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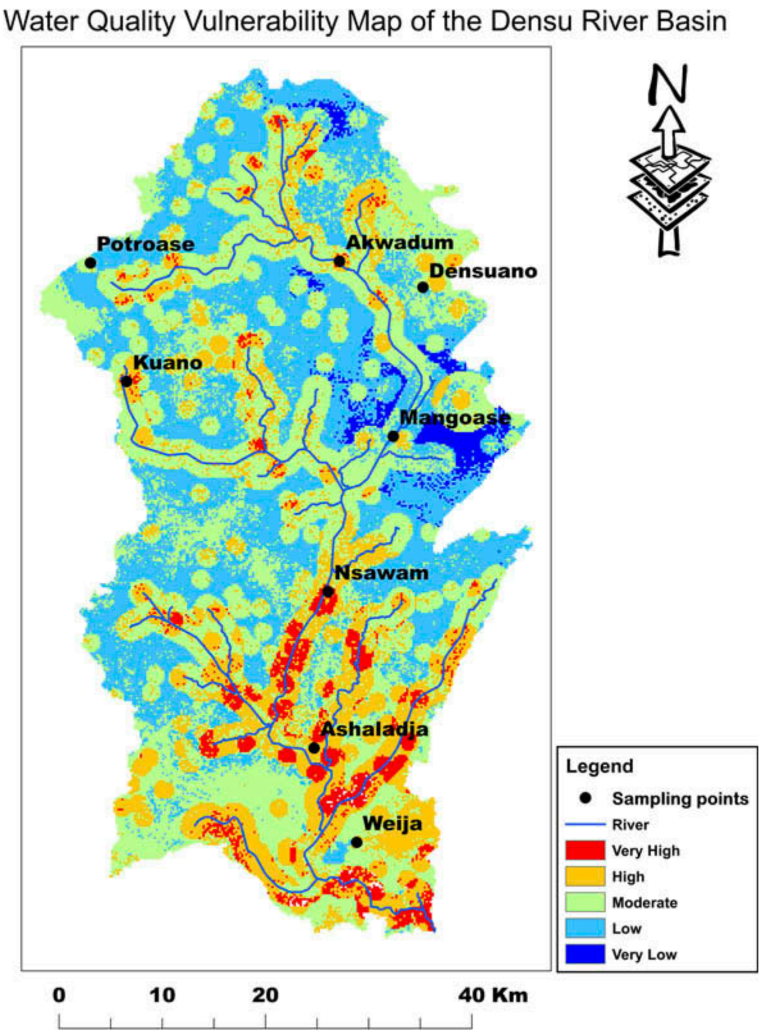

CIVIL & ENVIRONMENTAL ENGINEERING | RESEARCH ARTICLE

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Ecological vulnerability of the Densu river Basin due to land use change and climate variability

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Abstract: Ecological hazards such as floods, drought and poor water quality remain notable disparaging natural catastrophes of climate variability in West Africa. Associated hazard manifestation is an amalgamation of various factors, which require enhanced knowledge of its spatio-temporal extent. This work aims at the identification and mapping of areas prone to ecological vulnerabilities in the Densu River Basin of Ghana. This research utilized a combination of Analytical Hierarchical Process (AHP) and multicriteria methods (MCM) using dataset such as land use land cover, type of soil, slope, drainage density, rainfall variability and the community distribution in the basin, using Geospatial Technology. Vulnerability mapping models were developed for flooding, drought and surface water quality. The resulting analysis revealed that about 15% of the basin was highly vulnerable to flooding, about 1% was prone to drought and 6% was prone to poor surface water quality. It was revealed that the southernmost part of the basin was susceptible to flooding whilst communities along the tributaries of the Densu river were predisposed to flooding and poor water quality. The study further displayed the extent of vulnerability of the communities within the Densu basin. Uniquely, a combination of AHP and MCM was successfully used to map the vulnerability of a river basin. Therefore, it is now possible to extend the procedures to other river basins for the development of effective mitigating strategies for future hazards.

Subjects: Agriculture & Environmental Sciences; Environmental Management; Environment & Resources

Keywords: ecological; hazards; vulnerability; mapping; water quality

ABOUT THE AUTHOR

Samuel Anim Ofosu is a young researcher and a candidate for PhD in Water Resources Engineering and Management. He has an undergraduate degree in Civil Engineering an M. Sc degree in Water Resources Engineering and Management. His major research interest is in Water Resources Management and the Environment. This current paper seeks among other things to provide relevant information on the ecological vulnerability of river basins, to policymakers in the Ghanaian water sector.

PUBLIC INTEREST STATEMENT

Variations in land use and climate are associated with ecological hazards. These variations may cause great casualties in the environment. This paper examines the vulnerability of the Densu river basin due to changing land use and climate variability. Geospatial technology and analytical hierarchical process were utilized in this study. Vulnerability mapping models were developed for the study area. Results showed that ecological vulnerability such as flood, drought and water quality are mainly influenced by hazard indicators such as land use change, variations in climate and drainage density of the basin. These results could help in the development of ecological vulnerability adaptation strategies.

1. Introduction

Vulnerability to climate change, climate variability as well land use land cover changes has become a global phenomenon (Mattah et al., 2018), requiring attention and thorough study in order to properly comprehend the mitigation strategies to be adopted (Adger, 2002). Rapid urbanization, as well as climate variability, remain classified as the two most important situations influencing human life and welfare (Mattah et al., 2018).

The term vulnerability may be defined as the level to which a system is prone to, or incapable of handling, the adversative challenges arising out of climate extremes, climate change and variability (Moreno & Becken, 2017; Trenberth, 2012). Vulnerability research is said to have started based on the occurrence of natural ecological hazard (Füssel, 2010). The earlier studies centred on how the vulnerability of people to the effects of environment and developed into a significant feature in climate variability and policy research (Füssel, 2010; Yuksel, 2014).

Climate variability is reported to be responsible for erratic rainfalls, droughts, floods, storm flows, rising temperature and sea levels that regularly results in the devastation of human locales particularly built-up areas (Antwi-Agyei et al., 2017; Asante & Amuakwa-Mensah, 2014). Understanding the extent of vulnerability of rivers to drought situations is critical, considering the era of sustainable socio-economic development (Niu et al., 2017).

Pieces of evidence from researchers (Canencia et al., 2017; Dika, 2018; Kha et al., 2008; Rajsekhar & Singh, 2015) endorse the ideas that increasing climate variability has substantial impacts on rural ménages predominantly in sub-Saharan Africa. The effects of climate change phenomena are increasingly developing as an unparalleled global challenge to sustainable development especially among rural folks living in fringe regions with negligible livelihood options (Krause, 2016; Stephenson et al., 2010; United Nations Urban Settlement Programme, 2012).

The assessment of river basin vulnerability is not only based on risks of the hazards but also the relationship between identified hazards with other anthropological activities. Any observable variation in modern-day society—such as economic development, population increase, deforestation, urbanization, increase in residential areas, increased population and labour movement—tend to make the environment more vulnerable to identifiable natural hazards (Kha et al., 2008; Takeuchi, 2006)

The analysis of spatial and temporal information is significant to the proposal of adaptation schemes because the effects of climate and related hazards on societies differ across space and time (Eikelboom & Janssen, 2013).

Several scenarios for spatially assessing characteristics of vulnerability exist at different scales (Manyeruke & Mhandara, 2013; Shepard et al., 2012; W. Wang et al., 2012). Although past efforts generally acknowledge exposure, sensitivity and adaptive capacity as being part of overall vulnerability (Marshall et al., 2009; Virakul, 2015). According to (Weis et al., 2009; Wongbusarakum & Loper, 2011) a limited number of studies have endeavoured to model spatially, the adaptive capacity of river basins.

A study by Holsten and Kropp (2012) observed that fewer researchers have combined the various facets of vulnerability assessment into a unitary spatial map to represent vulnerability.

The significant connection between enhanced livelihoods, hunger alleviation, health and access to freshwater dictates in-depth deliberation of water vulnerability (Plummer et al., 2012). To mitigate the occurrence of natural hazards, it is expedient to develop hazard maps for identified hazards for river basins. These maps are important tools for a great level of information to help in reducing, if not totally prevent, the harm arising out of these identified hazards (Ozkan & Tarhan, 2016).

Geographical Information System (GIS) has been used to map vulnerability area in recent times. The application of GIS spans varying spheres of life—healthcare (Aboagye et al., 2017; Kenu et al., 2014), flood and drought mapping (Fadlalla et al., 2015; Lyon, 2014; Rincón et al., 2018), earthquake and fire (Rahman et al., 2015), water quality (Gandotra & Andotra, 2008; Singh, et al., 2017) and other environmental hazards (Feizizadeh & Blaschke, 2013; Tran et al., 2012; Wu, 2018).

In this study, the multi-criteria analysis system developed in the analytic hierarchy process method (AHP) as prescribed by Saaty (Saaty, 1987) and GIS were tools used for developing the hazard maps. The systems in GIS enable the spatial data to be pre-treated and unified analysis made. Furthermore, the visualization abilities of GIS make the explanation of the results from the assessment intuitionistic (Xiao et al., 2016).

The Densu River Basin in Ghana has been classified as an ecologically rich basin (Schep et al., 2016). The basin is noted to contribute meaningfully to the socio-economic progress of the country (Amoako et al., 2010; Anornu et al., 2012; Antwi-Agyakwa, 2014).

The Densu river is a major source of freshwater for the inhabitants in its watershed with urban townships that are confronted with three agents of degradation: deforestation, avantgarde agronomic and pastoral practices and also pollution. The activities of agriculturalists (agro-chemical usage) mostly commercial farmers inside the river basin are prompting several complications related to the qualities and quantities of water (Amoako et al., 2010; Zakari, 2012).

Research conducted in the Densu basin point to the fact that the basin is experiencing variations in both land use land cover and climatic systems (Benza et al., 2016; Logah et al., 2013; Matshakeni, 2016; Plessis et al., 2014). These observed variations have led to different forms of hazards and vulnerabilities (Alexander et al., 2014).

This study is aimed at assessing the vulnerability of the Densu River Basin due to land use land cover changes and climate variability. Factors related to topographic and hydrological features of the basin were considered during the assessment of hazards and vulnerability of the basin—slope, streamflow network, soil characteristics, rainfall variations, the density of towns and distance to the river.

These factors were used to establish the impact of the land use land cover change and climate variability on the vulnerability of the Densu basin. Afterwards, the study area was classified into risk levels based on identified risk condition.

