to 35% in October. This trend suggests that the response of the landscape's top rainfall is dependent on soil water storage, not rainfall intensity (Tilahun et al. 2016). This has also an implications on water quality constitutes transport in the landscape that will be discussed in later sections.

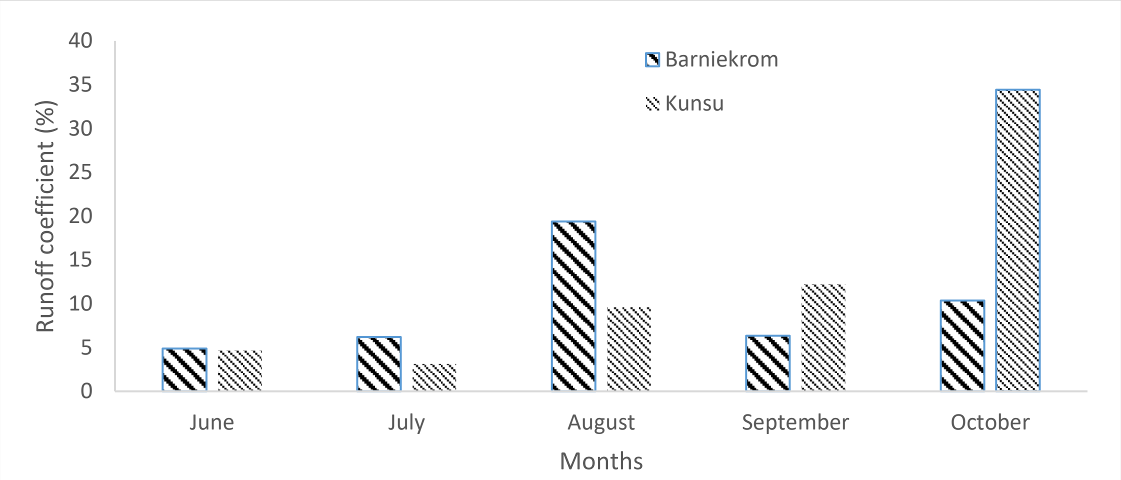


FIGURE 5. Runoff coefficient of monthly streamflow and rainfall at Barniekrom and Kunsu

Groundwater level: The groundwater depths of the Mankran watershed for 6 observation wells are presented in Figure 6. During the six-month period, the water level of the wells varied between 0.7 m and 13 m deep from the ground surface. Four wells (MGW1, BGW2, KGW1, and KGW2) from all landscape positions were within the depth of 4 m, indicating that the groundwater level was close to the ground surface during the rainy period. Only two wells (BGW1 and BGW3) located at Barniekrom were more than 7 m deep during this period. In general, the observation wells at Barniekrom recorded the highest depth, followed by Mmrobem. Observation well 1 at Barniekrom (BGW1) recorded the highest average depth of 13.6 m, while the other two wells in the communities had average depths of 7.6 m and 3.8 m for BGW3 and BGW2, respectively (Figure 6). The observation well at Mmrobem had an average depth of 2.6 m, while the observation wells at Kunsu wells recorded the lowest average of 1.5 m and 2.3 m for KGW1 and KGW2, respectively. The shallow depth of the observation wells at Kunsu was not surprising, considering their locations at the valley bottom of the landscape. The groundwater level fluctuation during the period was between 0.3 and 2 m. It is important to capture the water level during the dry period of the year.

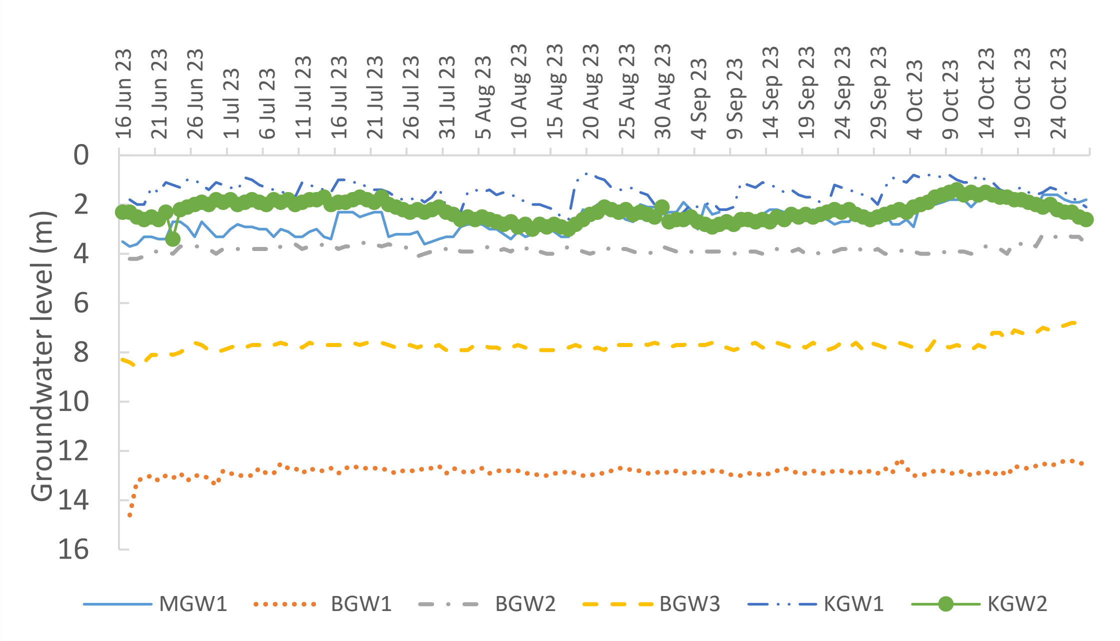


FIGURE 6. Groundwater level for wells at study sites

Note: MGW – Observation wells at Mmrobem; BGW – Observation wells at Barniekrom; and KGW – Observation wells at Kunsu.

Since September 16, two Skinny Dippers groundwater level sensors have been deployed to validate the daily groundwater levels recorded by the manual AC clamp device. The groundwater level sensor is used twice a week to validate the manual results. Comparing both sets of results, it was observed that there was a good fit with a correlation of about 99% and an average difference of 3%. A chi-square p-value of > 0.05 confirms that, statistically, there is no difference between the observed and expected values. This cost-effective technique for measurement adopted by the CSs is closely comparable to standard techniques. The technique can, however, be finetuned to reduce further the 3% variation observed.

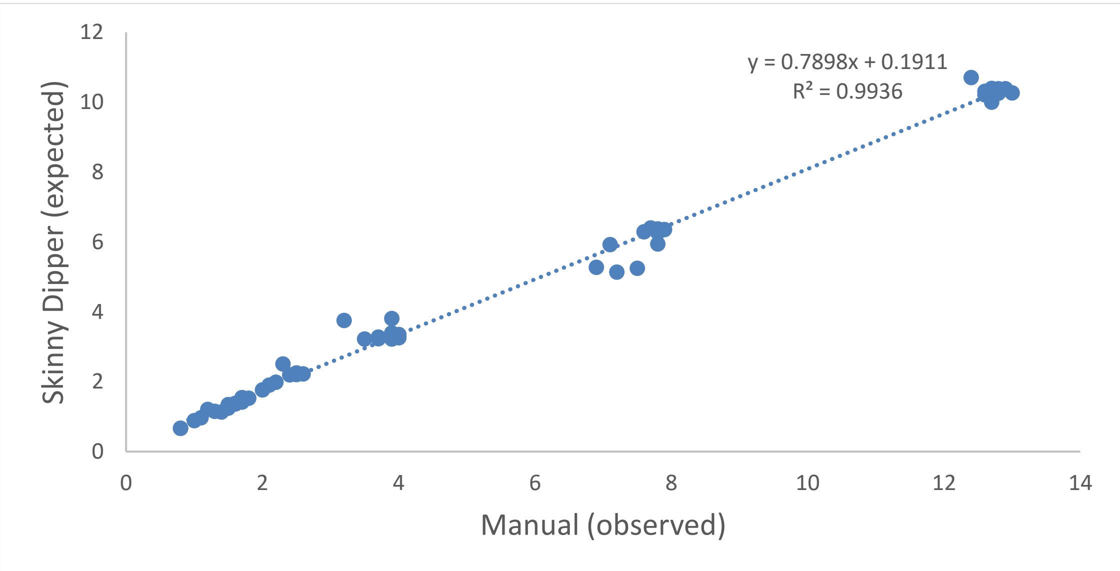


FIGURE 7. Comparison between manual and automatic groundwater dippers

3.2 Water quality

pH: The pH was within the normal pH range for surface water systems (6.5 to 8.5). The results of the CSs were corroborated by the laboratory analysis, where the pH for surface water under the reporting period is between 7.03 and 7.42 (Figure 8). The laboratory and CS results show a relatively stable pH in the stream at Mmrobem. The six-month average pH was 7.3 from the lab, while it was 8.3 from the citizen at Mmrobem. Similarly, the average pH from the lab and citizens were 7.1 and 6.8, respectively, at Barniekrom and 7.1 and 7.2, respectively, at Kunsu. The measurements are comparable, despite some differences. The extreme measurements recorded at Kunsu and Barniekrom in September were due to an experimental error, which was subsequently resolved by recalibrating the measuring device.

