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Research article

Groundwater quality and potential analysis using geospatial techniques: The case of Ashanti Region in Ghana

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A R T I C L E I N F O

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A B S T R A C T

The ecosystem and economy's reliance on clean water is influenced by various factors such as geology, topography, soil types, activities, and the presence of plants and animals. The Ghana Water Company is encountering difficulties in delivering water to consumers in the Ashanti Region due to the shortage of surface water resources, leading to water rationing in the area. Furthermore, poor waste disposal practices, illegal mining, use of fertilizers, and industrial activities have resulted in surface and groundwater source damage. Therefore, there is a need to implement a reliable, simple, and timely method to assess groundwater quality. This study aims to employ GIS and RS techniques to evaluate groundwater quality and potential in the Ashanti Region, Ghana. The Water Quality Index (WQI) was estimated using pH, Total Dissolve Solid (TDS), Chloride, Total Hardness (TH), Nitrate, Temperature, Turbidity, Iron, and Electrical Conductivity (EC). The study then used the WQI distribution to conduct a groundwater potential analysis to identify suitable areas for borehole placement. Digital thematic layers and maps were developed to expose the spatial distribution of water quality parameters, enabling the identification of groundwater pollution control and remedial measures. The study estimated the region's groundwater potential using an integrated GIS and Analytical Hierarchical Process (AHP) technique, grouping under excellent, good, fair, and poor potential. The WQI in the Ashanti Region ranged from 5.208 to 134.232, with 32.252% of the study area having an excellent WQI and 60.168% of the study area having a good WQI. Poor water quality covered 7.550% of the study area. The results showed that the GIS-based AHP approach accurately mapped the spatial distribution of WQI and Groundwater Potential Zones (GWPZ). This information is helpful to planners in water resource management in groundwater exploration and future planning. Policymakers and stakeholders must ensure that groundwater sources are protected from pollution.

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1. Introduction

The earth supports life, and life depends on water. One of the challenges societies face in the twenty-first century is water quality, which will impact the environment, society, and economy due to the widespread discharge of untreated wastewater [1]. Ghana Water Company is unable to adequately supply consumers within the Ashanti Region with water supply due to the limited surface water resources. The pipeline systems used for the distribution of water by Ghana Water Company do not extend to some areas within the region, especially in the villages and suburbs. This has made inhabitants in those areas rely more on dug wells, boreholes, streams, and rivers in the region. This has resulted in Ghana Water Company rationing the water supply to consumers on some specific days of the week as reported by Arnold et al. [2]. However, improper disposal of refuse, artisanal surface mining (illegal mining), excessive use of fertilizer in farms, and industrial activities within the Ashanti Region have been on the increase without any proper monitoring and regulation. These activities have the potential to deteriorate the source of surface and groundwater for the inhabitants within the study area. Therefore, there is a need to employ an effective, easy, and timely approach to investigate groundwater quality and potential zones. The motivation behind this research is to provide an innovative and cost-effective approach such as GIS and RS to assess the groundwater quality and potential zones in a fast and reliable approach as observed in previous research works by Elubid et al. [3] and Chen et al. [4].

Conventional methods such as the point-based approach by Qian et al. [5] and the statistical approach adopted by Boateng et al. [6] and Hayford & Appiah-Adjei [7] for assessing and monitoring water quality have several limitations [8]. These limitations include high cost, lack of spatial and temporal coverage, time-consuming analysis, inability to account for cumulative impacts, and limited effectiveness in detecting emerging pollutants. Sampling at specific points and limited frequencies make it difficult to track pollution sources and assess overall water quality status, while traditional laboratory-based tests can be time-consuming and may fail to consider cumulative impacts, underestimating overall water quality degradation and associated risks. Boateng et al. [6] performed basic statistics such as mean and standard deviation together with principal component and cluster analysis on the associated variables to determine the likely sources of heavy metals. Gibrilla et al. [9] utilized a multivariate statistical method to investigate the condition of groundwater for irrigation and drinking purposes in the Densu River and the Birimian granitoid in Cape Coast. The authors coupled these with the Water Quality Index (WQI) to make deductions from the study. The statistical analysis proved a valuable method for assessing water quality. However, it fails to show the distribution of the index in every location. To address these limitations, alternative methods like remote sensing and real-time monitoring can be considered.

Geospatial technologies, Remote Sensing (RS) and Geographic Information Systems (GIS), offer significant advantages over traditional methods in studying water quality and groundwater resources. GIS and RS applications in groundwater studies include mapping, suitability analysis, identify how susceptible groundwater is to contamination, and determining groundwater flow [8, 10–12]. Compared to more conventional methods, geospatial technologies are accurate and cost-effective for studying water quality [8]. GIS and RS techniques provide valuable tools for monitoring water quality [10]. For instance, Sander et al. [13] researched using GIS and RS datasets to develop an improved well-siting technique within the Voltaian basins in the central part of Ghana. The results revealed that RS data, Global Positioning System (GPS), and GIS can be used for the effective mapping of features that are conducive to

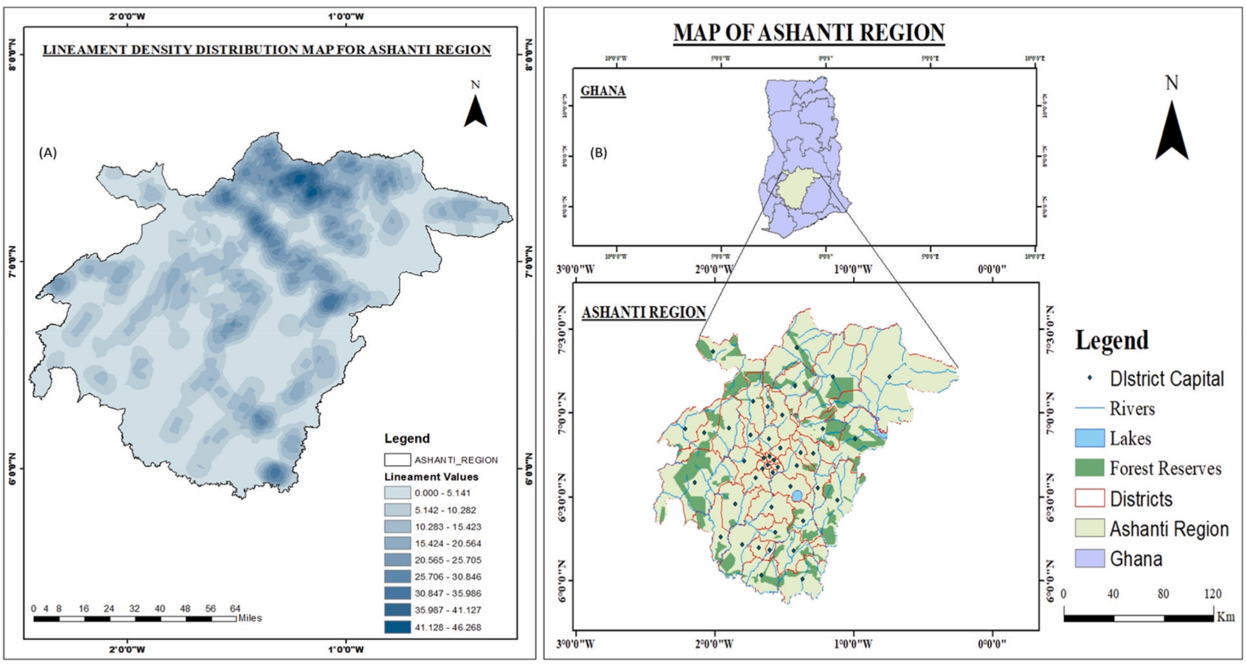

Fig. 1. (A) Lineament map for Ashanti Region; (B) Study area map of Ashanti Region.

groundwater development. Data integration in a GIS can be useful for conducting effective analysis. Soumya et al. [11] assessed and mapped the groundwater quality near the mining zone in India using GIS and RS methodologies. The findings demonstrated that GIS and RS can be utilized to gain a more thorough understanding of the current water quality situation in any place. Analysis revealed that the region's groundwater requires field-specific treatment before it can be used.