2. Study area and methods

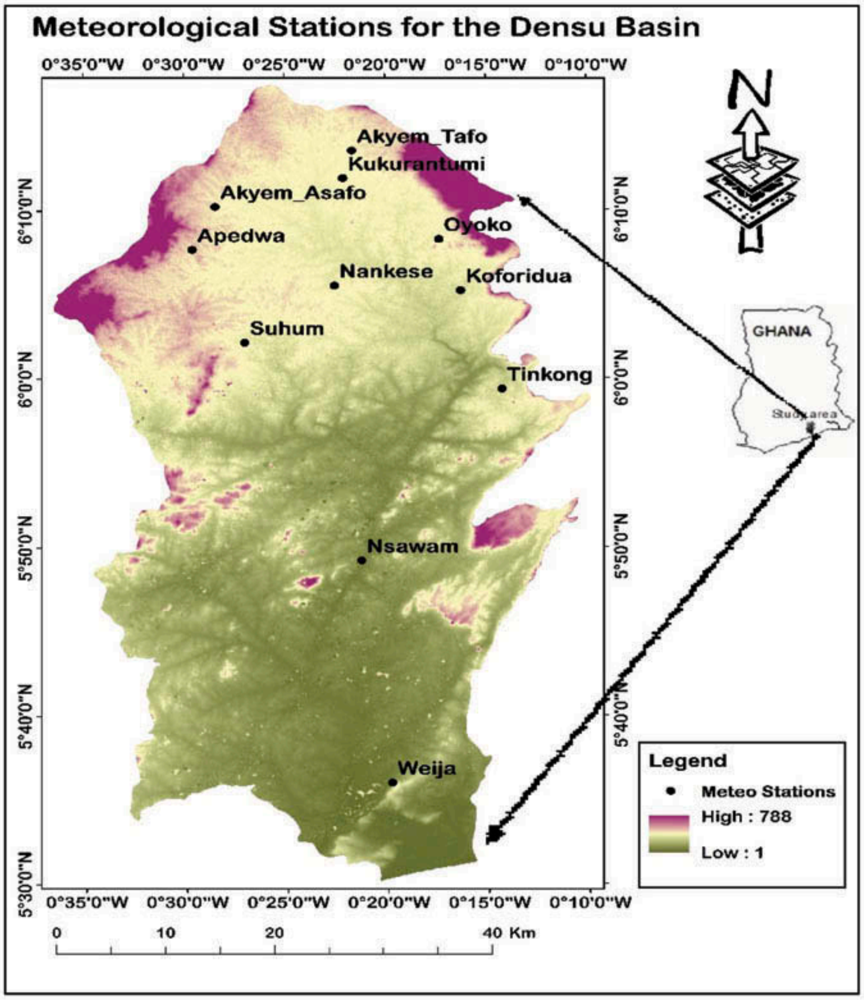
2.1. Study area

The Densu river takes its source from the Atewa-Atwiredu mountains and flows downstream through major communities such as Potroase, Akwadum, Koforidua, Nsawam, Ashaladza in a southward direction discharging into the Weija reservoir. The RAMSAR site receives the excess discharges from the Weija reservoir. Densu delta is one of the significant RAMSAR locations in Ghana. The stream discharges into the Gulf of Guinea. The Densu river travels a distance of about 120 km (Ansa-Asare & Gordon, 2012; Osei et al., 2016).

The Densu Basin is one of the coastal watersheds in Ghana and it covers a land area of almost 2,600 km^2. The basin bounded by latitudes 5°30′ and 6°17′ N and longitudes 0°10′W and 0°37′ W (Figure 1). The basin spans 12 District, Municipal and Metropolitan Assemblies in three regions (i.e. Central Region, Eastern Region and the Greater Accra Region) (Alfa, 2010; Alfa et al., 2011).

Based on the 2010 population census (Ghana Statistical Service, 2013) around 300 communities are located in the Basin and the total population is estimated to be 1.2million. This value is

Figure 1. Map of the Densu river Basin.



equivalent to about 460 persons per km^2, which is far higher than the national average population density of 77 persons per km^2 (WRC-Ghana, 2007).

The Densu river is the main source of freshwater supply to the population residing in urban communities such as Nsawam, Akyem-Tafo, Koforidua, Suhum and the western portions of Accra (Kasei et al., 2014).

2.2. Methods

2.2.1. Vulnerability indicators

The indicators that influence the vulnerability of a river basin were selected based on three factors—literature review which provided scientific pieces of evidence, in-depth interviews with key informants that gave expert opinions and prevailing conditions of the basin provided leads (Fadlalla et al., 2015; Kim et al., 2016). The vulnerability indicators used for the determination of ecological hazard zones served as proxies for different situations (Birkmann, 2007).

The thematic maps of indicators such as Rainfall variation, slope of the basin, drainage networks, soil type, land use land cover (Ajin et al., 2013), road network, water quality index, distribution of towns around the basin were assigned weights for each class (Herrera et al., 2018; Rincón et al., 2018; N. Sharma et al, 2010).

Climate data were obtained from the Ghana Meteorological Agency (GMet) for twelve (12) meteorological stations located across the study area (Figure 1). The longitude and latitude for each station were provided by the GMet. Daily rainfall data available from 1976 to 2015 was made available by the GMet. The mean annual rainfall variation for each station was determined. The rainfall interpolation map was generated using the Inverse Distance Weighted method (J. Li & Heap, 2014; Lu & Wong, 2008).

The drainage system of the basin was created using GIS software. Any form of hydrologic modelling includes demarcating streams and watersheds boundaries having some basic information on the flow length and stream network density (Fadlalla et al., 2015; Merwade, 2012).

The map for the soil types of the basin according and displayed in the GIS layer. Soil types were ranked based on proficient judgement bearing in mind the texture and orientation for causing a flood and other environmental hazards (Boer, 2016; FAO/IIASA/ISRIC/ISS-CAS/JRC, 2009, 2012). The soil categories in the study area are vital since they regulate the volume of water that can penetrate the soil profile and hence the quantity of water which turn into outflows (Ajin et al., 2013).

The slope of a river basin plays an essential role in the stability of the basin. The slope controls the course and the volume of surface runoff as well as the subsurface drainage (Dai et al., 2002). The map of the slope was developed from the Digital Elevation Model (DEM) of the basin.

The land use land cover changes of the study area are of prime concern because this indicator not only replicates the existing use of the land and categories of its use but also its importance considering the population growth and its connection with the prevailing growth (Fadlalla et al., 2015; Sakyi, 2013).

A road is one of the significant anthropogenic features inducing ecological hazards. Roads and related structures cover portions of the land area and have less capacity to accumulate rainfall (Prasad & Narayanan, 2016). Generally, construction activities often encompass clearing vegetation and forms of depressions from the land surface. The permeable soil is usually substituted by impervious surfaces such as road and rail network, which reduce penetration of water into the soil thereby accelerating surface runoff (Ajin et al., 2013).

The Water Quality Index (WQI) is a system that applies an index determined from carefully chosen water quality parameters. The index categorizes water quality into five classes ranging from excellent quality, good quality, fairly good quality, poor quality and grossly polluted. Each classification defines the water quality relative to approved guidelines such as the World Health Organization or the Ghana Water Standard (Ansa-Asare & Gordon, 2012; Deh et al., 2017; Kulinkina et al., 2017; Usman et al., 2018).

The Water Quality index of a River is calculated based on nine paramount parameters (Table 1)

The resultant WQI values from eight (8) sampling points for four sampling period (two sampling period per season—wet and dry) were analysed based on Table 2.

With reference to Figure 2, the average water quality of the Densu river lies within the medium class. The result supports the findings of earlier researchers that pollution of the Densu river is very alarming and requires urgent attention (Amoako et al., 2010; Karikari & Ansa-Asare, 2009; Paintsil & Abrahams, 2008).

2.2.2. Multi-criteria analysis

Multi-criteria decision analysis (MCDA) helps the decision makers in scrutinising probable activities or alternatives based on various criteria, by means of decision rubrics. There is the necessity to aggregate the identified criteria to rank the other possible alternatives (Chen, 2014; Yahaya et al.,

Table 1. Water quality index parameters (Akinbile & Omoniyi, 2018)

S/N	Parameters	Units
1	pH	-
2	Total Coliform	CFU/100 ML
3	Phosphate	Mg/l
4	Total Solids	Mg/L
5	Nitrate Dissolved Oxygen	Mg/l
6	Biochemical Oxygen Demand	Mg/l
7	Temperature	°C
8	Dissolved Oxygen	Mg/l
9	Turbidity	NTU

Table 2. Water quality ranges and interpretations

Water quality index ranges	Interpretation
90–100	Excellent
70–90	Good
50–70	Medium
25–50	Bad
0–25	Very Bad

2008). MCDA tools are generally deemed to be suitable for making key decisions in conflicts associated with river basin management (Jaiswal et al., 2015).

The Saaty's Analytic Hierarchy Process (AHP) (Goepel, 2017; Saaty, 1980) is considered to be the most frequently used MCDA tool that applies hierarchical structures to characterize a challenge and then generate priorities for the alternatives grounded on the evaluator's judgment (Taherdoost, 2017).

The AHP technique decreases the complication of a decision made due to a categorization of pairwise comparisons, which is usually produced in a ratio matrix that offers a clear rationale for collation of the decision alternatives starting from the greatest to the less desirable (Feizizadeh & Blaschke, 2013).

The ratio matrix or comparison matrix amongst the identified criteria was developed using the AHP model, which was then used to calculate an eigenvector. The resultant eigenvector eventually characterized the ranking of the criteria. An intensity of significance was connected for all probable alternatives and a comparison matrix generated by iterating the procedure for individual criterion (Sumathi et al., 2008).

By means of the comparison matrix between the alternatives and based on the evidence from the ranking of the criterion, the AHP model then created an overall ranking of the results. The alternative having the highest eigenvector ranking was selected as the foremost choice (Gbanie et al., 2013; Gupta, 2017; R. Sinha et al., 2008).

By means of the analytic hierarchy process elucidated, the pairwise comparison matrix (Table 7.3) was designed via the scale of 1–9. The level 9 designates extreme importance and 1 shows the equal worth of a criterion of the matrix (Table 3; Coyle, 2004; Saaty, 1987; Xiao et al., 2016).

Figure 2. Water quality index for the Densu river for 2017–2018.