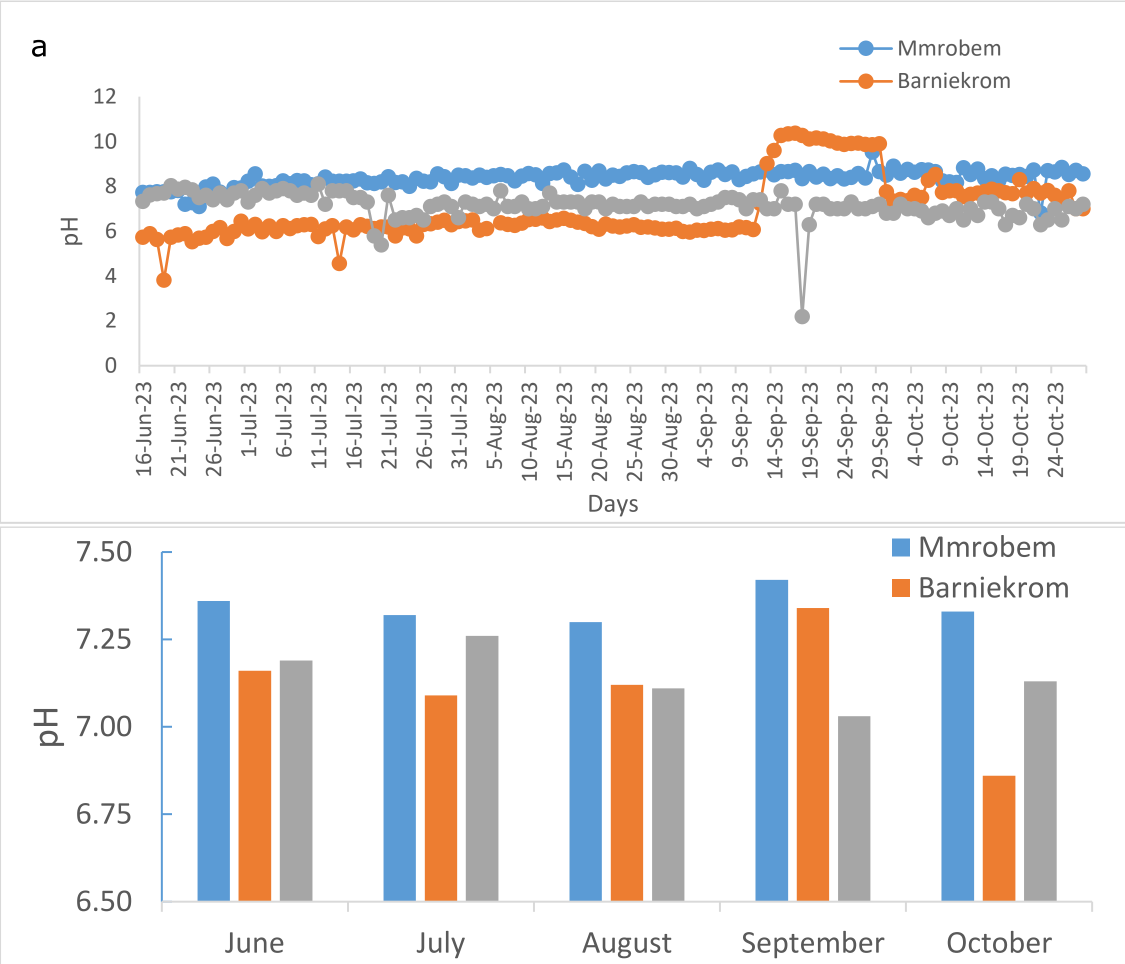


FIGURE 8. pH of surface water (a) measured by CSs (b) measured by the laboratory

Temperature: Since temperature also strongly influences pH, daily measurements are done at a specific time for consistency. Like pH, the results of temperature were all within the normal range for tropical climates (23 – 26 ºC).

Turbidity: Figure A4 in the appendix shows that the surface water at Kunsu was more turbid than that of Mmrobem and Barniekrom. This is expected since the activities of mining in water bodies result in the disturbance of the sediments. The fine sediment particles take time to settle and would readily be detected by the daily monitoring of CSs using Secchi discs (Appendix A, Figure A4).

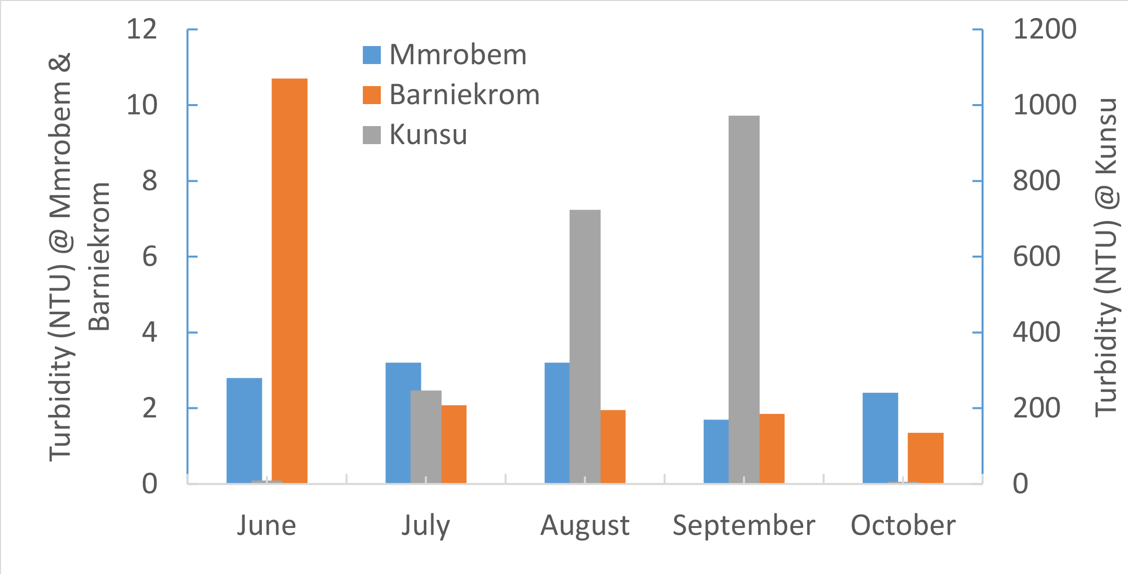


FIGURE 9. Turbidity of surface water using a turbidimeter

The higher values recorded at Mmrobem in the month of June in Figure A4 were due to human error and were resolved following further capacity development of the CS on the usage of the Secchi disk. Barniekrom shows an increase in turbidity during specific periods of the minor rainy season, especially following stormy events. When a turbidimeter was used to analyze the monthly samples in the laboratory, it was confirmed that, generally, the Mmrobem stream was the least turbid, followed by Barniekrom (Figure 9). The month-on-month increment in Kunsu from June to September was 96%, 66%, and 26%, respectively. Considering the increased activity of small-scale mining on the stream, there is an expectation for a further increase in October.

Dissolved oxygen (DO): The DO concentration for all surface water measurements was between 0.5 mg/l to 3.0 mg/l. The values for Barniekrom and Mmrobem appear stable, unlike Kunsu, which has high fluctuations. The Kunsu samples recorded the highest cumulative DO content, which is unexpected considering the high turbidity and aesthetic nature of the stream. Mmrobem recorded the least DO concentration, though an increase has been observed since September.

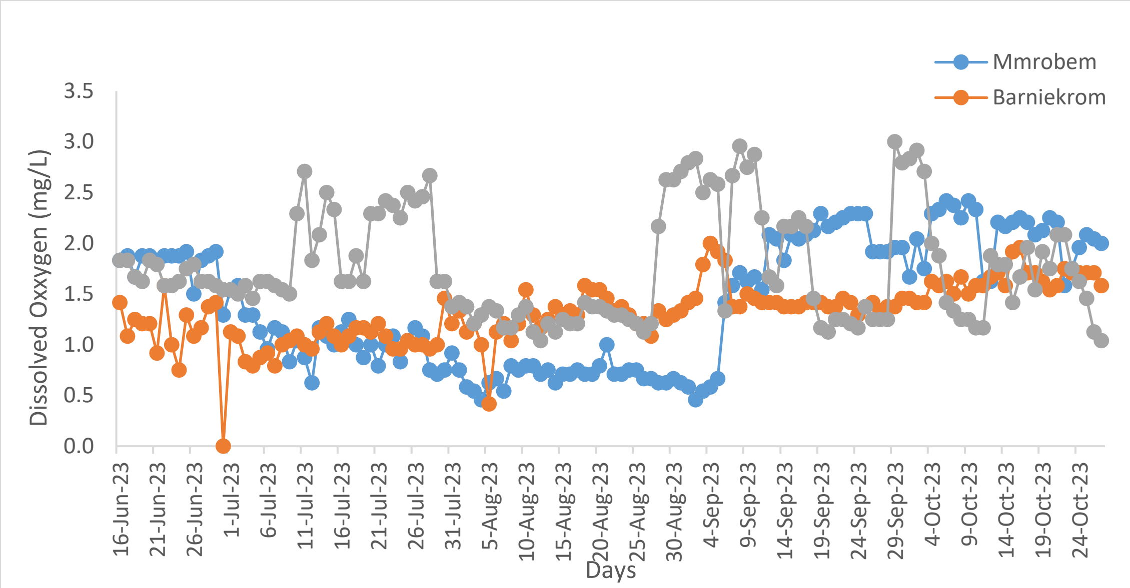


Figure 10: Dissolved oxygen concentration in surface water

Total suspended solids (TSS): The total suspended solids in the surface water sampled for the period under review ranged from 1 to 2300 mg/l, with Kunsu recording the highest suspended solids for all months (Figure 11). The levels of suspended solids in samples among months, in decreasing order, were September, October, July, June, and August. For some months, the suspended solids in the Kunsu sample were more than 50% of what was recorded in the other communities. The high levels of TSS recorded in September and July are likely due to the heavy rains, which transport a lot of runoff substances into the river body. The results of TSS obtained in the lab were confirmed by a supplementary analysis of the total dissolved solids, with Kunsu recording the least.