Most of the research done in Ghana on water quality assessment used a statistical and multivariate approach in assessing the quality of the groundwater source for drinking and irrigation purposes. Research done by Arnold et al. [2], Boateng et al. [6], Hayford & Appiah-Adjei [7], and Sander et al. [13] failed to determine spatially the groundwater zones and quality similar to works by Hagos & Andualem [14], Kabeto et al. [15], Rahmati et al. [16], and Saranya & Saravanan [17]. The purpose of this study is to create continuous surface and maps of groundwater quality data, which will help to identify areas where groundwater quality parameters exceed the acceptable limits. This will enable us to understand the spatial distribution of groundwater quality parameters, detect any spatial trends, and identify areas of concern within the study area. Additionally, we aim to integrate various datasets to identify potential zones for groundwater, where boreholes can be sited in areas where there is high yield potential. Therefore this study aims to use GIS and RS in assessing and analyzing groundwater quality as well as groundwater potential within the Ashanti Region, Ghana using similar approaches by Megahed [12], Singh et al. [18], Soumya et al. [11], and Usali & Ismail [10].

2. Materials and methods

2.1. Study area

Within Ghana's central belt, the Ashanti Region is located between latitudes 5.50° and 7.46° N and longitudes 0.15° and 2.19° W (Fig. 1(B)). Four political regions, including the Brong-Ahafo Region in the north, the Eastern Region in the east, the Central Region in the south, and the Western Region in the southwest, share borders with the region. The region is characterized by forest-dissected plateau terrain and pre-Cambrian rocks of the Birimian and Tarkwaian formations. The region consists of two main types of aquifers: sedimentary and crystalline rock aquifers. Sedimentary aquifers, which are made up of sandstones, siltstones, and clay stones, have high porosity and permeability, allowing for significant storage and movement of groundwater. Crystalline rock aquifers, formed by granite, gneiss, and schist, have low primary porosity but may have secondary porosity due to fractures and weathering. The physical characteristics of aquifers include porosity, permeability, and storage capacity. Geophysical methods such as electrical resistivity, seismic reflection, and ground-penetrating radar are used to examine aquifers in the region. Hydraulic conductivity and transmissivity are crucial in determining the rate of water flow [19–21].

2.2. Water quality index (WQI) estimation

WQI is a helpful instrument for evaluating water quality and disseminating details about its general quality [22]. The Weighted Arithmetic Water Quality Index (WAWQI) approach uses a mathematical equation to describe whether the sources of surface and groundwater are suitable for human consumption. The WAWQI approach evaluated the water quality following its level of purity using the most frequently utilized water quality factors as defined by Brown et al. [23]. The WAWQI was used in the study to calculate WQI as indicated by Asadi et al. [22], Brown et al. [23], Mali et al. [24], Sarwar et al. [25], and Soumya et al. [11]. This approach multiplies the water quality factors by a weighting factor before averaging them using the basic arithmetic average. In this study, pH, Total Dissolve Solids (TDS), Chloride, Total Hardness (TH), Nitrate, Temperature, Turbidity, Iron, and Electrical Conductivity (EC) were used in estimating the Water Quality Index (WQI). To determine the suitability of the groundwater, WAWQI is estimated using equation (1) and the proportionality constant estimated equation (2):

$$\text{Unit weight } (W_n) = \frac{K}{S_n} \tag{1}$$

$$K = \frac{1}{\sum_{i=0}^{n} \frac{1}{S_n}} \tag{2}$$

Table 1
Water quality parameters, GSA/WHO standards, and assigned unit weights.

Parameters	Unit	GSA/WHO Standards (Sn)	Weights (Wn)
pH		8.500	0.032
Total Dissolve Solids	mg/l	500.000	0.001
Chloride	mg/l	250.000	0.001
Total Hardness	CaCO3	500.000	0.005
Nitrate	mg/l	50.000	0.004
Temperature	°C	25.000	0.010
Turbidity	NTU	5.000	0.053
Iron	mg/l	0.300	0.893
Electrical Conductivity	μS/cm	300.000	0.001

where Wn should sum up to 1; Sn is the nth parameter's standard value; k is the constant of proportionality; and Wn is the unit weight of the parameters.

Table 1 shows the Ghana Standard Authority (GSA)/WHO requirements for the parameters affecting water quality and the assigned unit weights. Table 2 shows the WQI scale recommended by WHO/GSA is used to classify the WQI into different categories.

Calculating the sub-index (Qn) value for each water quality indicator using equation (3) defined below:

$$Qn = \frac{[(V_n - V_o)]}{[(S_n - V_o)]} \times 100 \tag{3}$$

where Vo is the actual value of the parameter in pure water, Sn is the standard desired value of the nth parameter, and Vn is the mean concentration for the nth parameter.

$Vo = 0$ for all the parameters except pH, hence the following equation (4) defines Vo for pH as:

$$Q_{ph} = \frac{\left[\left(V_{ph} - 7\right)\right]}{[(S_n - 7)]} \times 100 \tag{4}$$

Estimation of WQI is defined in equation (5) as follows:

$$WQI = \frac{\sum_{i=0}^{n} W_n W_n}{\sum_{i=0}^{n} W_n} \tag{5}$$

2.3. Potential groundwater zones within Ashanti Region

The training samples and validation points were selected on Google Earth Pro. Unique codes were assigned to different classes such as water bodies, vegetation, forests, settlements, and bare land. The samples were chosen through visual evaluation from Google Earth Pro. 30% of the samples were used for validation, and 70% were used for training. Random Forest (RF) classifiers applied to Landsat imagery in Google Earth Engine (GEE) were used to successfully map landcover categories. The contribution of each variable (class) to the classification output was measured using the RF classification approach, which is essential for determining the importance of each variable [26]. The study evaluated the effect of land use and land cover changes within the Ashanti Region by mapping the primary land cover conversion from 2022 to 2023. Based on Anderson's Level I Classification Scheme [27], this study employed different forms of land cover and grouped under five categories (less dense vegetation, forest lands, water bodies, settlements, and barren lands). Anderson's Level I Classification Scheme categorizes land cover and use into four main groups: Nature Conservation and Recreation, Agriculture and Grazing, Urban and Industrial, and Water. It categorizes dense vegetation into these groups, while less dense vegetation is classified as Agriculture and Grazing. Urban and Industrial areas include human settlements, while Water covers all water bodies. Unclassified areas are deemed unclassified. This system aids land managers and planners in managing and analyzing landscapes effectively. Evapotranspiration, penetration, and condensation are all influenced by variables including vegetation type and soil moisture, land use and land cover pattern are among the most crucial factors governing surface runoff [28]. Therefore, it significantly affects groundwater recharge. The land use and land cover map were given a normalized weight of 0.066, placing them fifth among the factors considered in this study to establish GWPZs. Table 3 shows the LULC classification scheme.

The main way that groundwater is recharged is through rainfall. The monsoon and tropical rains are essential to the region. Rainfall length and intensity have a significant impact on infiltration and runoff volume. Between 1100 mm and 1800 mm of rainfall falls on average each year in the research area [29]. The ECMWF Reanalysis v5 dataset is a reliable and precise meteorological variable, particularly rainfall, used in climate and weather research. It uses advanced data assimilation methods and a numerical weather prediction model and is validated against independent observational datasets. With a normalized weighted value of 0.381 among the variables taken into account in this study to develop GWPZs, rainfall ranks as the first most crucial element. The availability of rainfall was regarded as a significant source of recharge according to Rahmati et al. [16], Saranya & Saravanan [17], and Ifediegwu [28]. With various patterns impacting quantity, time, and intensity, rainfall has a considerable impact on groundwater potential. Over an extended period, low-intensity rainfall greatly recharges groundwater [17].