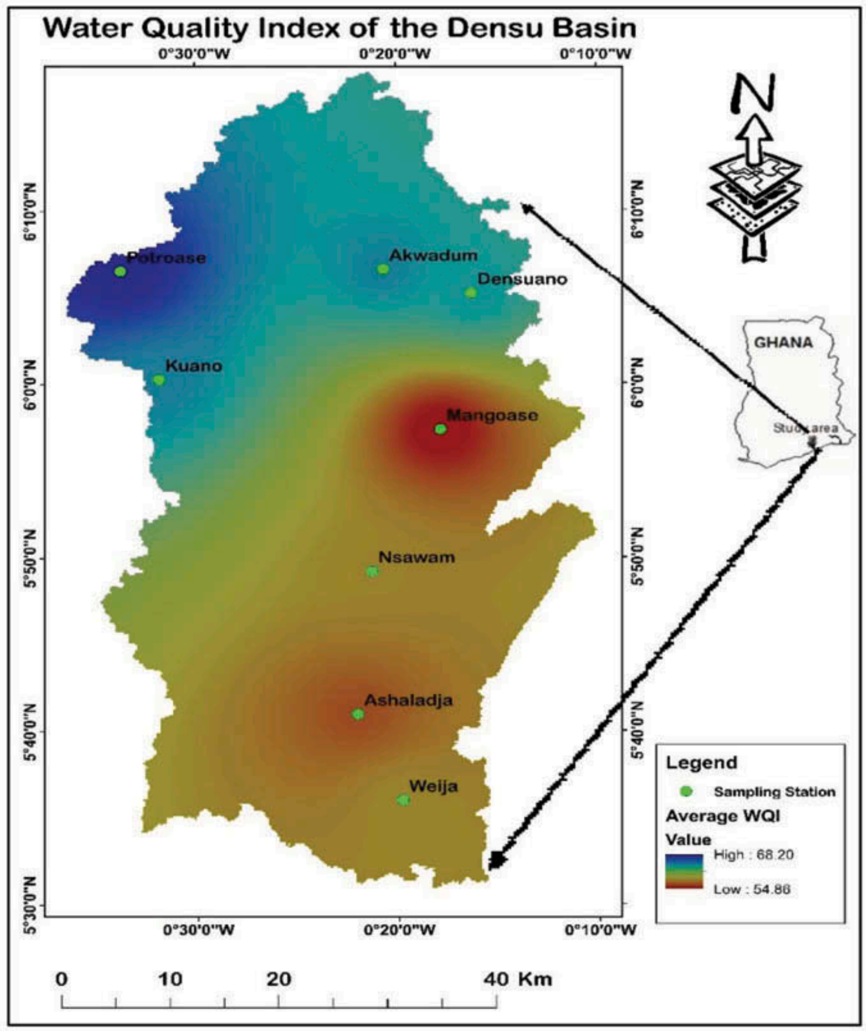


Table 3. Scale for pairwise comparison		
Intensity of Importance	**Definition**	**Explanation**
1	Equal Importance	Two elements contribute equally to the objective
3	Moderate Importance	Experience and Judgement slightly favour one element over another
5	Strong importance	Experience and judgement strongly favour one element over another
7	Very strong importance	One element is favoured very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one element over another is of the highest possible order of affirmation
Intensities of 2,4,6 and 8 can be used to express intermediate values		

Lastly, the consistency ratio (CR) was calculated to validate the consistency of responses in relation to hazard indicators. The values of CR obtained used a priority vector which has been emphasised by numerous researchers in AHP (Johnston & Graham, 2013; Ouma & Tateishi, 2014; Wackernagel et al., 2017; Yahaya et al., 2008). A major strength of the AHP method is that it makes room for erratic relationships whiles making CR as a pointer of the degree of inconsistency or consistency (Feizizadeh & Blaschke, 2013)

CR values measure the reliability of the responses which may perhaps be upheld only when the consistency ratio less than or equal to 0.10. According to (B. Song & Kang, 2016) the introduction of specialized commercial software, the calculation of CR values could be done easily. The calculation of CR values is based on Equation 2.1

$$CR = \frac{CI}{RI} \tag{2.1}$$

where RI represents the Random index, and CI explains the consistency index. These measures provide information on the departure of the CR values from consistency.

The consistency index is calculated from Equation 2.2

$$CI = \frac{\lambda - n}{n - 1} \tag{2.2}$$

where λ represents the mean consistency vector, and n is the number of criteria.

The random index measures the consistency index of the randomly created pairwise comparison matrix. The random index greatly hinges on the number of elements being related (Drobne & Lisec, 2009).

2.2.3. Weighted overlay analysis of hazard and mapping

In ecological hazard mapping, several causal factors are critical and worth consideration of the researcher. Preceding studies (Awanda et al., 2017a, 2017b; Carvalho et al., 2007; Mahmoud Ibrahim, 2016) used hazard indicators such as annual rainfall, watershed size, topography or slope stream network or drainage density (Dd), land use land cover changes and soil, communication lines and general infrastructure and water quality indices to rate potential hazard by means of a weighted method.

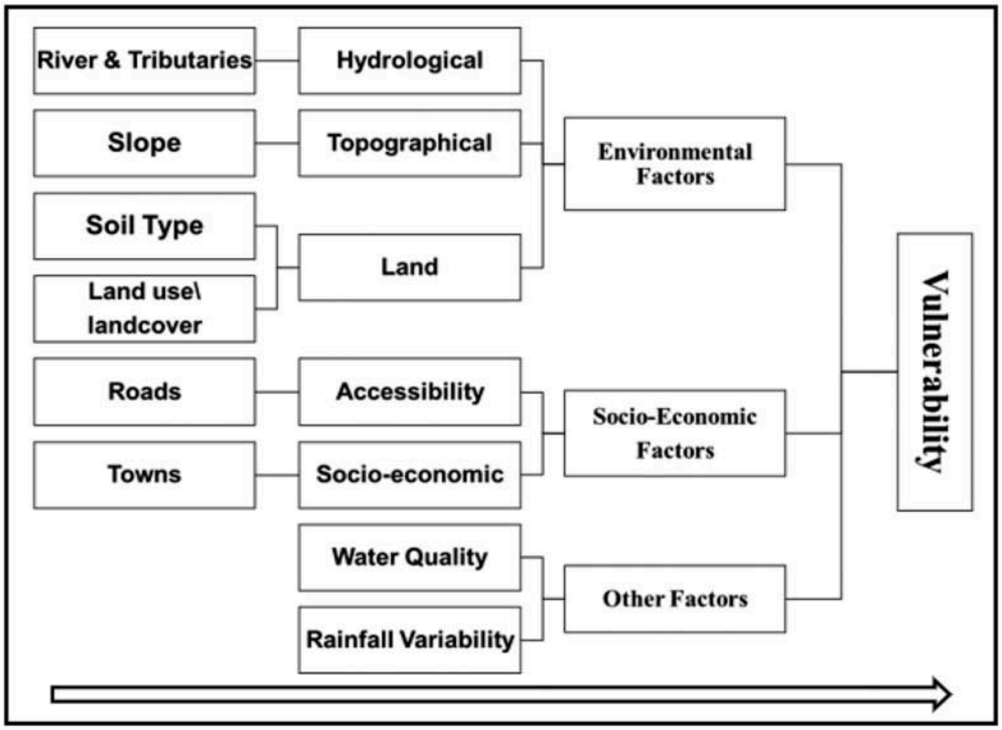
Flood Risk Index (FRI) was proposed by Surjit and Kaushik in a study conducted in 2012. The FRI method used GIS to evaluate the risk levels and vulnerability as experienced by the Ghaggar basin in India to flood hazards based on factors such as slope, soil category, hydrology, drainage density and LULCC (Surjit & Kaushik, 2014).

Other academics have contributed several criteria and varying concepts for assessing ecological hazards (Ajin et al., 2013; Forkuo, 2010; Mahler et al., 2012; N. Sharma et al., 2010; N. Sinha, et al., 2016). To successfully assess hazards and ecological risk in the Densu Basin based on the available dataset, various applicable features such as LULC map, slope, drainage network, rainfall variability, average water quality index, road network, towns and watershed map were aggregated using weighted overlay method (Figure 3). The weighted overlay analysis used here is an effective technique to delineate ecological hazard risk zones for the Densu basin. The resulting maps can be used for developing emergency response systems.

2.2.4. Weighted linear combination

The weighted linear combination also known as the simple additive weighting is constructed based on the principle of a weighted average. The weighted average is a criterion that is standardized to a numeric range and then combined with other attributes by means of weighted averages. It

Figure 3. Conceptual framework for weighted overlay.



behoves on the decision maker to allocate the weights based on the relative importance of the attributes directly linked to each feature map layer (Drobne & Lisec, 2009; Fernández & Lutz, 2010).

The overall score for every alternative was attained by multiplying the importance weighting allotted to the attribute by the ranked value given. The resultant scores were evaluated for all alternatives and then the alternative having the uppermost overall score was selected. The weighted linear combination method was implemented by means of a GIS system that provided overlay capabilities and permits the assessment criterion map layers to be linked to determine the merged map layer output (Drobne & Lisec, 2009).

By means of the weighted linear combination, features were put together by providing a weight to each feature and then linked by a sum of the outcomes to result in a suitability map of the hazard being assessed (Drobne & Lisec, 2009).

The suitability map of the hazard could be determined using Equation 2.3

$$S = \sum(w_i x_i) \tag{2.3}$$

$$S = \sum(w_i x_i). \prod c_j \tag{2.4}$$

where

S is hazard suitability,

w_i is the weight of factor *i*, and

x_i refers to the standardized score of the criterion (*i*),

c_j refers to the criterion score of the constraint j.

In situations where Boolean constraints may be applied, the procedure (Equation 2.3) could be adapted by multiplying the suitability determined from the features by the product of the identified constraints (Equation 2.3; Drobne & Lisec, 2009; Gorsevski et al., 2006).

3. Results and Discussion

3.1. Land use land cover changes

The land use, land cover of the Densu Basin for the year 2017 were grouped into five classes: Dense forests, mixed forests, agricultural lands, settlement and waterbody.

The area of each class is shown in Table 4 with the corresponding graphical representation of the LULCC in Figure 4

The land usage and administration of the Densu basin remain the primary challenge of the basin board (Figure 4). It is also significant due to its relation to the population density as well as existing development in the basin. The vegetation cover–grassland, crops forests or bare ground influences the water storage capacity of the basin.

Rainwater runoff is considered probable on bare fields than fields with ample crop cover. Thick vegetative cover tends to reduce the movement of water from the atmosphere to the soil and thence causes a reduction in the volume of runoff (Ajin et al., 2013).