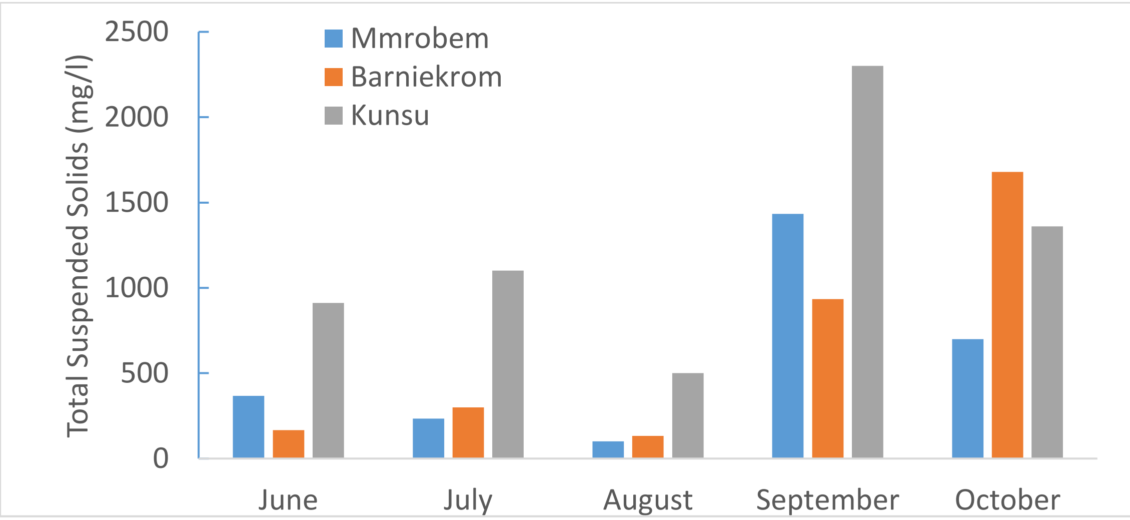


FIGURE 11. Total suspended solids (TSS) in surface water samples

Nitrate and Phosphate: Considering the period under review, the month of June recorded the highest nitrate concentrations in all study communities, with Mmrobem recording the highest (Figure 12a). This elevated concentration of nitrate likely originated from cocoa farms, even though Kunsu also recorded a very high concentration. Still, it is less impacted by agriculture. In cocoa farming, inorganic fertilizer products are applied twice per year, at the beginning of the rainy season (van Vliet and Giller 2017). Subsequently, the nitrate concentration dropped by more than 50% and appeared to have stabilized for July and August. For both months, Barniekrom recorded the highest concentration. The trend was, however, different for phosphate (Figure 12b), though inorganic fertilizers contain both nitrogen and phosphorus. Phosphate concentrations in surface water ranged from 2.57 to 10 mg/l, with Kunsu recording the highest concentrations in July and August (Figure 12b).

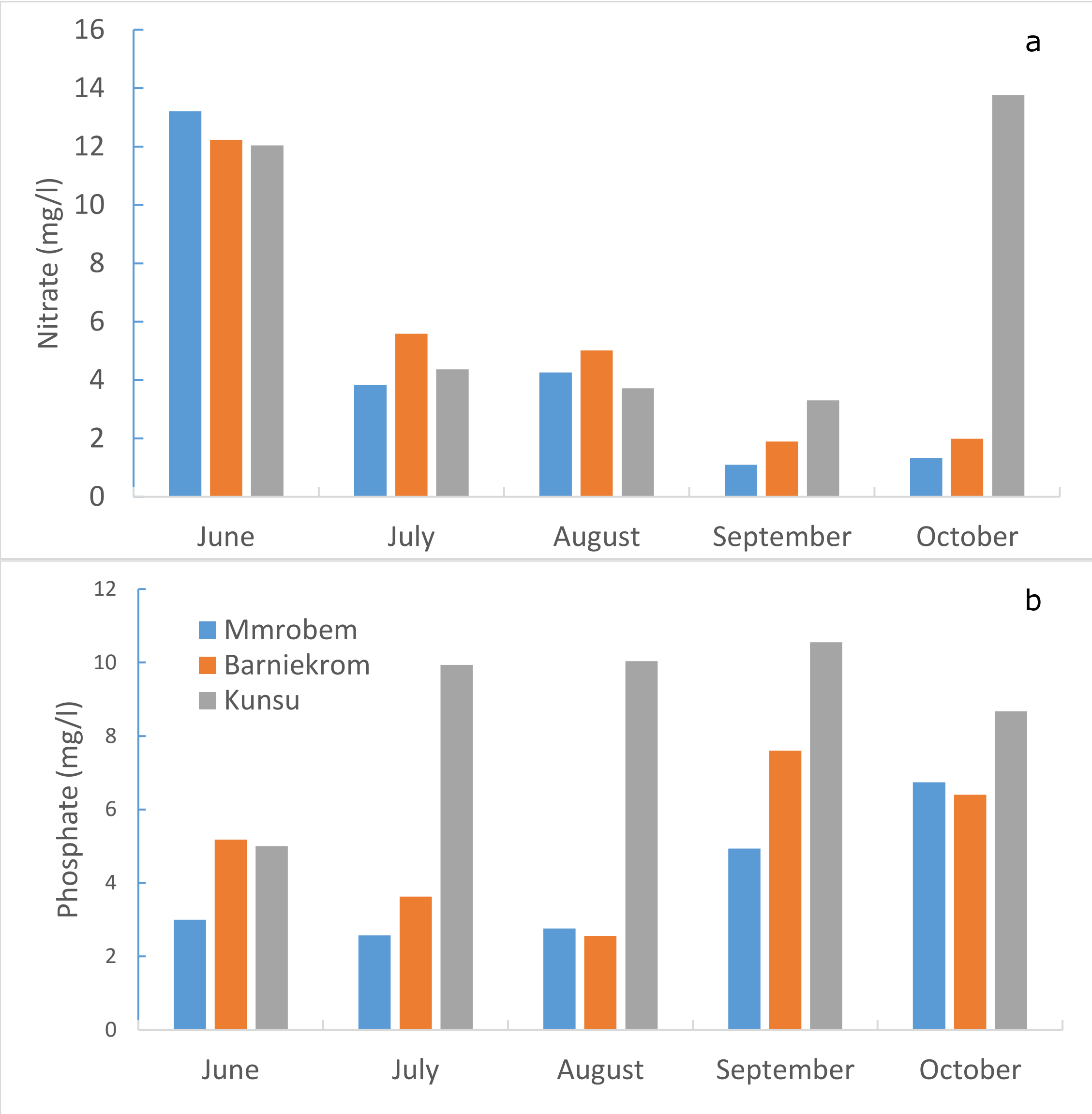


FIGURE 12. (a) Nitrate concentration in surface water (b) Phosphate concentration in surface water

Similar to the observed concentration in the surface water, all observation wells recorded high nitrate concentrations averaging about 13 mg/l for June (Figure 13a). Subsequently, there was a reduction in the concentrations recorded for Kunsu wells, while those of the other communities kept increasing. Both Mmrobem and Barniekrom are known to be very agricultural; hence, the nitrate levels in the observation wells could be due to the leaching of fertilizers from farmlands into underground water resources, although other sources could also contribute. For Mmrobem, both the hand-dug and machine-dug wells have similar concentrations of nitrate, which confirms that nitrate pollution may occur through leaching via the high drainable soil. The observation well (BGW 4) at Barniekrom, sited in a farming enclave, recorded a higher concentration than wells found within the communities.

Like the nitrate levels, the levels of phosphate in both observation wells at Mmrobem were similar in all months under review (Figure 13b). This trend was also observed in Barniekrom for both nitrate and phosphate concentrations in observation wells, which were in the increasing order of BGW1, BGW2, BGW3, and BGW4. The observation well BGW4 was on agricultural land and, hence, was more vulnerable to pollution compared to the others. The observation well KGW2 in Kunsu was close to an abandoned fishpond and scored the highest concentration of phosphate in all samples. This could be due to leaching from the pond. The dynamics of nutrient concentration are closely interconnected with both the depth of groundwater and the levels of dissolved oxygen. Oxygen in shallow groundwater can cause nitrate and phosphate levels to remain stable or increase due to agricultural runoff. On the other hand, deeper groundwater, with limited oxygen, favors denitrification, converting nitrates to nitrogen gas and reducing nitrate levels (Rivett et al. 2008). For example, BGW1 and BGW3 are deeper in groundwater level as shown in Figure 6. Correspondingly, the nitrate concentration is lower compared to the other wells (Figure 13a). Unfortunately, dissolved oxygen was not analyzed for groundwater samples; hence, the relationship between DO and nitrate concentration was not fully explored.