The soil is the earth's topmost layer and serves as a conduit for water percolation. The degree of infiltration is impacted by the soil's permeability and capacity to hold water. The amount of water that reaches the water table depends on how big the unconsolidated

Table 2
Categorization of the WQI based on the WQI scale prescribed by WHO/GSA.

WQI Index	WQI Status
0–25	Excellent
26–50	Good
51–75	Poor
76–100	Very Poor
>100	Unfit for consumption

Table 3
LULC classification scheme (adopted from [27]).

LULC Classes	Description of Land Use Land Cover Classes
Less dense vegetation	Areas covered with grasses, croplands, areas with a vegetative cover of less than 10%, and Shrubs.
Forest	Areas with tree canopy above 10%,
Water Body	Streams and open galamsey pits, Lakes, Ponds, Reservoirs, and swimming pools.
Settlement	Includes physical structures such as residential, commercial, industrial, roads, etc.
Bare lands	Bare areas without any vegetation cover.

zone is under the soil. Groundwater percolation and infiltration are entirely dependent on geology. High permeability and porosity of the geologic units increase groundwater storage and yields, making it an essential criterion for evaluating groundwater potential [17]. The kind of soil, which is controlled by pore saturation or desaturation processes, affects a rise in water entry into the soil. The permeability of the soil types regulates the amount of water that seeps into the ground [28]. Groundwater potential is better for soil types with a coarse-grained substrate than those with a fine-grained matrix [30].

The existence and mobility of groundwater are influenced by the features of different water-containing geological formations. The research area's geology has been divided into six main groups. The Tarkwaian, Obosum and Oti Beds, Dahomeyan, Birimian Sediments, and Birimian Volcanics are examples of these strata. The characteristics of various water-bearing geological formations influence the occurrence and transport of groundwater in significant ways [28]. The second crucial factor is geology, with a normalized weight of 0.245 used to determine the GWPZs in the Ashanti Region. Birimian Sediments, Birimian Volcanics, Dahomeyan, Obosum and Oti Beds, Tarkwaian, and Upper Voltaian are the six primary groups that make up the study area's geology. A weighted value of 5 was assigned to the Obosum and Oti Beds and Upper Voltaian as these group has a high yield capacity, especially in sandstone areas, and has very good water quality as indicated by Appiah-Adjei & Osei-Nuamah [31], suggesting that they have a good groundwater potential, while Birimian Sediments, Birimian Volcanics, Dahomeyan, and Tarkwaian all had a weighted rating of 1, indicating poor groundwater potentials. The Birimian group, Tarkwaian group, and Dahomeyan group have poor dissolution rates for some elements such as iron, manganese, and nitrates. As indicated by Appiah-Adjei & Osei-Nuamah [31], they tend to have low yields. The Tarkwaian Group is a geological formation consisting mainly of quartzite, phyllite, and graywackes, and is notable for its vast gold deposits. Additionally, the Obosum and Oti Beds, part of the Voltaian Basin, provide valuable insights into the area's geological evolution. The Dahomeyan Group, composed of shale, limestone, and sandstone, is crucial for understanding the region's geological history. Another significant geological formation is the Birimian Sediments, which form part of the larger Birimian Supergroup, and are renowned for their rich gold mineralization and have been a major economic activity in the area. The Birimian Volcanics, consisting of volcanic rocks, also hold significant economic potential. The Ghana Geological Service Department provided the soil and geology maps.

The DEM was accessed from the United States Geological Survey's (USGS) website (https://earthexplorer.usgs.gov/). The research involved creating an empty raster dataset in ArcGIS Pro, merging eight DEMs, filling sinks, and using the Ashanti Region shape file to clip the Area of Interest (AoI). The clipped dataset was used to model flow direction and flow accumulation, evaluating water flow directions. Drainage density, a measure of network texture, illustrates the equilibrium between overland flow's erosive power and surface soils and rocks' resistance [16]. The drainage system in an area is influenced by factors such as rock foundations, vegetation, soil's rainfall absorption, and slope gradient. Low drainage density leads to increased infiltration and surface runoff, while high permeability of underlying rocks results in minimal drainage [16,28]. The groundwater potential is therefore good in areas with low drainage density. According to the relative significance in evaluating groundwater potential zones among the characteristics included for this study, drainage density comes in fourth with a standardized weight of 0.089.

The Earth's surface has linear or curved structures called lineaments that provide a generic manifestation of underlying cracks. They fall under the category of supplementary porosity and are distinguishable from other topographical characteristics on satellite imagery by tonal changes [16,17]. A fault, fracture, or master joint may be represented by a lineament. Lineaments are joints, fractures, and faults that allow water to percolate through them and serve as a subliminal indicator of a potential zone [28]. They have a significant impact on the transport and storage of groundwater as well as the penetration of surface discharge into the subsurface [16,28]. Since lineaments typically indicate a permeable zone, an area's lineament density can immediately expose the groundwater potential [17]. Several Hilshade maps were generated from the filled DEM through different combinations of the azimuth angle and altitude parameters in ArcGIS. The curvatures on the different Hilshade maps were digitized. These were converted to a line density map which represents the lineament density in the area. With a normalized weighted value of 0.05, lineament density is ranked sixth among the characteristics used in the current study to determine groundwater potential zones. Lineaments, linear structures on Earth's surface, represent cracks and porosity, impacting groundwater transport, storage, and surface discharge penetration. Their density reveals potential zones, and their slope proportion can determine groundwater conditions. Lineaments are crucial in hydrogeology, as they indicate potential groundwater sources and impact recharge processes [16,17,28].

The slope map was derived from the filled DEM. The region's slope is the determining element for runoff and infiltration. The higher the runoff, the higher the gradient [28]. Depending on the slope value, the study area's slope map was divided into five classes. Five different grades were assigned to the slope map. Mountain hydrology dominates the hydrology of sloped terrain. Because of the significant impact of land inclination and height, this area of terrestrial hydrology is being differentiated. Ashanti Region has a varying elevation and land inclination. Therefore, the runoff formation in the study area is influenced in many different ways such as the recharge, flow patterns, and storage zones by an inclined and sloping aspect associated with it.

The groundwater potential index (GWPI), a measure without dimensions, assists in determining the locations of groundwater potential zones [16]. The GIS-based AHP approach was used to create the groundwater potential map. Utilizing the weights generated by the AHP technique, groundwater occurrence and movement controlling criteria were combined in ArcGIS to determine the groundwater potential zones of the Ashanti Region. To assign weights to specific layers and determine their relative weight, decision matrices were created using the AHP technique utilizing Satty's scale of 1–9 [14,32,33]. Satty's Measure of Relative Importance is displayed in Table 4.

Weights were assigned to the variables influencing the presence and movement of groundwater after thematic maps were created. The groundwater prospective map was created using GIS environment-weighted index overlay analysis. Using equation (6), a weighted linear combination approach was used to calculate the groundwater potential index. Fig. 2 illustrates the general methods used and accepted.

$$GWPI = Ge_r Ge_w + Sp_r Sp_w + Lu_r Lu_w + Rf_r Rf_w + Dd_r Dd_w + Li_r Li_w + S_r S_w \tag{6}$$

GWPI stands for groundwater potential index; Geology is represented by *Ge*, slope by *Sp*, LULC by *Lu*, rainfall by *Rf*, and drainage density by *Dd*; *S* is for soil, *Li* is for Lineament, and the suffixes ***r*** and ***w*** represent the rank and weight of each layer, respectively.