3.2. Rainfall variation

In order to study the relative long-term variations in annual rainfall across the Densu basin from 1976 to 2015, the coefficient of the annual precipitation variations for eight (8) stations was analysed and plotted. The inverse-distance weighting (IDW) method of interpolation (Lu & Wong, 2008) was used to plot the rainfall variations (Figure 5).

High intensities of rainfall are associated with flood scenarios. The mean annual rainfall was estimated for each station.

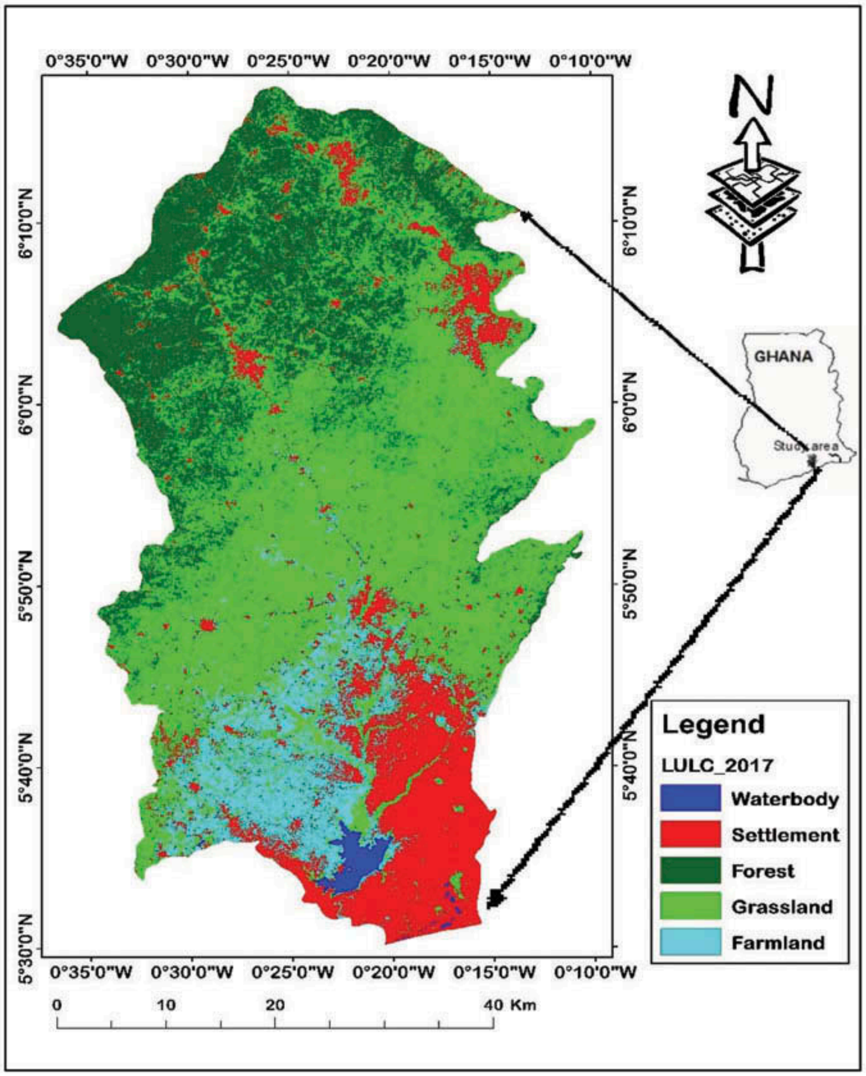
3.3. Hydrology and drainage density

High drainage concentration values are major contributors for runoff and then indicate the flood occurrence. The drainage system data for the Densu basin (Figure 6) was transformed into a GIS compatible format (Ajin et al., 2013).

Table 4. Land use classes for 2017

S/N	Land use classes	Area (ha)	Percentage (%)
1.	Waterbody	2846.86	0.84
2.	Settlement	50,318.3	18.95
3.	Dense Forest	71,050.6	26.75
4.	Mixed Forest	111,136	41.85
5.	Agricultural land	30,823.8	11.61

Figure 4. Map of the land use of the Densu river Basin for 2017.



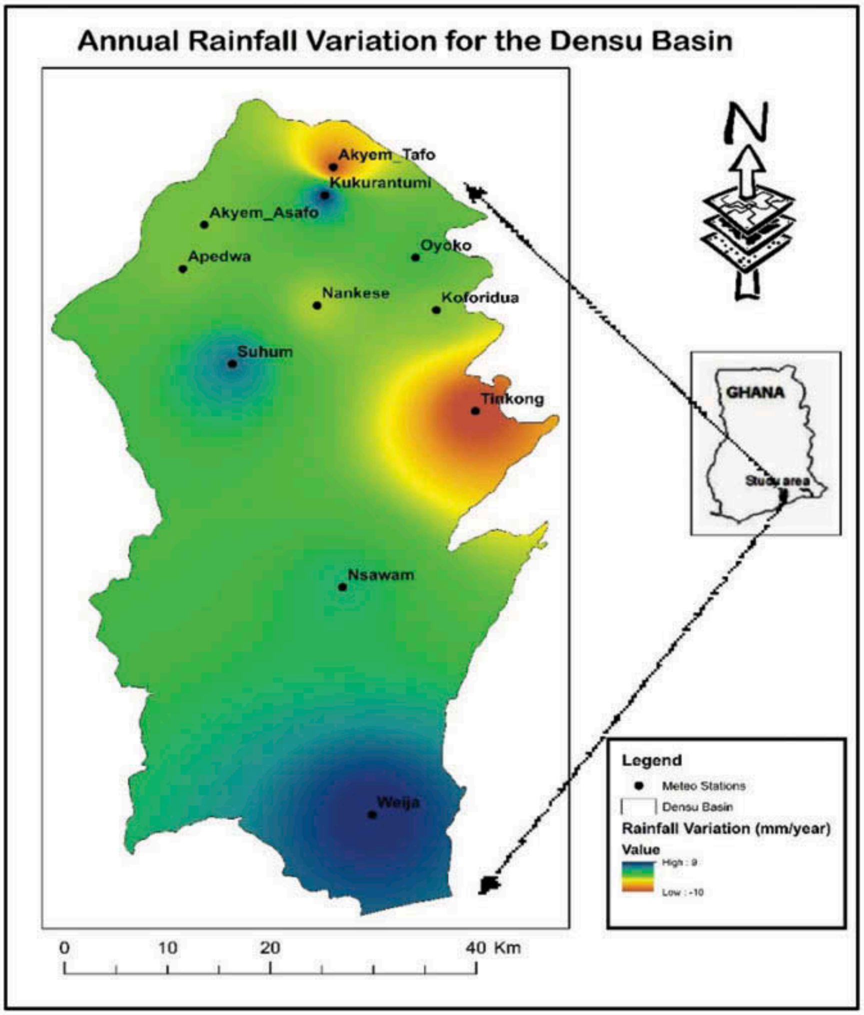
3.4. Slope, soil and communication network

Slope or topography of river basins plays an essential part in directing the runoffs reaching a specific point in the basin. Sharp slopes tend to create more velocity relative to lower slopes. Steep slopes can generate the runoff faster. For terrains that range from flat to mild or gentle slopes, runoff is usually stored over a large expanse and it is disposed out steadily over a period of time. Consequently, lower slopes mostly located at lower reaches are extremely vulnerable to flood incidences when related to relatively higher slopes (Gupta, 2017).

In the Densu river basin, the slope distribution across (Figure 7) has about 21% of the basin within the flat to gentle slopes (0-5%). Around 29% of the basin fall within 5-10% slope region whilst the rest of the basin have slopes ranging between greater than 10%. It is worthy of note that about 16% of the basin have slopes higher than 20%.

The areas within 0-5% slopes were note to be highly susceptible to flooding whilst the areas within slopes greater than 20% always battle with drought situations. The topography in the basin ranges from 850 m above mean sea level in the Northmost part to 42 m above mean sea level on the southern part of the basin (Adomako, 2010; Obeng, 2005; Owusu, 2012).

Figure 5. Annual rainfall variation for Densu Basin.



The soil categories identified in the Densu basin are vital because the soils control the volume of water that can penetrate the soil and also the quantum of water that ultimately develops into flows (Ajin et al., 2013; Ozkan & Tarhan, 2016).

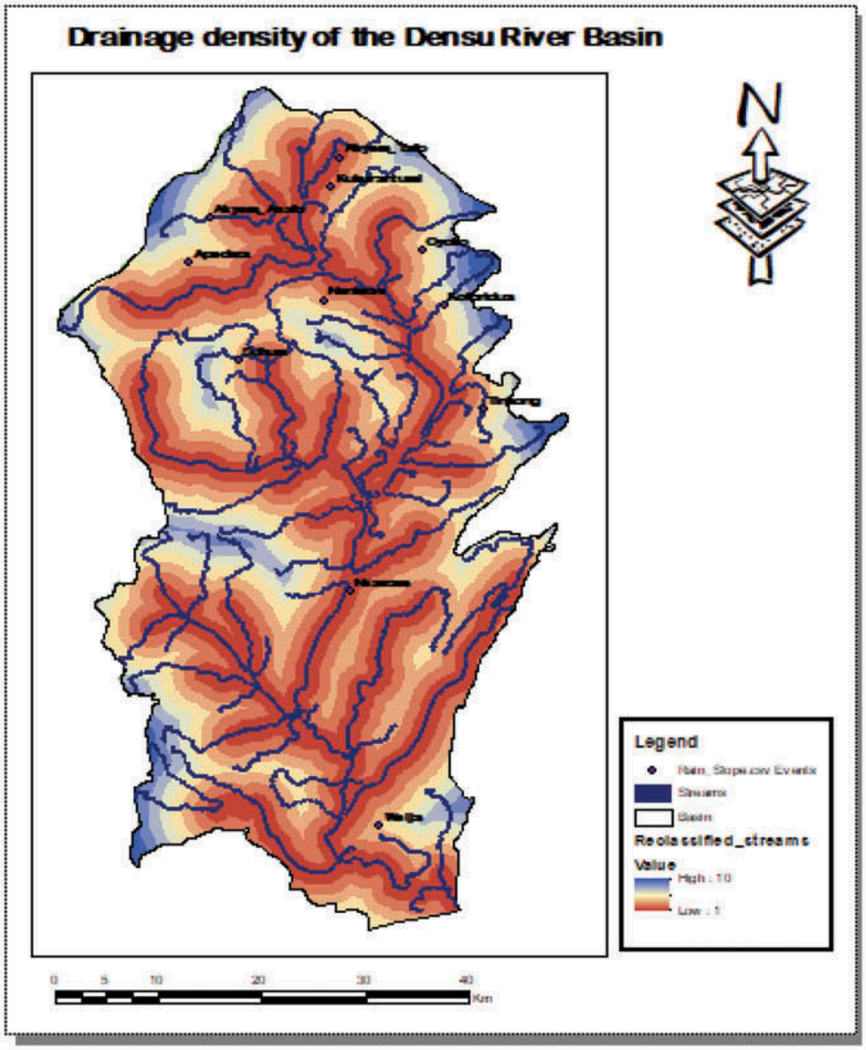
The most important soil categories in the Densu basin (Figure 8) comprise of Acrisols, Arenosols, Leptosols, Luvisols, Fluvisols, Lixisols, Solonetz, and Plinthosols with the luvisols being dominant in the basin (Owusu, 2012). The Densu basin is underlain largely by granites and granodiorites of the Pre-Cambrian series which lies within the Dahomeyan granitoid and homogeneous rocks, metamorphosed magma, schists tuffs and greywacke. (Adomako, 2010; Obeng, 2005; Owusu, 2012).