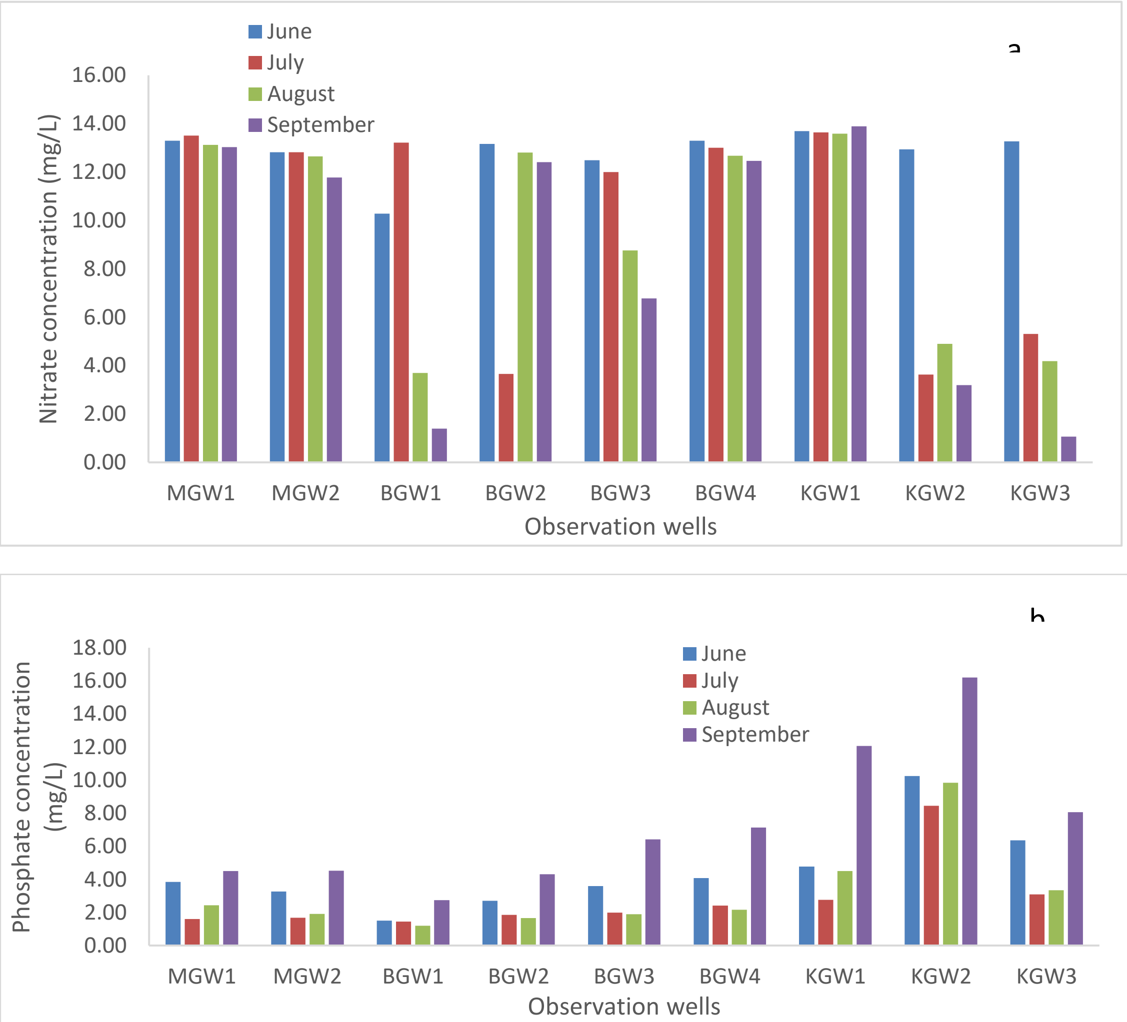


FIGURE 13. (a) Nitrate concentrations in observation wells and (b) phosphate concentration in observation wells

Note: MGW – Observation wells at Mmrobem; BGW – Observation wells at Barniekrom; and KGW – Observation wells at Kunsu

Mercury: The concentrations of mercury in the surface water samples were very low, ranging from non-detectable concentrations to 0.4 µg/l (Figure 14). In June, no mercury was detected in samples in all study communities. Trace levels were detected for the subsequent months, with Kunsu recording the least for July and August, even though it was a known mining community, while Mmrobem recorded the least for September. Considering the period under review, September recorded the lowest concentration of mercury. Generally, the concentration of mercury recorded in the observation wells is higher than in the surface water.

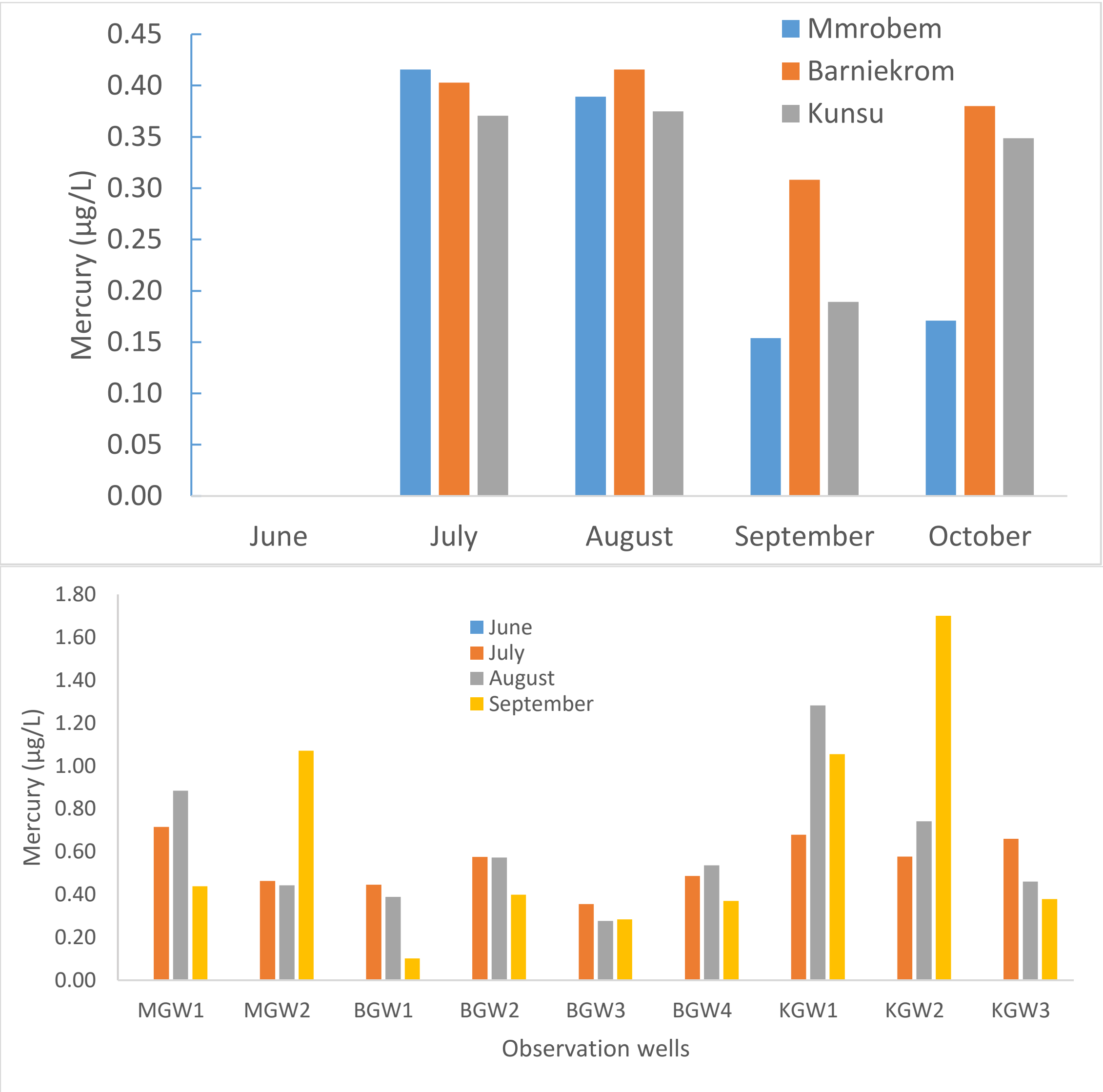


FIGURE 14. Concentration of mercury in (a) surface water and (b) observation wells

Note: MGW – Observation wells at Mmrobem, BGW – Observation wells at Barniekrom, and KGW – Observation wells at Kunsu

Like the surface water samples, no mercury levels were detected in the groundwater samples for June. For the subsequent months, there was no well-defined pattern among the different wells, though cumulatively, Barniekrom samples had the lowest mercury levels. Surprisingly, KGW3, which is in the mining enclave recorded the lowest concentrations among all samples from Kunsu. The relatively higher concentration of mercury in the groundwater than in surface water also confirms the dominance of subsurface flow in the landscape.