Equation (6) can be simplified as shown in equation (7):

$$GWPI = \sum_{w=1}^{m} \sum_{i=1}^{n} \left(X_{ij} * W_{ij}\right) \tag{7}$$

Groundwater potential zones were identified and categorized as low potential, fair potential, high potential, and outstanding potential by integrating all the maps (classified maps of slope percent, geology, lineament, soil, drainage, LULC, and rainfall). The percentage of influence is shown for each thematic layer in Table 5.

3. Results

3.1. WQI distribution in Ashanti Region

A highly helpful and effective tool for determining water quality is the Water Quality Index (WQI) [34]. Table 1 lists the parameters used to calculate the WQI and the unit of weight allocated to each parameter. Unit weight for each parameter is estimated to a common scale. Maximum weight (0.899) was given to iron (Fe), suggesting the significance and impact of this parameter in the water quality index. The findings indicated that approximately 32.252% of the land area covered by the groundwater sample falls into the excellent water category. The highest WQI value recorded within the Ashanti region is 134.232 whereas the lowest WQI value estimated was 5.208. The Water Quality Index (WQI) is divided into five categories: Excellent (0–25), Good (25–50), Poor (50–75), Very Poor (75–100), and Unfit for Consumption (>100). Table 6 shows the WQI Index, WQI status, and the Percentage of land size within the Ashanti Region. Fig. 3 shows the WQI distribution map within the Ashanti Region.

3.2. Groundwater potential zones within Ashanti Region

The Birimian sediments, which are subaqueous fine-grained sediments with bimodal volcanic material encompassing over 668550.100 Ha (27.401%), make up the majority of the studied area's rock types. The Birimian Volcanics covers 116966.34 Ha (4.794%). It consists of basalt-andesite-rhyodacite lavas, with elevated Mg–Ca–Na contents, and volcaniclastics. Dahomeyan is made up of mafic and felsic gneiss extending 544117.34 Ha (22.301%). Obosum and Oti Beds mainly contain Shale, Mudstone Beds, Sandy, and Pebbly Beds. This area covers 584719.01 Ha (23.965%). Tarkwaian is made of quartzite, phyllite, grit, conglomerate, and schist. It extends to about 225914.06 Ha (9.259%). Upper Voltaian contains mainly Sandstone extending to about 299586.002 Ha (12.279%). Fig. 4(A) shows the geology map for Ashanti Region. Table 7 shows the allocated weights and AHP rating for geology.

The study identified soil type as the seventh key parameter in determining groundwater potential zones. Ten soil types are present in the research region: Arenosols, Alisols, Arenols, Fluvisols, Gleysols, Leptosols, Lixisols, Luvisols, Nitosols, and Plinthosols. Soil types vary in permeability and particle sizes. Aerosols have low permeability due to their small size, while Alisols are rich in organic matter and have good permeability. Arenols are sandy, Fluvisols are formed from river sediments, Gleysols have low permeability due to high clay content, and Leptosols are shallow, with good permeability and particle sizes. Table 8 displays an overview of the normalized weights and the weights given to the various soil types. Fig. 4(B) shows the soil type map for the Ashanti Region.

The topography of a terrain significantly influences groundwater's state, as it affects the rate of water entry and flow. Steep slopes

Table 4
Satty's relative importance scale.

Strength of Significance	Explanation
1	Equal Significance
3	Medium Significance
5	Strong
7	Very Strong Significance
9	Maximum Significance
2,4,6, and 8	An interim number between two adjacent numbers

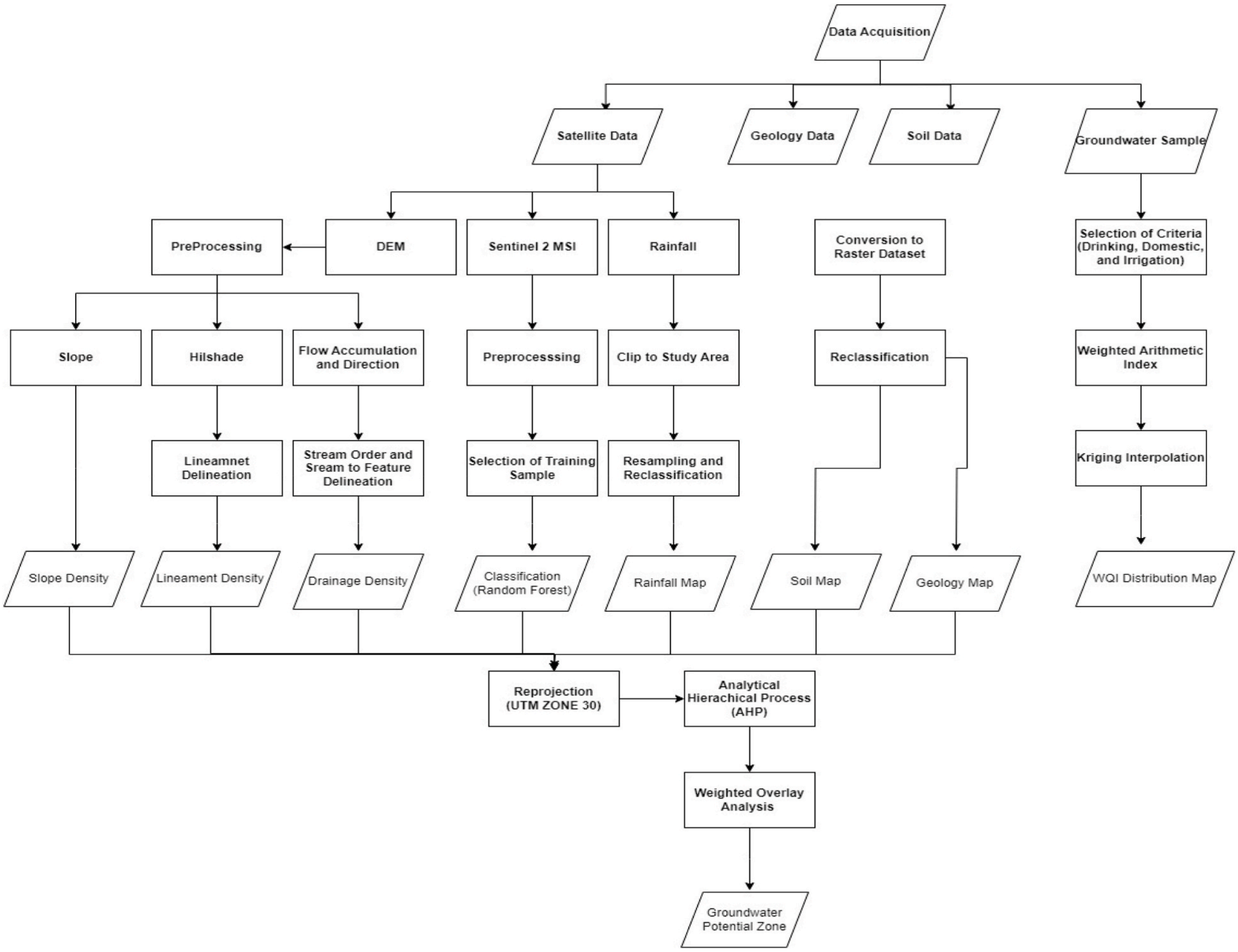

Fig. 2. Methodology for GWPZ and GWQI.

Table 5
Influence ratio for each theme layer.

Datasets	Percentage of Influence (%)
Rainfall	38.100
Geology	24.500
Slope	13.100
Drainage Density	8.900
LULC	6.600
Lineament	5.000
Soil	3.700

Table 6
Summary of the WQI status and percentage of coverage.