The road network of the basin connects the over 300 communities that are located in the basin. The classes of roads identified in the basin include Highways, Arterial and sub-arterial, urban roads, feeder roads. These roads were considered as vector data used for creating a road density map of the study area. The urban road density map is shown in Figure 9.

3.5. Water quality index

Research conducted in the Densu basin (Fianko et al., 2009; Karikari & Ansa-Asare, 2009) has revealed that the quality of the Densu river has been declining greatly. This decline is been

Figure 6. Drainage density of the Densu Basin.



attributed to anthropogenic activities, climatic variations and other natural ecological processes (Akbar et al., 2013).

The average Water quality index for the Densu river during the study period showed that the quality index of the densu river ranged between 54 and 70.

The average Water quality index for the Densu river (Figure 10) during the study period showed that the quality index of the densu river ranged between 54 and 70.

3.6. Analytical Hierarchy Process

Based on expert opinions from literature, interviews with environmental health officers, municipal and regional extension officers, assembly members and unit committee members as well as opinion leaders, the environmental vulnerability indicators for the basin were identified.

The vulnerability indicators that related to the Densu river basin include rainfall variation (Kurukulasuriya & Rosenthal, 2003; William et al., 2017; Zope et al., 2016), land use land cover changes (Matshakeni, 2016; Mohmmed et al., 2018; Ortolani, 2013; Ouma & Tateishi, 2014), slope or topography (Fadlalla et al., 2015; Ozkan & Tarhan, 2016; Rincón et al., 2018), density of the drainage networks

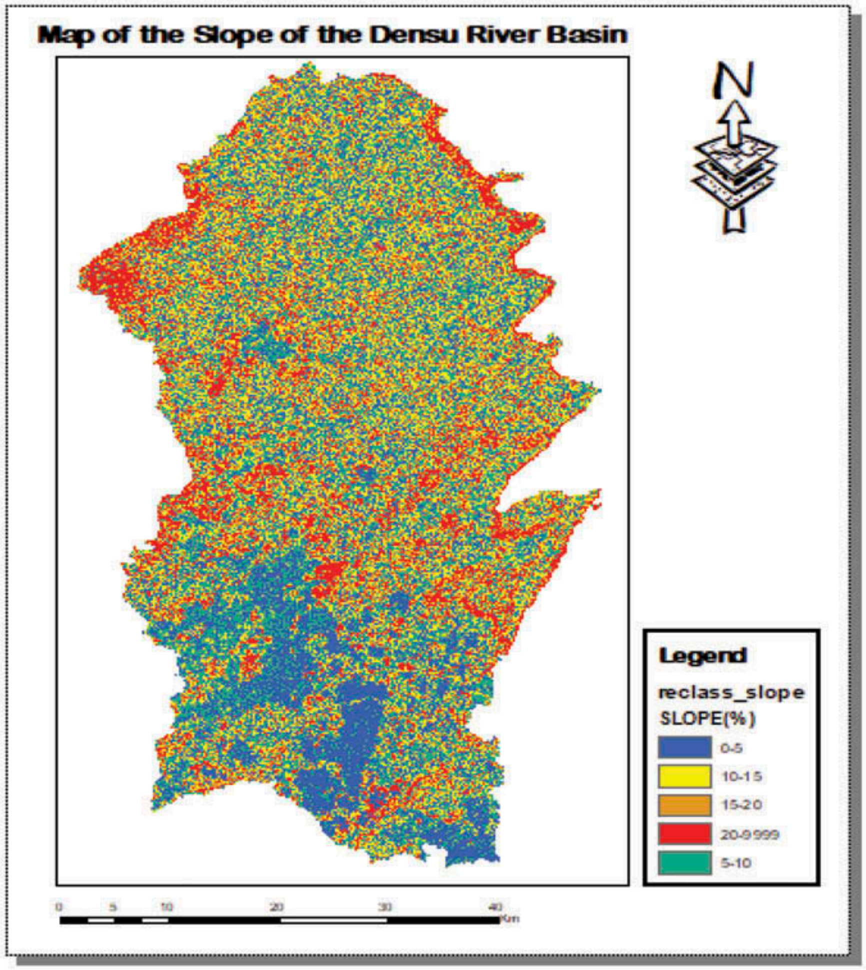


Figure 7. Slope map of the Densu river Basin.

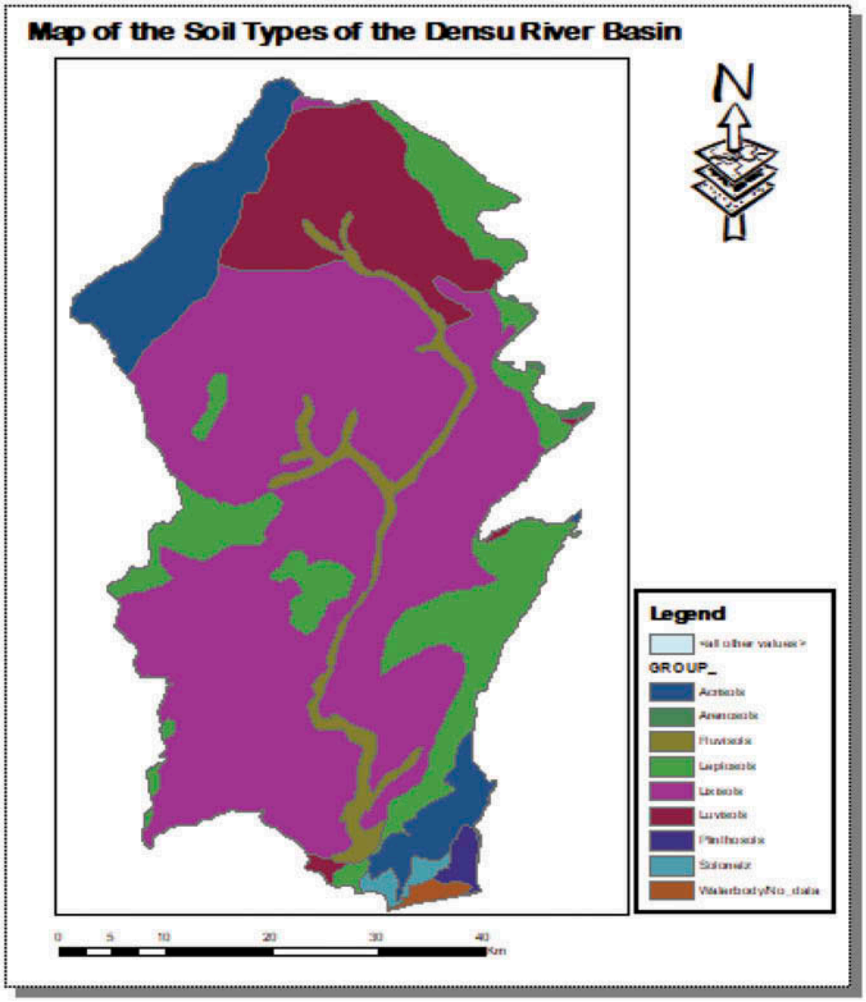
(Mohmmed et al., 2018; S. K. Sharma, et al., 2015), soil type (Ntajal et al., 2017; Nyamekye et al., 2018; Xiao et al., 2016) and water quality (Hazbavi et al., 2018; A. Li et al., 2006; X. Wang et al., 2015).

The distribution of communities around the basin and road networks, population density are the factors that were used to measure risks and effects of the hazards and adaptive capacity (Ahmad & Simonovic, 2013; Ryu et al., 2017; G. Song et al., 2015). According to Sakyi (2013), flooding may lead to damages to infrastructures such as bridges, roads, flood management systems, telephone and light poles.

The analytical hierarchy process (AHP) advanced by Saaty (1980) was used to determine the levels of importance of designated causal indicators. The pairwise comparison matrix of causal criteria (Table 5) was used as a tool for the measurement of the levels of significance of the specific criteria used. Also, the pairwise comparison was used to regulate how the assessed variants achieve the tenacity of these individual criteria (Zeleňáková et al., 2018).

The ranking of the criterion (Table 6) has rainfall variability contributing to about 30% of the environmental vulnerability in the Densu basin. This is followed by a distribution drainage network (24%), LULCC (15%) whilst road network and soil type having lower influences. The flood or drought vulnerability is greatly linked with rainfall variation, drainage density and the land use change of an area.

Figure 8. Soil map of the Densu river Basin.



The value of Consistency Ration = 9.8% (Table 7), which is lower than the threshold value of 10% and it showed a high degree of consistency. Therefore, the weights and rankings can be accepted (Yahaya et al., 2010).

Weighted Linear Combination (WLC) method is an approach for producing a suitability map by combining the factors that are being employed based on a predetermined weighting and then followed by a sum of the outcomes. The Vulnerability suitability map was then generated.

Equation 3.5 defines suitability design.