Arsenic: There was a progressive month-on-month increase between June and August (Figure 15). However, like mercury, the concentration of arsenic in samples for September was the lowest. These trace concentrations are likely to be from natural sources and not from mining. Like the surface water samples, the levels of arsenic in the groundwater samples for September were the lowest during the study period, while the highest levels were recorded in August. Like mercury, the levels of arsenic in samples did not show any well-defined pattern among the different observation wells.

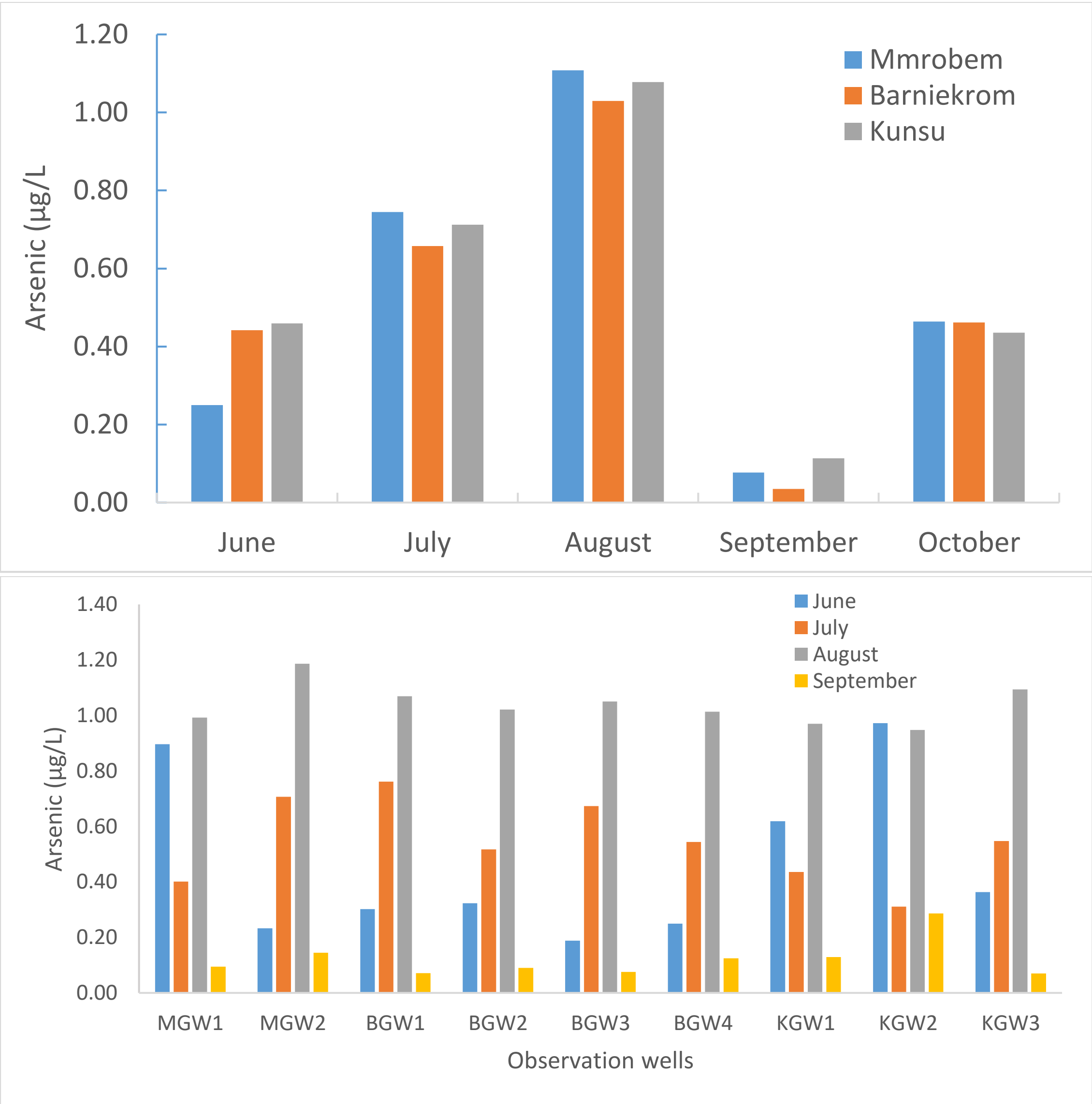
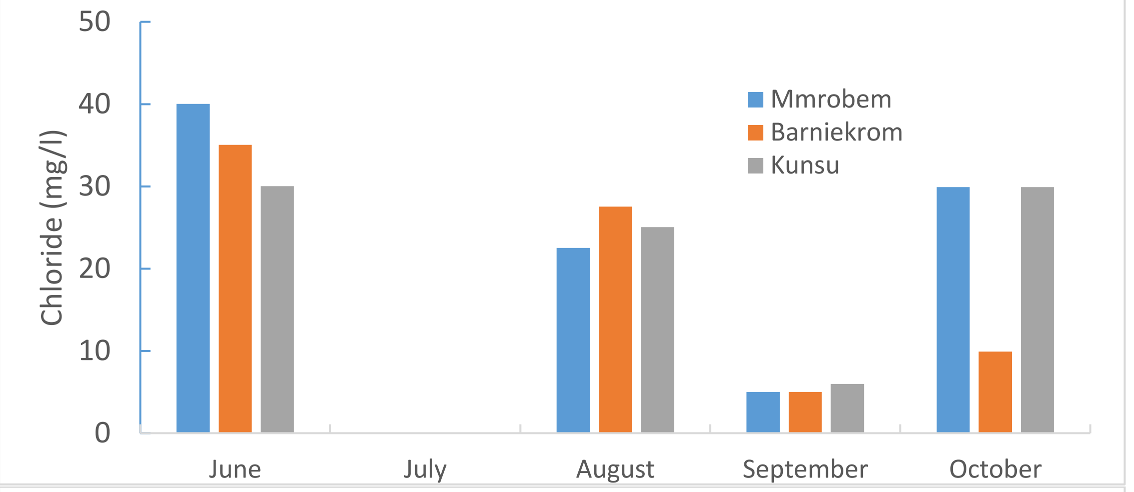
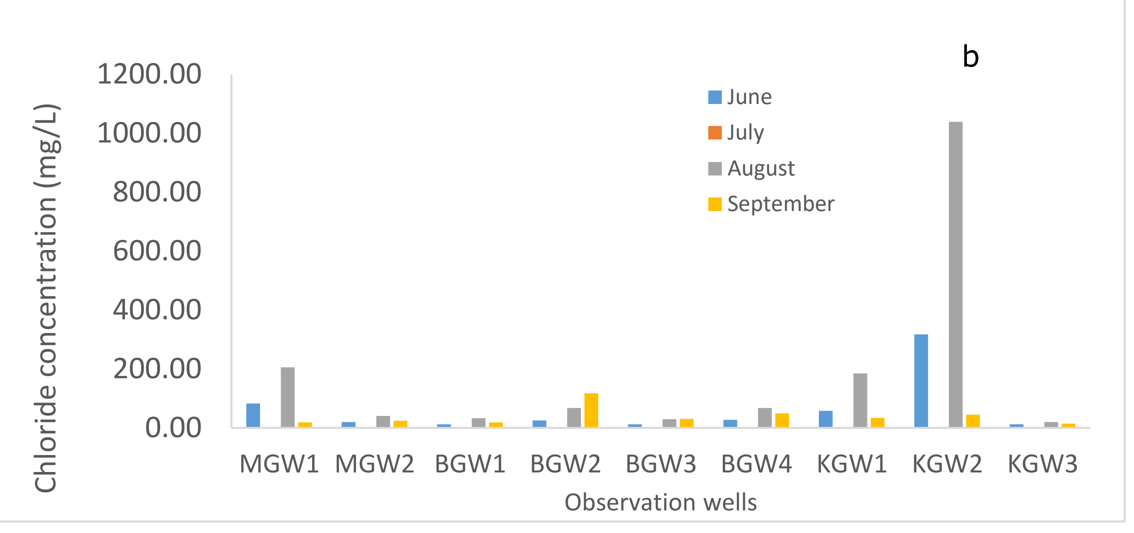


FIGURE 15. Arsenic concentrations in (a) surface water samples and (b) observation wells

Note: MGW – Observation wells at Mmrobem, BGW – Observation wells at Barniekrom, and KGW – Observation wells at Kunsu

Chloride: Generally, the chloride concentrations in rainwater decreased from 40 mg/l to 5 mg/l in the period from June to September (Figure 16a). For groundwater wells (Figure 16b), there was an increasing trend from June to September, where the average concentration was 65 mg/l for Mmrobem, 40 mg/l for Barniekrom, and 190 mg/l for Kunsu. Surface water samples saw a progressive increase from month to month (Figure 16c) within a range of 7.49 mg/L to 60 mg/l. No measurement was done for July due to suspected contamination of samples during storage. June recorded the least cumulative concentration. Overall, Kunsu surface water samples had the highest chloride concentrations, followed by Barniekrom. These data will be useful for future discussions on the nitrate pollution pattern in the landscape and to estimate the groundwater recharge using chloride mass balance, assuming there is a balance within the hydrological cycle.