Status	WQI Index	Area (Ha)	Percentage (%)
Excellent	0–25	786901.300	32.252
Good	26–50	1468011.000	60.168
Poor	51–75	184208.900	7.550
Very Poor	76–100	561.166	0.023
Unfit For Consumption	>100	170.790	0.007

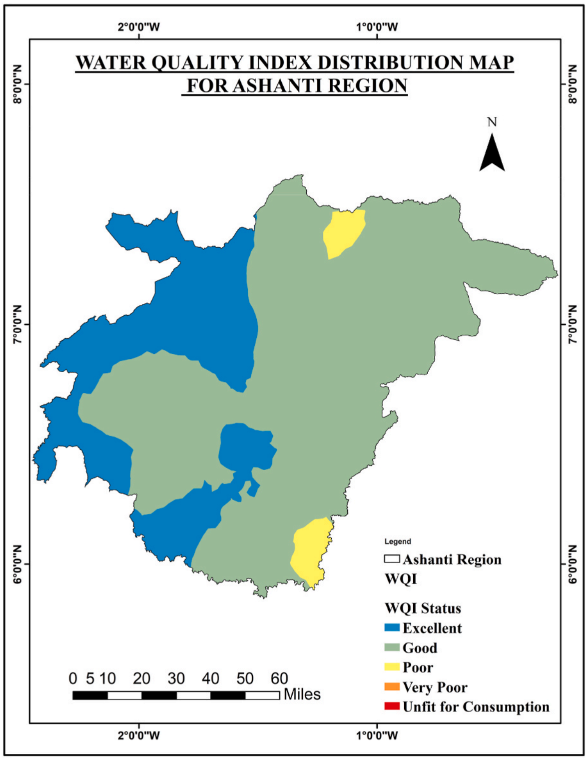

Fig. 3. WQI distribution categorization map within the Ashanti Region.

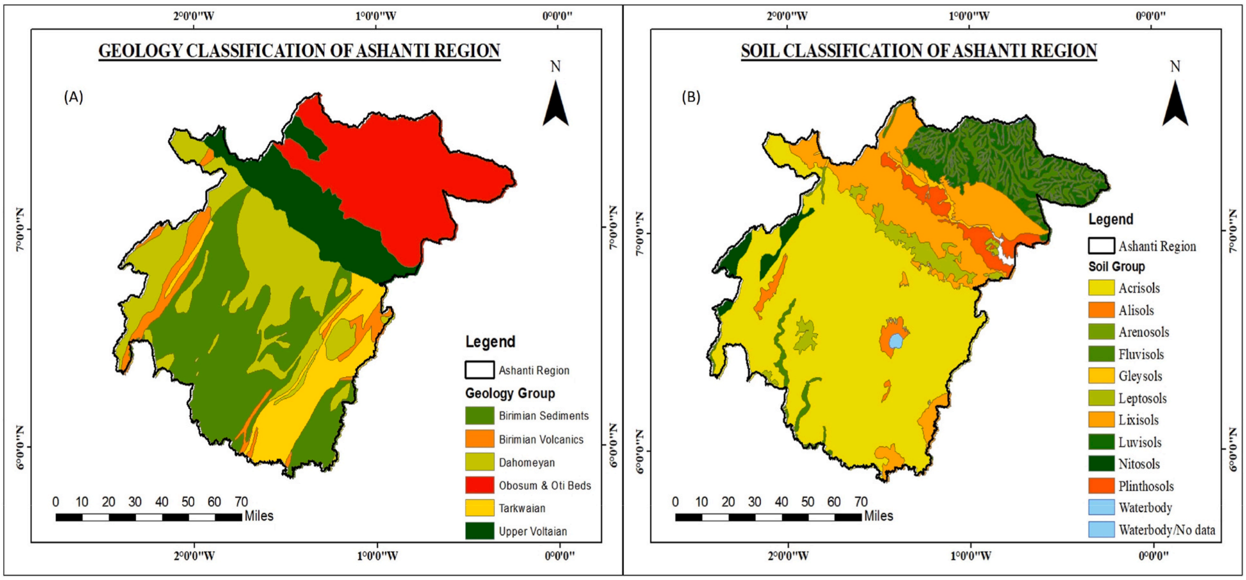

Fig. 4. (A) Geology map for Ashanti Region (Source: Ghana Geological Survey Authority; https://ggsa.gov.gh/); (B) Soil map for Ashanti Region (Source: FAO/UNESCO Soil Map of the World; https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/faounesco-soil-map-of-the-world/en/).

allow water to penetrate the earth more quickly, while gentle slopes slow it down and may accumulate on the surface. The velocity of water runoff also affects groundwater replenishment. Gentle slopes help in infiltration, while steep slopes create recharge areas, potentially forming local reservoirs. The slope percent ranges from 72 to 90, covering 1,404,082 Ha (57.548%). This slope per cent was assigned a rank of 1. A slope per cent from 0 to 18 was assigned a rank of 5 since it has a high infiltration rate. The slope density was

Table 7
AHP ratings and weight for geology.

Parameter	Range	Rank	Weight	Area (Ha)	Percentage (%)
Geology	Birimian Sediments	1	0.245	668550.100	27.401
	Birimian Volcanics	1		116966.340	4.794
	Dahomeyan	1		544117.340	22.301
	Obosum and Oti Beds	5		584719.010	23.965
	Tarkwaian	1		225914.060	9.259
	Upper Voltaian	5		299586.002	12.279

Table 8
AHP ratings and weights for soil type.

Parameter	Range	Rank	Weight	Area (Ha)	Percentage (%)
Soil	Lixisols	1	0.037	425521.840	17.440
	Acrisols	1		1359716.560	55.729
	Luvisols	1		221112.092	9.063
	Fluvisols	5		163868.560	6.716
	Gleysols	5		17934.640	0.735
	Leptosols	5		85865.160	3.519
	Plinthosols	1		81197.240	3.328
	Arenosols	5		3685.200	0.151
	Nitosols	1		43055.420	1.765
	Alisols	1		33166.800	1.359

Table 9
AHP score and weights for slope.

Parameter	Range	Rank	Weight	Area (Ha)	Percentage (%)
Slope	0–18	5	0.131	115778.869	4.745
	18–36	4		83689.091	3.430
	36–54	3		213326.283	8.743
	54–72	2		622976.296	25.533
	72–90	1		1404082.312	57.548

given an overall weight of 0.131. The slope map for the research region is depicted in Fig. 6(B). The assigned weights and AHP score for geology are displayed in Table 9.

To allocate weights, the study area's lineament density was divided into five classes, ranging from 0 to 46.268 km/km^2. The highest rating of 5 was given to regions with lineament densities between 35.987 and 46.268 km/km^2, which indicates the maximum potential for groundwater recharge. 3.975% of the region has been covered by this class. The range of the moderate lineament density is 25.706–30.846 km/km^2. This category makes up nearly 21.280% of the study area, and a 3 was given for this class. A rating of 1 was given for the areas with the lowest lineament density, or 0–15.423 km/km^2, which has coverage of approximately 34.608% of the total area. The lineament density for the study area is shown in Fig. 1(A). Table 10 shows the allocated weights and AHP rating for lineament density.

The drainage density values in this study range from 0.492 to 18.503 km^2/km^2. Five categories were assigned to the area's drainage density map. With rising ranking values, the weights attributed to the various themes vary from 1 to 5. The likelihood of runoff, which ultimately results in less percolation, is higher when drainage density is maximum. The area covered by the high potential ranking theme layer 5 is 8.004% (19527.361 ha), while the areas covered by the ranking theme layers 4, 3, 2, and 1 are 20.131% (491160.114 ha), 30.722% (749577.830 ha), 26.317% (642107.088 ha), and 14.826% (361733.201 ha), respectively. Fig. 5(A) shows the map of drainage density. Table 11 shows the allocated weights and AHP rating for lineament density.