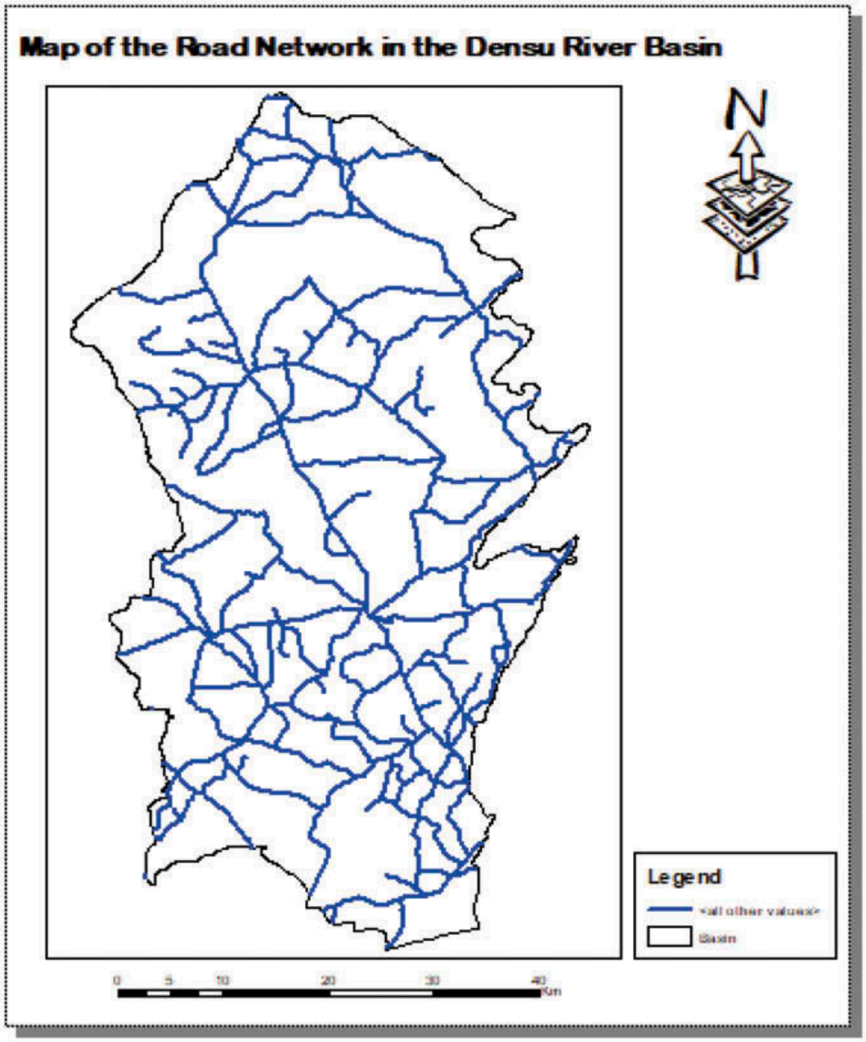
Equation 3.6 and Equation 3.7 models the suitability map for the Densu basin

$$Suitability = \sum_{i=1}^{n} w_i C_i \tag{3.1}$$

$$S = c_1 \times Rv + c_2 \times H + c_3 \times L + c_4 \times W + c_5 \times Tn + c_6 \times Rds + c_7 \times Sp + c_8 \times So \tag{3.2}$$

$$S = 0.30 \times Rv + 0.24 \times H + 0.15 \times L + 0.12 \times W + 0.07 \times Tn + 0.05 \times R + 0.05 \times Sp + 0.03 \times So \tag{3.3}$$

Figure 9. Road Network of the Densu Basin.



3.7. Flood Vulnerability Analysis

The criterion weights for the development of the flood vulnerability map of the Densu basin, as well as the normalized weights, were decided on by ranking and applying the weighted overlay analysis in GIS, using the modified version of Equation 3.3.

The weighted overlay analysis was based on Equation 3.4

$$FVA = 0.35 \times Rv + 0.26 \times H + 0.17 \times L + 0.07 \times Tn + 0.04 \times Rd + 0.05 \times Sp + 0.03 \times So \tag{3.4}$$

All the Thematic maps were transformed into raster maps and then incorporated into Equation 3.4 which was modelled in GIS software. The normalized weight of the respective criteria was also adopted in the analysis.

The flood vulnerability of the Densu basin was classified into 5 classes. The classifications of the flood vulnerability for the Densu basin (Table 8) ranged between Very high vulnerability to Very low vulnerability.

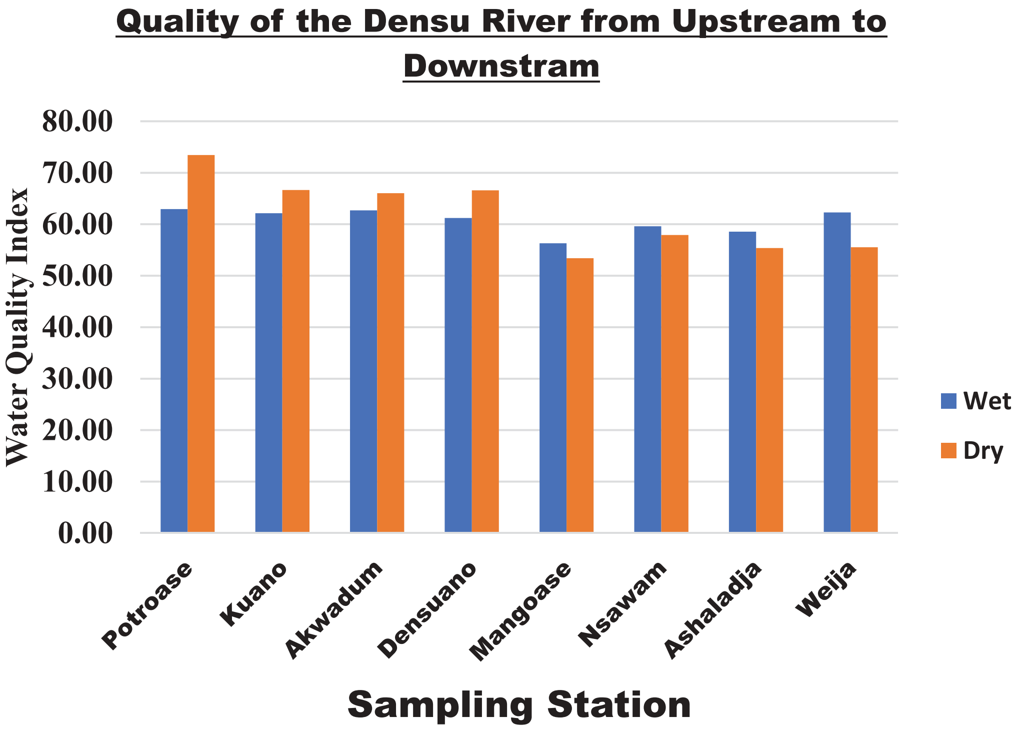


Figure 10. Water quality index for sampling stations.

The flood zones of the Densu Basin (Figure 11) and the corresponding distributions (Figure 12) indicates that about 15% of the basin is highly vulnerable to flooding, High vulnerability (52%), moderate vulnerability (28%) and low to very low vulnerability make up about 6% of the Basin.

The above results represent the potential flood situation based on the land use land cover changes for 2017. These findings support results of (Onuigbo et al., 2017) which concluded that slope, land use land cover, soil type, rainfall variations are the main factors that influence flooding.

The flood vulnerability of the basin was classified into 5 classes. The classifications of the flood vulnerability for the Densu basin (Table 8.) ranged between Very high vulnerability to Very low vulnerability.

The Greater Accra Region of Ghana, which forms the major region for the southern part of the basin is highly prone to flooding. Communities such as Ablekuma, Nsakina, Oblogo, Awoshie, Malam, Ashaladza are some of the localities that suffer damaging effects of flooding in the basin.

According to the IWRM report (WRC, 2014; WRC-Ghana, 2007) on the Densu basin, the riparian districts located in the Greater Accra Region have the highest population densities in the basin which influences the socio-economic risks resulting from the high flood hazards in the basin.

This supports the results demonstrated in Figure 13 that outlined the flood-prone zones in the basin. The Districts in the Greater Accra Region contribute about 55% of the flood-prone zones in the basin whilst the Districts in the Eastern and Central Regions make up 40% and 5% respectively.

3.8. Drought vulnerability analysis

Drought has been classified amongst the most significant socio-ecological disasters touching humanity and the environment (Núñez et al., 2017). Drought usually denotes lack of water relative to normal environmental conditions (Van Loon et al., 2016). Four types of drought vulnerabilities

Table 5. Pairwise comparison matrix for criteria for vulnerability analysis

Matrix		Water Quality	LULCC	Soil type	Slope	Rainfall variation	Road	Hydrology	Towns	Normalized Principal Eigenvector
		1	2	3	4	5	6	7	8	
Water Quality	1	0	1/2	4 5/7	3 3/4	1/5	5 1/8	2/7	2 5/7	11.87%
LULCC	2	2	0	5 5/9	2 3/7	1/3	4 4/5	1/3	3 4/7	14.64%
Soil type	3	1/5	1/6	0	2/7	1/5	1	1/5	1/5	2.90%
slope	4	1/4	2/5	3 4/9	0	1/5	4/5	1/5	1	4.99%
Rainfall variation	5	5 1/7	3 1/7	5 1/7	5 1/6	0	5 1/3	1 1/3	5	30.04%
Road	6	1/5	1/5	1	1 1/4	1/5	0	3/5	1/3	4.62%
Hydrology	7	3 5/9	2 7/8	5 1/6	5 2/9	3/4	1 2/3	0	5 4/9	24.13%
Towns	8	3/8	2/7	5	1	1/5	3 1/3	1/5	0	6.82%

Table 6. Ranking of vulnerability criterion

Criterion		**Comment**	**Weights**	**Rank**
1	Water Quality	Water Quality	11.9%	4
2	LULCC	Land use land cover change	14.6%	3
3	Soil type	Soil type	2.9%	8
4	Slope	Slope or topography	5.0%	6
5	Rainfall variation	Rainfall Variation	30.0%	1
6	Road	Road network across the basin	4.6%	7
7	Hydrology	Drainage Network of the basin	24.1%	2
8	Towns	Towns	6.8%	5

Table 7. Consistency analysis

Eigenvalue				**Lambda (λ):**	**8.963**	
Consistency Ratio	0.37	GCI:	0.35		CR:	9.8%

Table 8. Flood vulnerability classes

S/N	**Classification**
1	Very High
2	High
3	Moderate
4	Low
5	Very Low

were identified—Meteorological drought, Agricultural drought, Hydrological drought and Socio-economic drought (Hagenlocher et al., 2019; Van Loon et al., 2016; Yang et al., 2017).

This study focused on meteorological drought because climate variability results in precipitation deficit that initiates meteorological drought (Hagenlocher et al., 2019). The criterion weights used for generation of the drought vulnerability map of the Densu basin and also the normalized weights were arrived at by grading and applying the weighted overlay analysis in GIS.