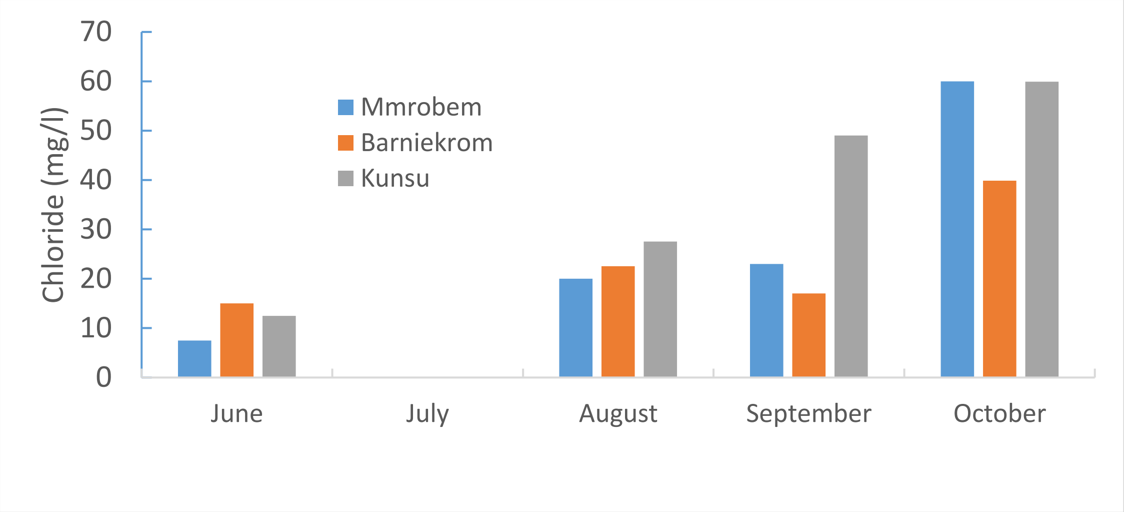


FIGURE 16. Chloride concentrations in (a) rainwater, (b) observation wells, and (c) surface water samples

4.0 DISCUSSIONS

4.1 Hydrology of the landscape

In the Mankran watershed, the average annual count of rainy days within the study period (June to October) was 45, resulting in an average rainfall depth of 621 mm. For the entire reporting period, Mmrobem recorded the least rainfall depth, representing about 70% of what was recorded in the other study communities. This is surprising for an area known to be bordered by a forest reserve. This low rainfall depth could be due to the variation in agroecological zones in the landscape. From the stream stage data, the stream level recorded at Barniekrom was higher than at Kunsu. Comparing the rainfall trend to that of the stream stage, it was observed that there was a correlation between the rainy days at Barniekrom and the corresponding stream levels recorded for the day. However, at Kunsu, there is a delay between when the rainfall peaks and when it reflects in the stream. This is not surprising since the watercourse at the Barniekrom site has been less influenced by human activities.

When the rainfall depth for each month and streamflow rate were used to estimate the runoff coefficient, it was observed that the runoff coefficient at Kunsu for October was three times greater than at Barniekrom (Figure 5). The higher flow recorded at Kunsu is not due to flash flooding during stormy events, as it does not correlate with the monthly total suspended solids recorded. It is most likely due to an alteration of the river channel by the activities of illegal small-scale miners. The diversion of the watercourse by galamseyers on the Mankran River upstream of Kunsu heavily impacts its discharge. These anthropogenic interferences may have modified the vegetation, slope, contribution area, and permeability (Machado et al., 2022). However, the increasing runoff coefficient from July to October indicates that subsurface flow likely dominates in the landscape (Tilahun et al. 2016).

4.2 Water quality of the landscape

Aesthetically, the color of the river at Kunsu is milky. Further, complementary analysis of the nature of solids responsible for the high turbidity of the stream at Kunsu shows that it is more likely to be due to the presence of suspended particles since dissolved solids are very low. The low total dissolved solids highly correlate with the low electrical conductivity. Furthermore, since Kunsu is downstream, its stream receives lots of runoff suspended particles, especially after a stormy event. This is expected to be why the turbidity values reported by CSs for Barniekrom in the minor rainy season increased. The high suspended solids (> 100 mg/l) recorded in almost all communities indicate the possibility of sediment exports in high quantities (Bessah et al. 2021). However, it must be noted that the immediate climatic conditions before sampling the monthly samples can affect the turbidity; hence, the daily results of CSs better represent the surface waters' condition.

Although the dissolved oxygen (DO) content of all waters was lower than the threshold for healthy waters (6.5 – 8 mg/l) (Best et al. 2007), Kunsu samples surprisingly had the highest DO amidst their high turbidity. At the same time, Barniekrom showed comparatively steady DO content. The elevated DO levels in Kunsu seem counterintuitive, as illegal mining is often associated with water pollution, and increased turbidity reduces dissolved oxygen. This observation can be attributed to the high stream velocity (more than twice what was recorded for other communities) resulting from environmental disturbances caused by mining activities. The high flow rate increases turbulence and aeration in the water, thereby leading to higher DO concentrations. Hence, the stagnant nature of the stream at Mmrobem could explain why, cumulatively, it has the lowest DO compared to the other sites, though it has the least turbidity. It must be noted that the analysis of DO is quite technical, and an error in sampling can falsify results. However, supplementary DO measurements on the monthly samples in the laboratory confirm the trend reported by the CSs. Thus, CSs can develop the capacity to perform some semi-technical measurements when given the right training.

The natural level of nitrate in surface water is typically less than 1 mg/l, while the threshold of phosphorus in surface water is 0.01 mg/l (APHA, 1992). Thus, none of the samples analyzed (Figure 12 and Figure 13) were below the nitrate threshold. The concentrations in this report are higher than those in the report by Bessah et al. (2021) for the offin sub-basin at Adimbera. Figure 12 shows that the nitrate concentration of streamflow in June was higher than the WHO limit of 10 mg/l. For the remaining months, it is below the permissible limit of WHO and usually 50% of the groundwater level concentrations shown in Figure 13. Excess nitrates around 10 mg/l in groundwater can cause a significant reduction in the concentration of dissolved oxygen (hypoxia) and can become toxic to warm-blooded animals. It was observed that even for samples where higher nitrate levels were recorded, it did not translate into a corresponding increase in phosphate.

However, the interesting result is that the phosphate concentrations in groundwater and surface water are in a similar order of magnitudes, indicating that the flow paths in the landscape are dominated by subsurface flow. If overland flow by surface water is dominant, the phosphate concentration in the streams could have been higher than the groundwater concentrations. To understand this link, we must first examine hydrology and the flow pathways that water takes. There are no defined channels on the hillsides of the Mankran watershed; thus, all rainfall on the uplands infiltrates and subsequently evaporates or flows as base and interflow downhill. This allows rainfall to leach dissolved phosphorus into groundwater wells, which then transports the phosphorus to the stream via subsurface flow. Similar cases have been documented in the Ethiopian highlands (Moges et al. 2016). But more investigation is needed with additional data in the remaining months of the year.

4.3 Heavy metals in the landscape

The results show that all the locations in the landscape had mercury (Hg) and arsenic (As), which are, however, not above the WHO limits for drinking water (WHO 2022). Toxic heavy metals usually accumulate with acute or chronic exposure, leading to various detrimental effects on human health, from brain dysfunctions to several types of cancer and other diseases. Considering the widespread mining activities in the part of the landscape at Kunsu, it was expected that the concentration of mercury recorded would be higher. However, the highest concentration recorded for the study period is 0.38 µg/l. This is, however, not surprising considering the high cost of mercury and the difficulty in acquiring it. Thus, miners no longer carry mercury to the mining site for fear of losing it but rather perform the amalgamation process at home. Recent studies on the river Pra basin, River Offin sub-basin, Birim sub-basin, and Pra sub-basin, which have all been impacted by the activities of illegal mining, recorded mean mercury levels of 0.49 µg/l, 0.5 µg/l, 0.02 µg/l, and 0.02 µg/l, respectively (Bessah et al. 2021). Another study on the Ankobra and Tano basins, both of which have been heavily impacted by illegal small-scale mining, found the average mercury concentration in the surface water to be 0.38 µg/l and 0.23 µg/l, respectively (Asare-Donkor and Adimado 2016). These studies have corroborated the observation that the levels of mercury contamination in river bodies in mining communities have drastically dropped.

However, mercury concentrations in sediments or aquatic fish were not assessed in this study. The higher dissolved organic matter in sediments interacts very strongly with mercury, affecting its speciation, solubility, mobility, and toxicity in the aquatic environment (Ravichandran 2004). Thus, it could be that the mercury in the river is deposited in the sediments, leaving trace concentrations in the water phase. Other studies have found higher mercury levels in sediments than in water and fish (Asare-Donkor and Adimado 2016). Mercury deposition in fish is in a more toxic form, as methylmercury and presents a high toxic risk to consumers. The levels of mercury and arsenic in groundwater samples were generally higher than in surface water samples, with the highest concentration of mercury recorded at 1.70 µg/l for KGW2, while the highest concentration of arsenic was recorded at 1.19 µg/l for MGW2. Though assessment of heavy metals in sediments would help establish the flow path of these pollutants, the concentrations in the groundwater become high, informing the dominance of subsurface flow in the landscape.

There is also strong advocacy to safely and economically recover gold without the use of mercury (USEPA 2023)**.** Naturally occurring levels of mercury in surface water are less than 0.5 µg/l. Hence, the concentrations of mercury recorded in samples are expected to be from natural sources. The trace levels of mercury in the surface water samples determined in this study indicate an insignificant impact on human activity, although these levels in surface waters can lead to high concentrations in insects, fish, and birds (Environmental Agency 2019).