The region's average annual precipitation is broken down into five distinct classes and runs from 1470.903 to 1526.633 mm/year. The weights of these theme layers range from "1" to "5", and ranking rises in lockstep with the assigned weights. The amount of water

Table 10
AHP ratings and weights for lineament density.

Parameter	Range (km/km^2)	Rank	Weight	Area (Ha)	Percentage (%)
Lineament Density	0–15.423	1	0.050	844380.392	34.608
	15.424–25.705	2		707370.900	28.992
	25.706–30.846	3		519200.610	21.280
	30.847–35.986	4		271925.220	11.145
	35.987–46.268	5		96975.730	3.975

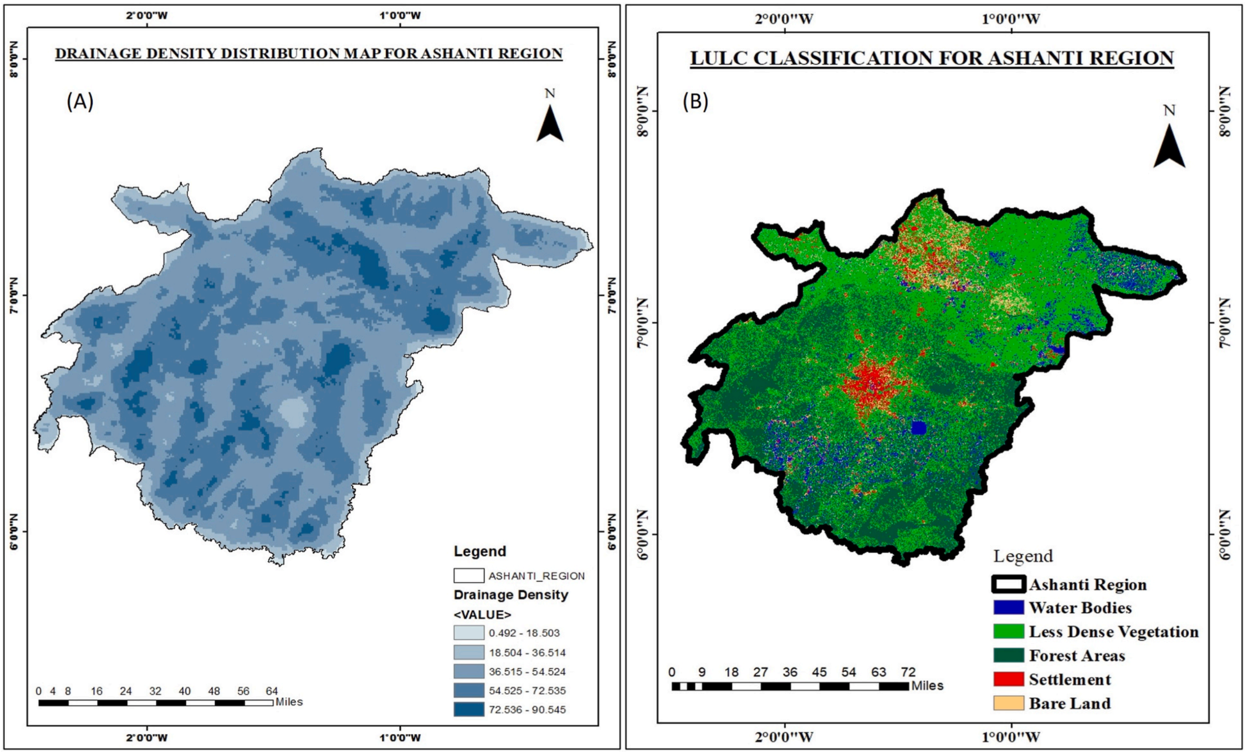

Fig. 5. (A) Drainage Density map for Ashanti Region; (B) LULC map for Ashanti Region.

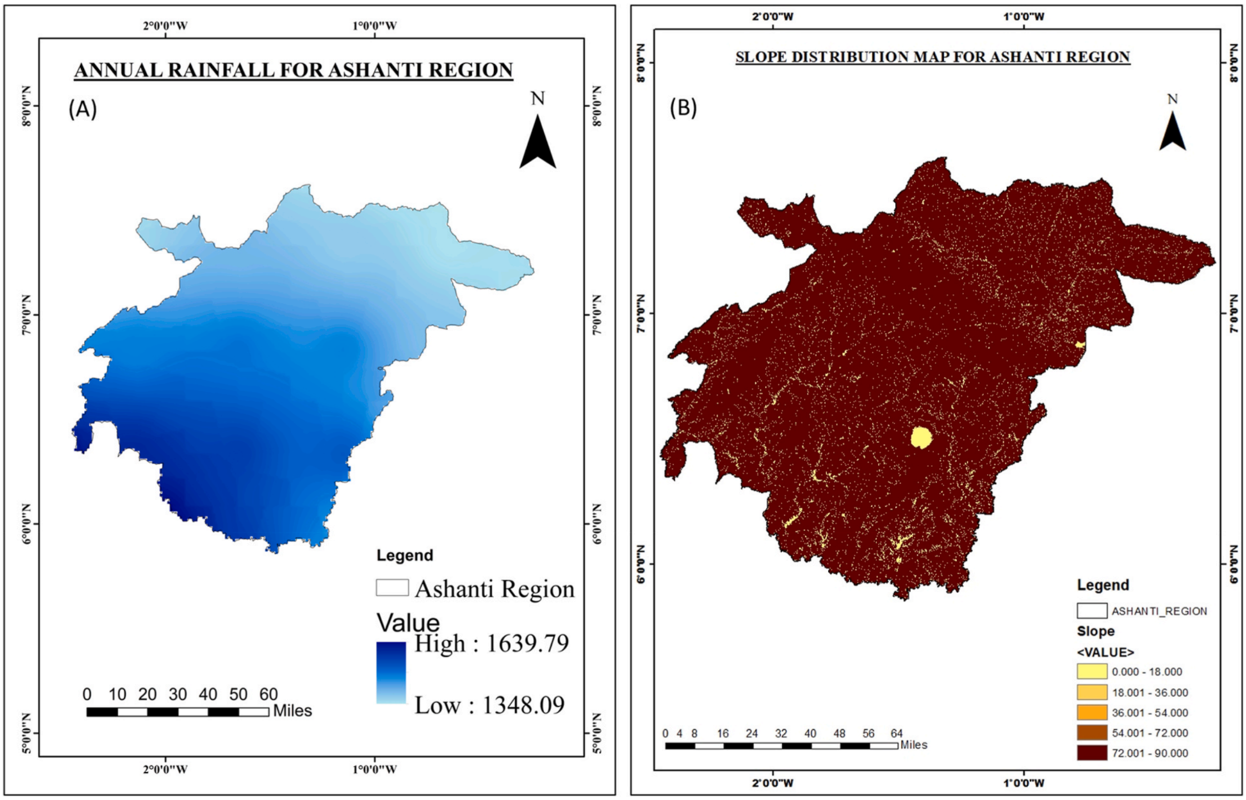

Fig. 6. (A) Rainfall map for Ashanti Region; (B) Slope map for Ashanti Region.

Table 11
AHP ratings and weights for drainage density.