The weighted overlay analysis was based on a modified version of Equation 3.3 which culminated into Equation 3.5

$$\mathrm{DVA} = 0.35 \times Rv + 0.26 \times H + 0.17 \times L + 0.07 \times T + 0.04 \times Rd + 0.05 \times Sl + 0.03 \times So \tag{3.5}$$

The ranking of the criterion was modified to suit the weighted overlay analysis. Areas closer to stream channels had a lower ranking. Higher topographic locations were considered to be susceptible to drought compared to lowlands (Maleknia et al., 2017; Mohmmed et al., 2018).

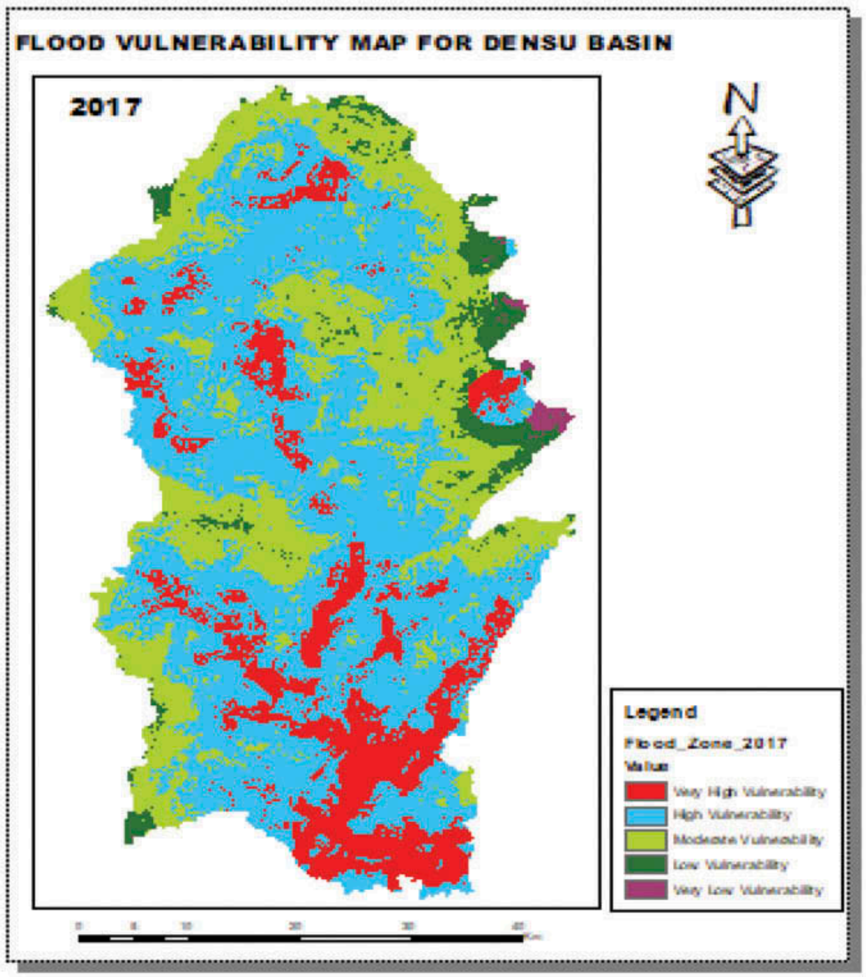


Figure 11. Flood zones of the Densu river Basin.

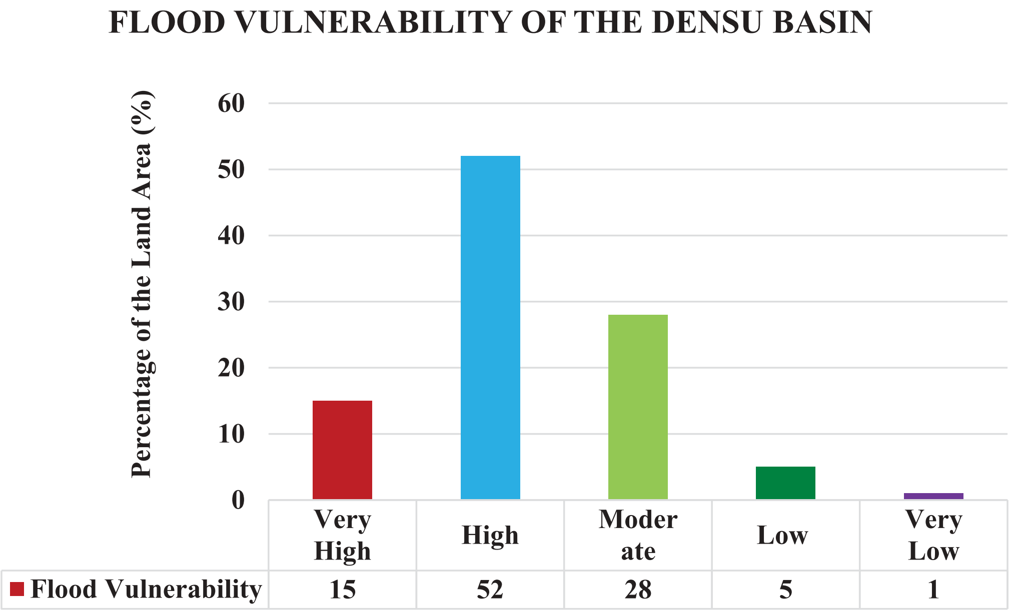
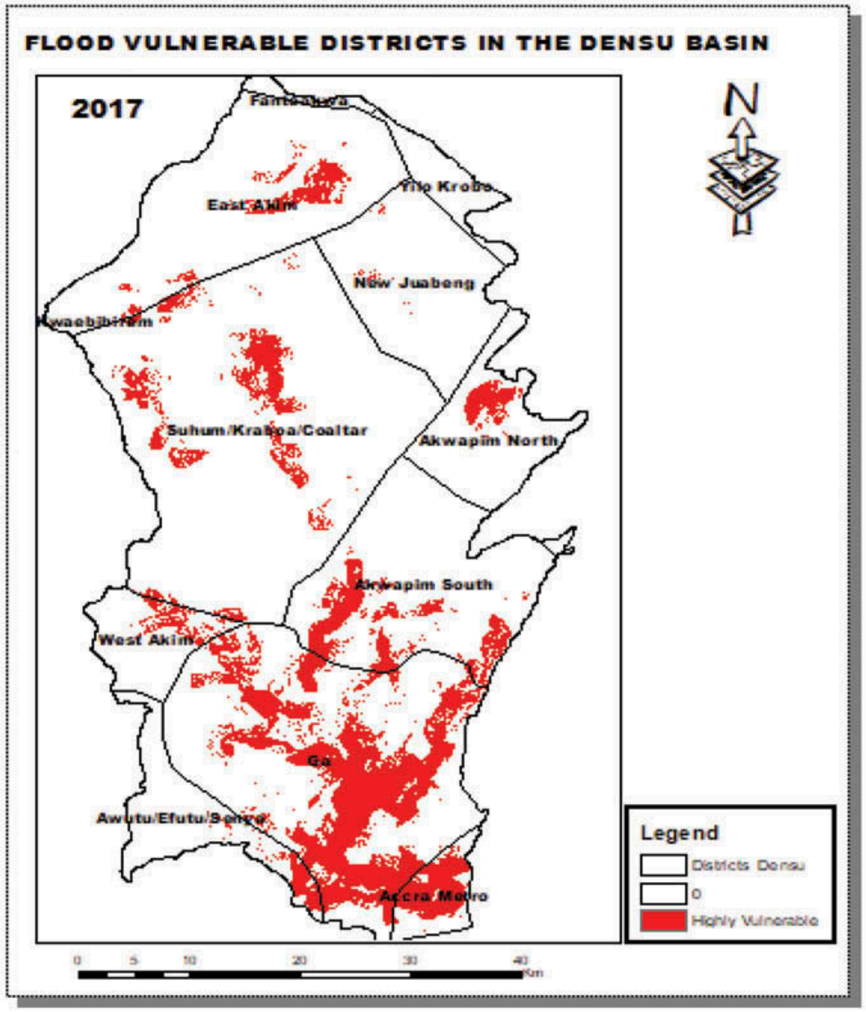


Figure 12. Flood vulnerability distribution for the Densu Basin.

Figure 13. Districts prone to flooding in the Densu river Basin.



With reference to Figure 14 and Figure 15, about one per cent (1%) of the basin is highly vulnerable to drought whilst high vulnerability (10.5%), moderate vulnerability (37.5%), low vulnerability (43%) and very low susceptibility (7.7%) to drought situations.

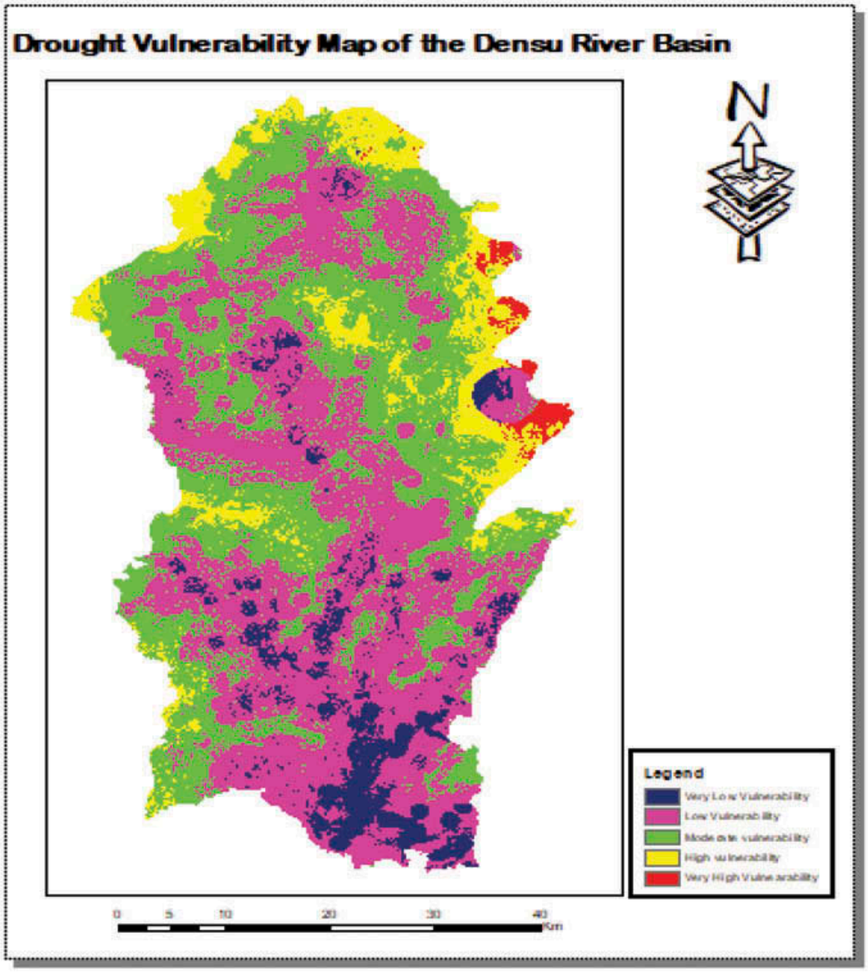
According to research conducted on the drought issues in the basin, Akyem Tafo, parts of Asokore, Nankese were identified as prone to drought condition (Alfa, 2010; Nyamekye et al., 2016). Figure 14 supports the earlier findings on drought situations of the Densu basin. It can be deduced that about12% of the basin is really prone to drought.