4.4 Water Quality Index (WQI)

Several parameters can give an indication of the status of a particular water body with respect to the measured parameter. However, there is no single measure that can describe the overall water quality of any one body of water, either on a local or global level. Hence, a composite index that quantifies the extent to which a set of measured parameters deviate from normal, expected, or 'ideal' concentrations may be more appropriate for estimating the water quality of different water bodies (UNEP 2007).

TABLE 1. Water quality index for surface water samples

Sample	**WQI**	**Designation**	**Description**
Mmrobem	35.41	Poor	Conditions usually depart from natural or desirable levels.
Barniekrom	32.5		
Kunsu	29.56		

Comparing the quality of surface water, it was observed that all the samples fall within the lowest index range of 0–44, which is designated as poor and represents undesirable levels of pollution. Within this range, Kunsu had the poorest water quality, with an index of 29.56. Among the studied communities, the surface water at Mmrobem has the best water quality. Depending on the pollutant present, such samples may not even be fit for irrigation purposes.

TABLE 2. Water quality index for groundwater samples

Sample	**WQI**	**Designation**	**Description**
Mmrobem	30.11	Poor	Conditions usually depart from natural or desirable levels.
Barniekrom	30.21		
Kunsu	27.93		

Like the surface water, the observation wells at Kunsu recorded the lowest water quality index of 27.93, although all samples are within the lowest index range of 0–44, designated as poor. This is worrying as the community depends on these wells as a water source for several domestic activities. And poor water quality can be detrimental to the health of consumers.

4.5 Engaging Citizens in Landscape Management Planning

In the citizen science paradigm, maintaining a reciprocal flow of information—where data is collected from citizens and subsequently shared with them after analysis—is deemed crucial for sustaining motivation and engagement (Drechsel et al., 2023). On September 12th, the regional initiative TAFS-WCA organized a collaborative multistakeholder workshop in Mankranso, the capital of the Ahafo Ano Southwest District Assembly (AASWD) for the co-design of an inclusive landscape management plan. Citizen scientists took center stage during this event, presenting their observations and insights into the district's ecosystems (Figure 17). Their presentation encompassed activities related to monitoring water quality and hydrology, along with their perceptions of water quality status gleaned from data collection and interactions with researchers during the analytical phase.

Figure 17. Citizens present their experience and impression about the water quality and hydrology of the landscape.

This valuable information played a pivotal role in shaping the landscape management plan. Furthermore, the dissemination of results to the community and stakeholders remains an ongoing process, with continued communication taking place in subsequent meetings throughout the plan's implementation.

4.6 Challenges during the Citizen Science Approach

During the data collection and analysis process, various challenges arose, and a proactive and inclusive approach was employed to address them. Challenges included the unavailability of citizen scientists (CSs) and suspected falsification of results, leading to the replacement of unavailable CSs and enhanced training to improve accuracy. Blunders and gross errors by some CSs were mitigated through additional training and task reassignments. Experimental errors were addressed by replacing or recalibrating the affected devices.

Delays in data transmission due to communication issues were tackled by implementing more reliable communication channels. Illegal mining activities upstream of Kunsu altered the stream course, requiring remeasurement of the cross-sectional area for accurate discharge calculations. Concerns about the security of CSs while taking photos on-site led to adjustments in communication methods, and measures were taken to ensure CS safety during stormy events, including the provision of personal protective equipment (PPE) such as life jackets, reflective suits, and safety boots. These adaptive strategies demonstrate the commitment to overcoming challenges and maintaining the integrity of the citizen science approach.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Through the citizen science approach, daily data on the hydrological properties and monthly water quality status of the Mankran watershed has been acquired at a minimal cost. This approach has further provided a detailed understanding of the hydrology and water quality of various water bodies within the landscape. During the monitoring period, the results obtained by citizen scientists (CSs) were comparable to laboratory results, showcasing their enhanced capabilities in basic and semi-technical water analysis. Equipped with correlation charts and acceptable pollutant thresholds, CSs demonstrated proficiency in basic results interpretation and water quality prediction. These evolving skills have inspired behavioral change, transforming CSs into environmental stewards within their communities. Analyzing the results from both CSs and the laboratory revealed that competing land uses negatively impacted groundwater and surface water properties in the district.

While the studied groundwater sources were utilized for drinking and domestic purposes, all were deemed of poor quality. The surface water quality index suggested that, depending on the pollutant present, it might not be suitable for irrigation. Although turbidity is generally inversely proportional to dissolved oxygen, the Kunsu station's hydrological properties, such as a high flow rate, seemed to alter this relationship. Further investigation into the river's organic matter content is recommended to fully understand this trend, extending the assessment to sediments to unravel potential complexations between mercury and functional groups and confirm heavy metal flow paths in the landscape. Studying mercury concentrations in fish is also advised to evaluate the potential transport of mercury from mining to non-mining locations and assess the toxicological risk to consumers. Moreover, assessing the dissolved oxygen concentration in observation wells is recommended to fully understand nitrogen speciation, especially in deep wells.

The six-month study also revealed an increasing runoff coefficient from July to October, indicating the likely dominance of subsurface flow in the landscape's hydrological dynamics. Similar phosphate concentrations in both groundwater and surface water support the prevalence of subsurface flow pathways. Although an assessment of heavy metals in sediments could shed light on pollutant flow paths, elevated concentrations in groundwater strongly suggest subsurface flow dominance in the landscape, aiding the comprehension of contaminant flow paths and the connection between surface and groundwater. The valuable insights gained from this study period and beyond will inform the design of appropriate landscape management practices, considering subsurface flow, for socio-economic and ecological benefits.

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Appendix A: stage-discharge relationship and *Secchi* disk *depth*

Stream Stage and Stream Velocity: Stream water level and stream flow rate helped to monitor changes in water volume and speed. These parameters are vital for flow rate estimation, managing water resources, and understanding the health of aquatic ecosystems. The cross-section of the river at the staff gauges was also used to construct a stage-discharge relationship.

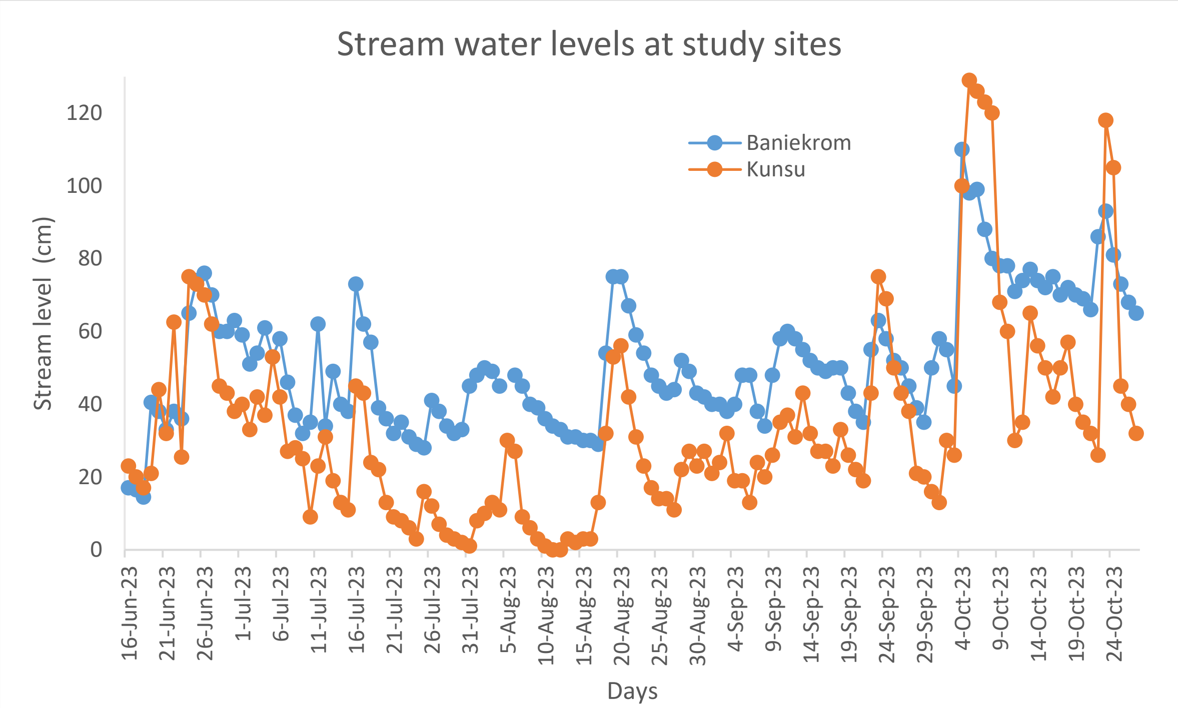

Figure A1: Stream water levels recorded by manual staff gauges

The recorded water levels for the reporting period ranged from 0 to 129 cm (Figure A1). Generally, the water levels at Barniekrom were higher than that of Kunsu. The trends of the rise and fall of the water levels were similar, confirming the data quality.