Parameter	Range (km/km^2)	Rank	Weight	Area (Ha)	Percentage (%)
Drainage Density	0.492–18.503	5	0.089	195274.618	8.004
	18.504–36.514	4		491160.115	20.131
	36.515–54.524	3		749577.830	30.722
	54.525–72.535	2		642107.088	26.317
	72.536–90.545	1		361733.201	14.826

available to percolate through the soil increases with rainfall intensity. Therefore, a higher rating of 5 was given to regions with higher rainfall, such as those receiving 1597.471–1639.793 mm/year, and a lower rating of 1 was given to regions with lesser rainfall, such as those receiving 1348.089–1403.820 mm/year. The district is heavily reliant on the monsoon season. With peaks in May/June and October, the area sees double the annual average rainfall. Average annual rainfall is higher in the southern parts of the area than in the northern parts, where average annual precipitation is lower. Fig. 6(A) depicts the rainfall map for the research area. Table 12 shows the allocated weights and AHP rating for rainfall.

Land Use Land Cover (LULC) classification helps understand groundwater sustainability and availability by identifying high groundwater potential areas, forecasting water availability changes, and implementing appropriate land management practices. Surface runoff and groundwater recharge are influenced by LULC, with impervious surfaces hindering infiltration increasing surface runoff and areas with dense vegetation, permeable soils, and wetlands promoting recharge. Soil type also influences groundwater recharge, with high vegetation rates causing higher evapotranspiration rates. Five classes were created out of the LULC kinds. Less dense vegetation, forests, barren fields, built-up areas, and waterbodies were the different types of land use in the research region. The study area is made up of 36.707% forest, 5.313% settlements, 5.931% water body, 4.906% barren land, and 47.142% less dense vegetation area. The LULC classes were ranked as follows: “1” for bare ground (very bad potential), “1” for settlement (very poor potential), “5” for less dense vegetation (excellent potential), “5” for forest (good potential), and “5” for waterbody (good potential). The LULC classification had an overall accuracy of 0.892. Water bodies, forest areas, bare land areas, settlements, and less dense vegetation areas had an accuracy of 86.5%, 93.8%, 89.2%, 90.0%, and 83.3% respectively. The area’s land use and cover patterns are depicted in Fig. 5(B). Table 13 shows the allocated weights and AHP rating for LULC types.

Four groundwater potential zones were created using the GWPI values: low potential, fair potential, good potential, and exceptional potential. Around 0.751% (18310.764 Ha) of the study’s total area is made up of poor potential zones, whereas 42.867% (1045474.173 Ha) of it is made up of fair potential zones. 11.067% (269907.697 Ha) of the whole land is deemed to have exceptional potential zones, while 45.315% (1105160.219 Ha) of the total area is regarded as having good potential zones.

In conclusion, the findings of this study demonstrated that groundwater potential mapping could be accomplished using the GIS-based AHP approach. To manage water resources and conduct a thorough review of groundwater exploration and development for future planning, planners can benefit from the findings of the groundwater potential map. The different types of groundwater potential zones and their geographic range are displayed in Table 14 for the Ashanti Region. Fig. 7 shows the groundwater potential zones within the Ashanti region.

4. Discussion

4.1. WQI distribution in the Ashanti Region

There is groundwater practically everywhere underneath the surface of the planet, but there is not a single large aquifer; rather, there are thousands of smaller aquifer systems and compartments [35]. Water quality comprises the overall characteristics of water. The index is very effective and important to relate the tendency of data for water quality with the management of the quality of water [36]. WQI is an important parameter for demarcating groundwater quality and its suitability for domestic purposes, and industrial, and farming activities [35]. The study shows that the Ashanti Region has groundwater of varying quality. However, despite the mining activities, farming, and heavy industry, spatial analysis of the evenly distributed groundwater samples revealed that, except about 7.550% of the land area where the water quality is poor, groundwater is generally suitable for drinking, industrial, and irrigation purposes similar to findings by Hayford & Appiah-Adjei [7]. Obuasi Municipal, Amansie West, Amansie South, and Amansie Central are known for their mining activities, both small-scale and large-scale. The chemicals used by the miners are harmful to the environment and the groundwater resources [37]. However, it is encouraging to note that these areas are currently within the good WQI zone [38]. This indicates that the mining companies and small-scale miners in these areas are following the regulations set by Environmental Protection agencies with regards to the use of harmful chemicals, which is a positive step towards protecting the environment and ensuring the safety of the community. About 60.168% of the study area had an index ranging from 26 to 50 indicating that the groundwater was also good for domestic purposes, industrial, and irrigation purposes. Access to excellent to good groundwater quality has a significant impact on public health, as it reduces the incidence of waterborne diseases. Moreover, industries can benefit from better water quality, which can lead to increased economic development and job creation. To guarantee sustainable water resource management in the future, the Ashanti Region must establish a robust groundwater monitoring system. It is important to adopt a comprehensive approach that considers surface water and groundwater as interconnected systems. Furthermore, investing in water infrastructure such as treatment plants and irrigation systems is crucial. To promote responsible water usage and conservation

Table 12
AHP ratings and weights for rainfall.

Parameter	Range (mm)	Rank	Weight	Area (Ha)	Percentage (%)
Rainfall	1348.089–1403.820	1	0.381	615787.359	25.239
	1403.824–1470.902	2		653069.276	26.767
	1470.903–1526.633	3		659673.553	27.037
	1526.634–1597.470	4		458385.219	18.787
	1597.471–1639.793	5		52937.445	2.170

Table 13
AHP ratings and weights for rainfall.

Parameter	Range	Rank	Weight	Area (Ha)	Percentage (%)
Land Use Land Cover Classification	Water Bodies	5	0.066	144699.648	5.931
	Less Dense Vegetation	5		1150203.680	47.142
	Forest Areas	5		895607.909	36.707
	Settlement Areas	1		129641.456	5.313
	Bare land Areas	1		119700.160	4.906

Table 14
Groundwater potential zone summary.

Status	Area (Ha)	Percentage (%)
Poor	18310.764	0.751
Fair	1045474.173	42.867
Good	1105160.219	45.315
Excellent	269907.697	11.067

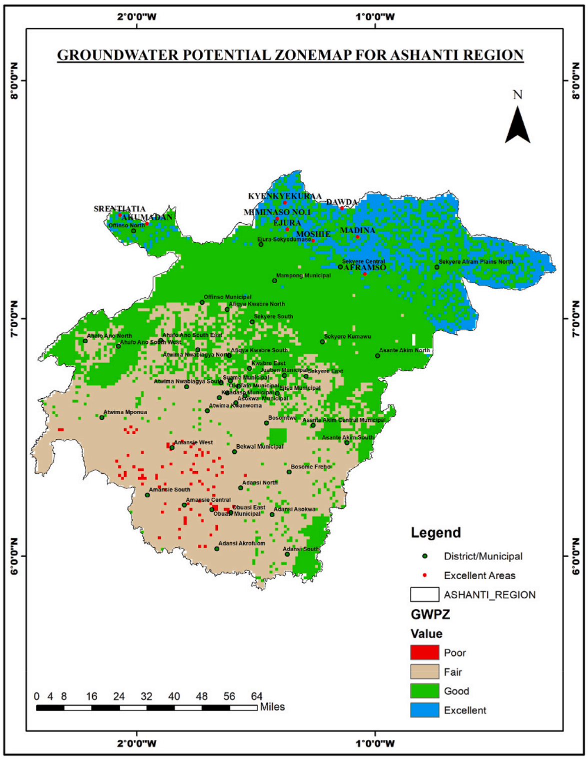

Fig. 7. Groundwater potential zone map within the Ashanti Region.