3.9. Water quality vulnerability analysis

The quality of the Densu river has been a matter of concern and discussions in Ghana (Obeng, 2005; Osei et al., 2016). The Densu river and its tributaries are the main sources of water for the inhabitants of the basin. The level of pollution through anthropogenic activities in the basin (Osei et al., 2016; Yorke & Margai, 2007) creates vulnerabilities for surface water users.

The standard weights used for generation of the surface water quality vulnerability of the Densu basin together with the normalized weighting of the criterion were derived by applying the weighted overlay analysis in GIS.

Figure 14. Drought vulnerability map for the Densu river Basin.



The analysis was based on a modified version of Equation 3.3 which resulted in Equation 3.6

$$\mathrm{WQV} = 0.20 \times Rv + 0.15 \times H + 0.30 \times L + 0.10 \times W + 0.13 \times T + 0.07 \times Sl + 0.05 \times So \qquad (3.6)$$

The thematic maps were changed into raster maps and then combined using Equation 3.6, which was modelled and implemented in a GIS software.

From Figures 16 and 17, about 6% of the basin lies in very high-water quality vulnerability areas. The communities that were relatively closer to the streams were deemed to be highly vulnerable.

Results from the water quality vulnerability analysis indicate that Akwadum, Nsawam, Adoagyiri, Pakro, Medie, Obuotumpan, Kuano, Asuboe, Ashaladza were some of the communities that lie within the very high vulnerability areas. The distribution of the water quality vulnerability High (22.8%), Moderate (39.5%), Low (29%) and Very low (2.5%).

These results (Figure 16) are supported by the findings of (Khatri & Tyagi, 2015), that attributed declining water quality to anthropogenic factors such as deforestation, urban sprawl, misuse and misapplication of agro-chemicals.

Figure 15. Drought vulnerability distribution for the Densu Basin.

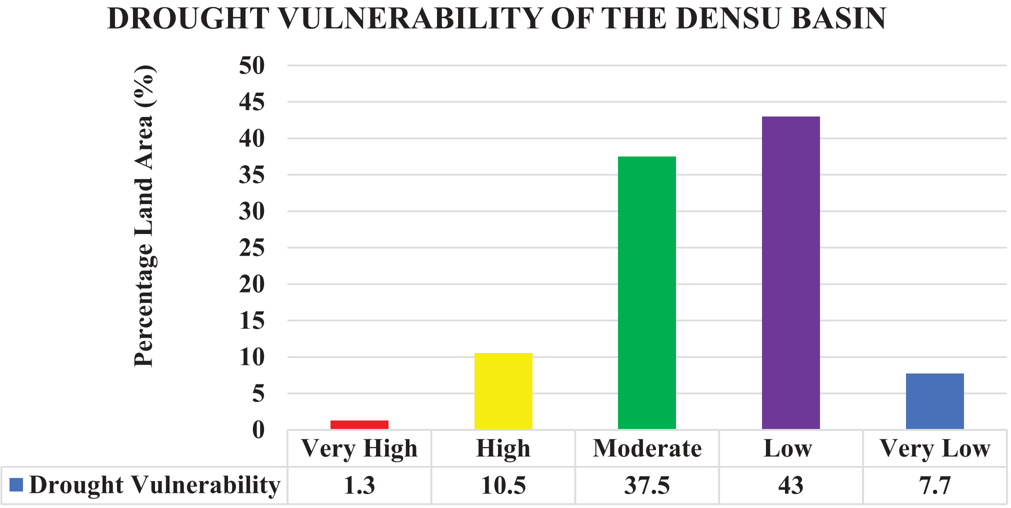
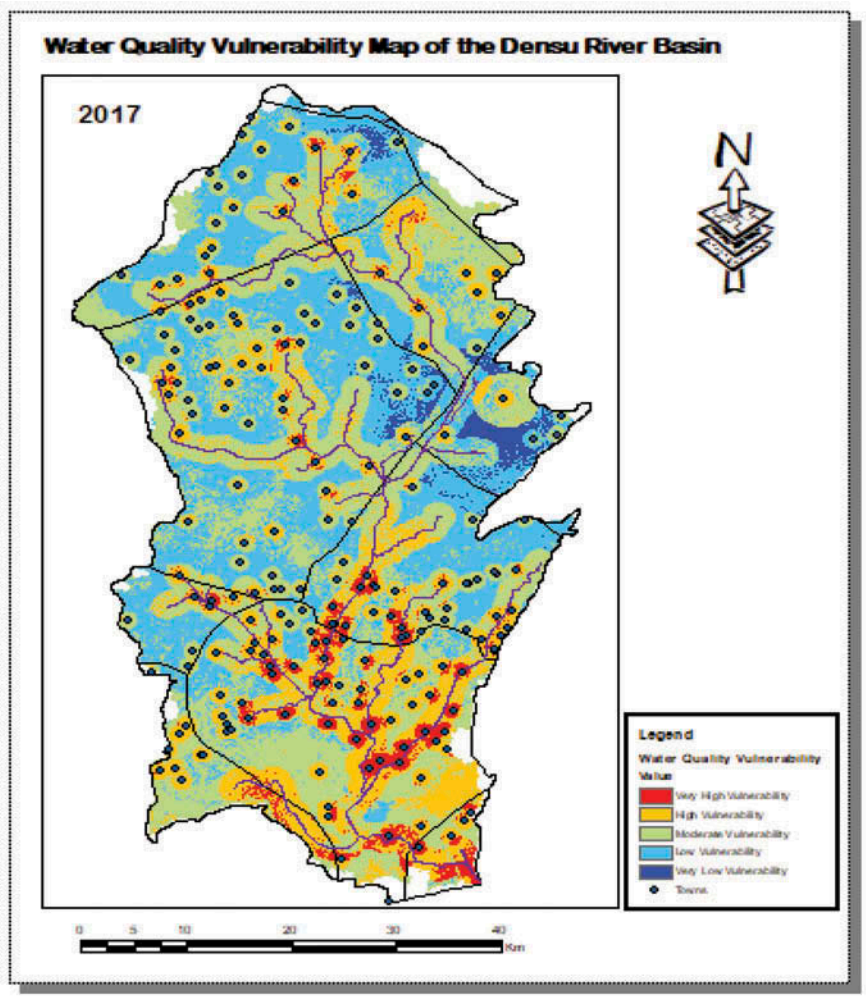


Figure 16. Water quality vulnerability map for the Densu River Basin.



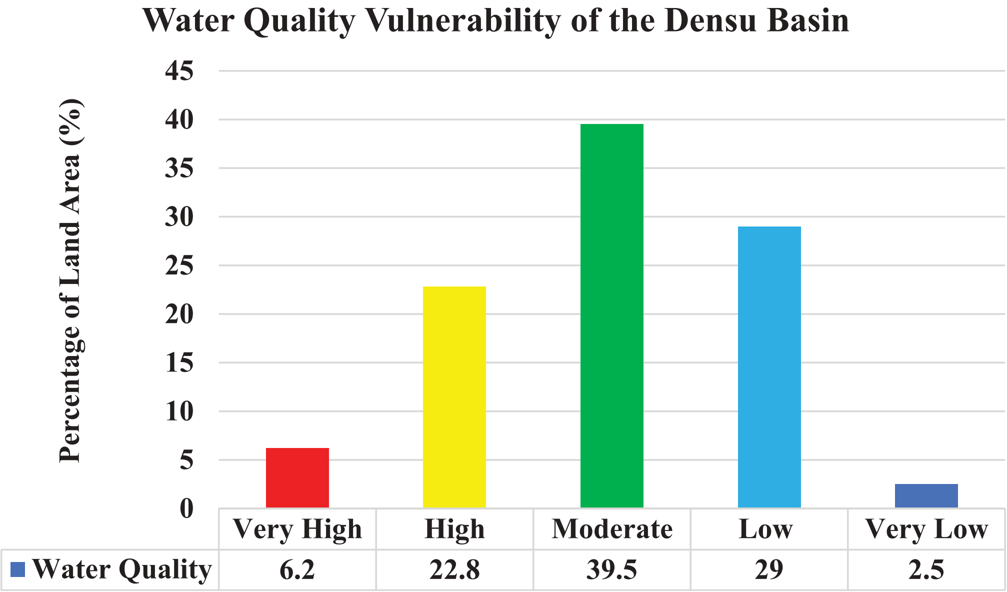


Figure 17. Water Quality vulnerability distribution of the Densu river Basin.

4. Conclusion and recommendation

The ecologically hazard-prone zones of the Densu basin were identified using multicriteria analysis techniques (MCM), analytical hierarchy process (AHP) and geospatial technology. The study identified hazard-prone zones in the Densu basin. The hazard-prone areas in the study area were grouped into five categories: very high vulnerability, high vulnerability, moderate vulnerability, low vulnerability and very low vulnerability. About 15% of the basin was found to be highly vulnerability to flooding, one per cent (1%) was highly vulnerable to drought and six per cent (6%) was also highly vulnerable to poor surface water quality. The existing vulnerability indicators—land use land cover changes, soil type, rainfall variability and streamflow patterns of the basin, contribute immensely to the vulnerability and the interference in the interaction between inhabitants of communities and biodiversity. Generally, a combination of AHP and MCM was effectively used to delineate river basin vulnerability. Subsequently, it is presently conceivable to extend the method to other river basins for the improvement of sustainable environmental sustainability against future risks.

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