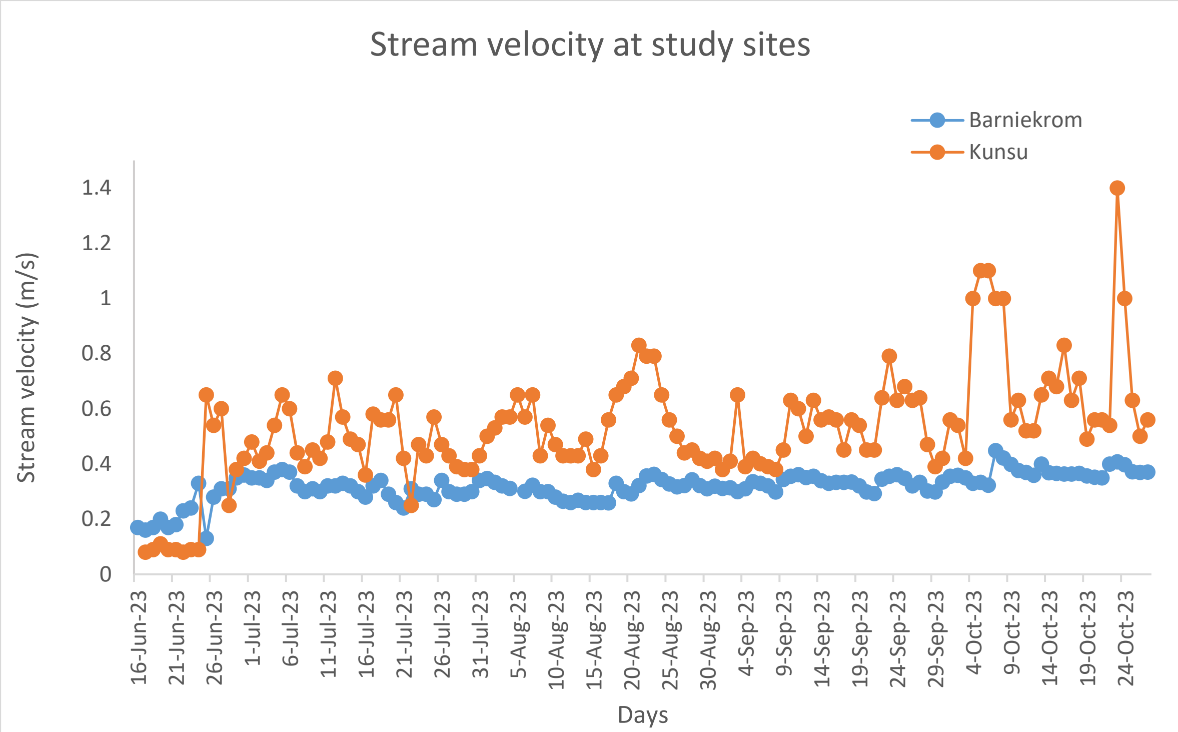

Figure A2: Stream flow velocity at study sites

The stream velocity recorded for the reporting period was between 0.08 m/s and 1.4 m/s, with both the lower and upper limits recorded at Kunsu (Figure A2). Generally, the stream velocity recorded at Kunsu was about 30% to 50% higher than at Barniekrom. This could be due to the diversion of the River course by small-scale miners. The stream at Barniekrom flows steadily through farmlands, which is beneficial to farmers as this low stream velocity reduces soil erosion and sediment transport and promotes the stability and sustainability of agriculture in the area.

Stage-Discharge relationship: The stage–discharge relationship for the surface water channels was established by simultaneously measuring the stage and discharge through velocity measurements. This dynamic association was obtained through a unique mathematical relationship for each site. The significant amount of data on the water level, velocity, and cross-sectional area has made it possible to develop a relationship between the amount of water flowing at a given point in the river based on the water level recorded. This relationship, referred to as the stage-discharge curve, has been developed for the Kunsu and Barniekrom study sites (Figure A3). Periodic verifications were done on streams to assess possible changes to the dimensions of the streambed or stream channel after a flood or due to human activities in the stream.

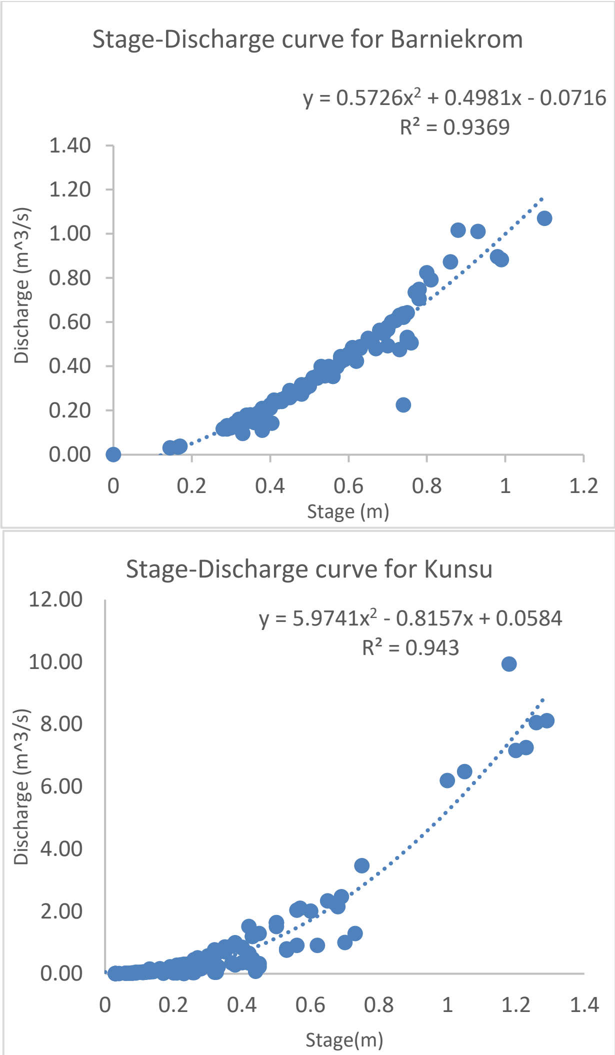

Figure A3: Stage-Discharge curve for Kunsu and Barniekrom

Turbidity using Secchi disk: A 20 cm diameter white circular disk was divided into four quadrants using masking tape. Two opposite quadrants are colored black, and a hole is drilled at the center of the disk. A graduated rope was attached to the disk at the center while a stone was tied at the end of the rope that emerged at the back of the disk to increase its density. The turbidity measurement was done daily, with the CSs positioned at or close to the center of the stream. The disk was slowly lowered into the stream until it disappeared. The depth of the cord that was immersed in the water was noted before the disk was slowly pulled up until it was seen again. The new depth on the cord was noted, and the average was recorded (Figure A4).

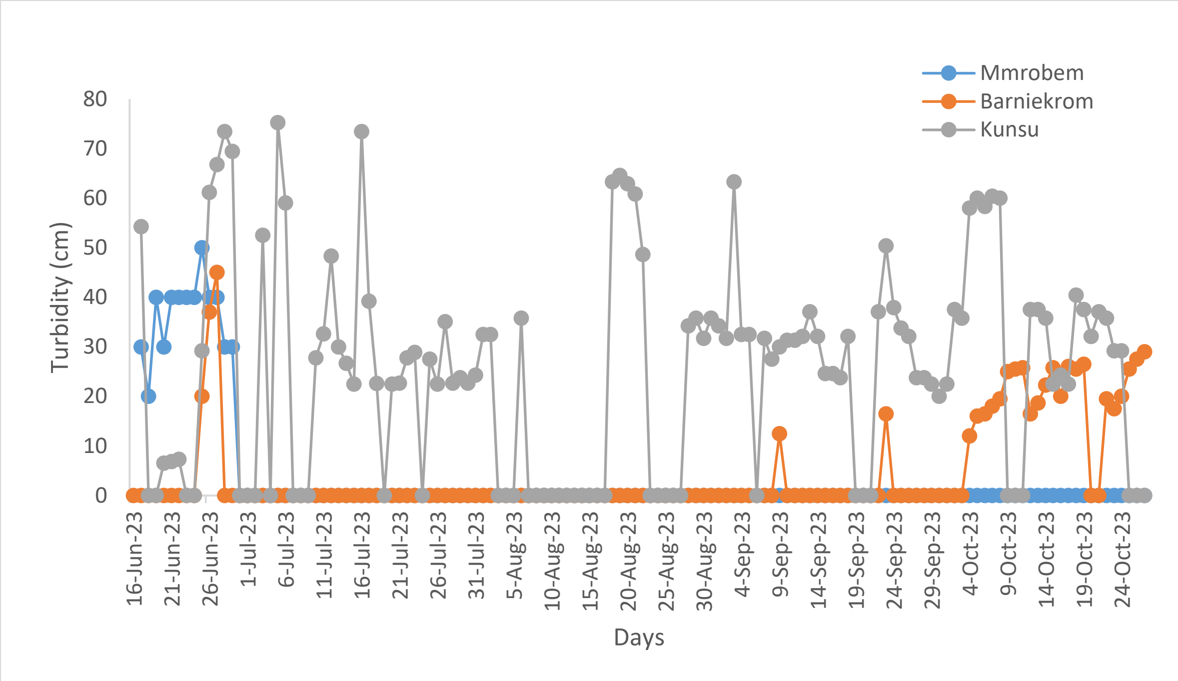

Figure A4: Turbidity of surface water using Secchi disk depth by the citizen