practices, public awareness campaigns should be carried out. By implementing these recommendations, the region can effectively manage groundwater resources, minimize losses, and ensure long-term sustainability. This will also help to reduce the impact of climate change on rainfall patterns and water availability, ultimately benefiting current and future generations. Farmers can use various water-saving practices to manage and use water efficiently. In South Africa, the Water Administration System helps with this, while in China, Alternate Partial Root Zone Irrigation techniques can reduce water usage by 50% while maintaining crop yield. Decision support systems like the Mycanesim technique and the Wetting Front Detector also help farmers create better irrigation schedules [39]. Therefore, policymakers and Stakeholders should ensure that areas within excellent to good WQI zone are kept safe by implementing rules and guidelines to inhabitants, industries, and the mining companies to ensure continuous protection of the groundwater resource in the area. An insignificant area within the region of the study was categorized as very poor and unfit for consumption. These results indicate that generally, the groundwater source within the Ashanti Region is fit for use. In these areas farmers can the partially treated or untreated wastewater for its farm irrigations as practiced in Israel to aid in the freshwater depletion [39]. Yeleliere et al. [40] reported that there are no clear regulations and laws enacted to protect the water resources in Ghana. However, there are customary laws in place to check the pollution of water resources. These laws are put in place by chiefs together with the local district assemblies where there are punitive actions like fines to culprits who are found polluting water bodies. Given these extra measures should be put in place to continually check the good practices of protecting water resources. This study's findings demonstrate how well geospatial tools and WQI work together to give managers a useful tool for monitoring and evaluating groundwater quality. However, the sample data size was small and clustered within an area. If more sample sizes were used and evenly distributed, it could have influenced the results of this study. Therefore, this result does not depict the overall accuracy of WQI nature in the Ashanti Region.

4.2. GWPZ within Ashanti Region

Groundwater is a vital resource that has to be replenished annually by precipitation. For recharging and an understanding of its potential in particular places, identifying prospective zones is essential. The groundwater potential-affecting characteristics were specifically dependent on the presence and distribution of the groundwater potential. Rainfall, geology, lineament density, LULC, soil type, slope, and drainage density were considered to be the most important factors influencing groundwater potential in this study. These variables were given a new classification and rated according to how important they were in affecting groundwater potential. Currently, there seems to be no recorded empirical data on the rate of groundwater extraction and replenishment as the public extraction of groundwater in the region is not monitored or regulated. However, the range of depth at which groundwater is available in the Ashanti Region is 30–100 m.

According to Fig. 7, the regions with excellent groundwater potential are found in the north of the study area, where alluvial deposits are more common. These regions have Fluvisols, Lixisols, Arenosols, Leptosols, and Gleysols soil group development. The majority of these soil types are aerated, with loamy sand and coarse sandy loam textures allowing for infiltration and percolation, which raises the potential and recharge of the groundwater. They also have a high filtration rate to allow water to flow through very easily [14,41,42]. Also, the Obosum and Oti beds geology groups were found within the excellent groundwater potential zone. This geology group contains sedimentary rocks like sandstone and limestones, they tend to be good aquifers, hence an excellent groundwater potential recharge capability. However, low rainfall areas were found within the excellent groundwater potential zones, despite higher rainfall ranges given the higher ranking and weights. Nonetheless, these excellent zones were found to be in areas with less dense vegetation, low drainage density, high lineament density, low to moderate slope, the Obosum and Oti beds, and places with alluvial deposits which compensated for the low rainfall in the region. This could have resulted in those areas having excellent potential. From Figs. 7 and 9 communities were delineated to be within the excellent GWPZ. These areas include Aframso (Sekyere Central District), Akumadan (Offinso North Municipal), Dawda (Ejura-Sekyedumase), Ejura (Ejura-Sekyedumase District), Kyenkyekuraa (Ejura-Sekyedumase District), Madina (Sekyere Central District), Miminaso NO. 1 (Ejura-Sekyedumase District), Moshie (Sekyere Central District), and Srentiatia (Offinso North Municipal). These areas can produce higher borehole yield and are very suitable regions for siting boreholes.

The study also revealed that LULC areas covered with a water body, less dense vegetation (farmlands, shrubs, and grasses), and forest areas were found within areas with good to excellent GWPZ. Good groundwater potential zones can be found in the region's central area. Obosum, Oti, and Upper Voltaian geological groups are found in areas with excellent groundwater potential. This geology type has sedimentary properties which makes them good aquifers. Due to lesser lineament density and a more evenly distributed drainage system, the region's middle portions, where rainfall is moderate, fall under the excellent GWPZ. From the study, areas with low lineament density were discovered to have a good groundwater potential. These assertions are similar to the findings of [15–17]. Groundwater potential and recharge were good in areas with a low to moderate slope and high drainage density, as demonstrated by Ref. [15]. Therefore, boreholes can be sited within these areas which in turn can have high borehole yield. The study area's lower centre region demonstrates that the region has good groundwater potential zones. These areas are made of some less dense vegetation, forest areas, settlements, bare lands, low lineament density, high slope density, high drainage density, and soil groups with less penetrating characteristics like Acrisols. Due to the high slope, high drainage density, and low permeability (Acrisols), a small section of the southern region is classified as having poor groundwater potential zones. These areas are mostly galamsey areas.

Based on the study, it was found that the regions falling under the category of excellent to good GWPZ exhibited an equally excellent to good WQI. In contrast, only a negligible percentage of the areas within the zone of very poor WQI was discovered in the fair GWPZ. This indicates that excellent to good GWPZ areas have a positive impact on the water quality index, while fair GWPZ areas have a lesser impact on the water quality.

5. Conclusions

The combination of RS and GIS creates a powerful tool that enables us to evaluate data visually and spatially. The study of the findings generated at various stages of the research showed that the integration of RS and GIS is a powerful tool for creating a variety of digital themed layers and maps displaying the spatial distribution of different water quality criteria. The water quality index (WQI) is a useful tool for evaluating and regulating water quality in the Ashanti Region. Groundwater quality varies, with 32.252%, 60.168%, and 7.550% of the study area having excellent, good, and poor quality respectively. The WQI map can serve as a guide for environmental conservation efforts and policy formulation aimed at promoting sustainable water management. By highlighting areas with poor water quality, interventions can be targeted to improve health and well-being. Ultimately, these findings have the potential to make a significant contribution to the achievement of sustainable regional development. Policymakers can manage and understand data using GIS and RS-based indexes.

An integrated GIS and AHP technique were employed to investigate the groundwater potential zones in the Ashanti Region. Geology, land use, lineament density, slope, drainage density, soil type, and rainfall were all examined using the AHP method. It was decided to divide the groundwater potential zones into four categories: exceptional, decent, fair, and poor potential. Excellent and good prospective locations are suitable for the siting of boreholes because they have higher recharge potential. The groundwater table can rise and overexploitation can be avoided with the help of synthetic recharge methods and participative strategies. The GIS-based AHP method helps manage water resources and assess groundwater development for future planning. From the research, the identified groundwater potential zones in the Ashanti Region have the potential to inform water resource management strategies, infrastructure planning, and irrigation projects. Moreover, these zones can facilitate the identification of suitable regions for agricultural output and food security. In conclusion, the findings of this study demonstrated the viability of using the GIS-based AHP approach for mapping groundwater potential. To manage water resources and conduct a thorough review of groundwater exploration and development for future planning, planners can benefit from the findings of the groundwater potential map.

The small and clustered sample data in used for the WQI delineation within the Ashanti Region may not accurately depict WQI nature, as uneven distribution could have influenced the results. Therefore, further studies on groundwater quality should include more data samples which are evenly distributed. In the future, more parameters that affect water quality could be included in the analysis of the WQI. In future studies, more parameters should be included in the analysis of the groundwater potential zone study, such as meteorological data, geomorphology data, and lithology data.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

J.N. Marfo: Writing – review & editing, Writing – original draft, Methodology. **J.A. Quaye-Ballard:** Supervision. **S.O. Kwakye:** Supervision, Conceptualization. **K. Obeng:** Supervision, Methodology. **A. Arko-Adjei:** Supervision. **N.L. Quaye-Ballard:** Supervision. **R.N.A. Quao:** Writing – review & editing, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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