



Flood vulnerability assessment in the Accra Metropolis, southeastern Ghana

Benjamin Wullobayi Dekongmen¹ · Amos Tiereyangn Kabo-bah² · Martin Kyereh Domfeh² · Emmanuel Daanoba Sunkari^{3,4} · Yihun Taddele Dile⁵ · Eric Ofofu Antwi² · Rita Akosua Anima Gyimah¹

Received: 8 January 2021 / Accepted: 24 June 2021 / Published online: 4 July 2021
© The Author(s) 2021

Abstract

Floods in Ghana have become a perennial challenge in the major cities and communities located in low-lying areas. Therefore, cities and communities located in these areas have been classified as potential or natural flood-prone zones. In this study, the Digital Elevation Model (DEM) of the Accra Metropolis was used to assess the drainage density and elevation patterns of the area. The annual population estimation data and flood damages were assessed to understand the damages and population trend. This research focused primarily on the elevation patterns, slope patterns, and drainage density of the Accra Metropolis. Very high drainage density values, which range between 149 and 1117 m/m², showed very high runoff converging areas. High drainage density was also found to be in the range of 1117–1702 m/m², which defined the area as a high runoff converging point. The medium and low converging points of runoff were also found to be ranging between 1702–2563 m/m² and 2563–4070 m/m², respectively. About 32% of the study area is covered by natural flood-prone zones, whereas flood-prone zones also covered 33% and frequent flood zones represent 25%. Areas in the Accra Metropolis that fall in the Accraian and Togo series rock types experience high floods. However, the lineament networks (geological structures) that dominate the Dahomeyan series imply that the geological structures in the Dahomeyan series also channel the runoffs into the low-lying areas, thereby contributing to the perennial flooding in the Accra Metropolis.

Keywords Accra Metropolis · Contours · Drainage density · Flood-prone areas · Geology · Waterways

Introduction

The immense expansion of many cities in Ghana without strict adherence to developmental regulations has made cities vulnerable to a range of natural disasters. Floods in Ghana have become a perennial challenge in the major cities and communities located in low-lying areas. Naturally, low-lying areas have been found to be liable to flooding (Attipoe 2014). Low-lying areas include; rivers, basins, valleys, lakes, low-elevated areas, among others. Therefore, cities and communities located in these low-lying areas can be classified as potential flood-prone areas. Also, infrastructural developments have encroached on these areas; that is building on waterways and paving of surface areas prevent infiltration of precipitation into the soil (Okyere et al. 2013). Areas (swamps and valleys) meant for the detention of runoffs have been used for infrastructural developments, which eventually contribute to flooding. These areas were naturally designated for detaining excessive runoff and overland flows, which help to cut down the time of concentration of surface runoffs.

✉ Benjamin Wullobayi Dekongmen
dejongmen@gmail.com

- ¹ Civil Engineering Department-Regional Water and Environmental Sanitation Centre Kumasi, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
- ² School of Engineering, University of Energy and Natural Resources, Sunyani, Ghana
- ³ Department of Geological Engineering, Faculty of Mineral Resources Technology, University of Mines and Technology, P.O. Box 237, Tarkwa, Ghana
- ⁴ Department of Geological Engineering, Faculty of Engineering, Niğde Ömer Halisdemir University, Main Campus, 51240 Niğde, Turkey
- ⁵ Department of Ecosystem Sciences and Management, Texas A&M University, 534 John Kimbrough Blvd, Room 305, College Station, TX 77843-2120, USA

Surface runoffs are normally collected in these areas (basins, rivers, valleys, etc.), which are then channeled into bigger basins and the sea. Due to the increase in the area of artificial land cover features and encroachment on naturally preserved areas (waterways, valleys, lagoons, forests), natural disasters have become rampant in low-lying areas. However, over the years, climate change has led to various facet changes of life on earth. Therefore, a significant change in both land surface and sea temperatures, pressure, and rainfall patterns has resulted in spatial and temporal changes in rainfall and evaporation (Avand et al. 2021). NASA reported in 2018 that the average earth's surface temperature has increased by 0.93 ± 0.07 °C as compared to the 1880s (Kim and Kang 2021). The frequency of maximum and magnitude of rainfall increases upon the increasing trend of global warming, and this leads to floods (Hirabayashi et al. 2013; Avand et al. 2021). According to Hirabayashi et al. (2013), the global exposure to floods occurrence is bounce to increase depending on the degree of global warming.

As cities expand, the local drainage capacity becomes inadequate to accommodate the runoff.

Notwithstanding this, there are other rural communities in Ghana (especially, those in the Upper West Region, Northern Region, Upper East Region and Afram Plains), which are not in low-lying areas but have been experiencing flooding due to overbank flooding resulting from the spill of excess water from the Bagre and Kampainga dams (Bempah and Øyhus 2017).

However, the natural breaks in elevation patterns of the Accra Metropolis range between -4 and 130 m above mean sea level (MSL), which makes the capital city of Ghana appear to be relatively flat. Generally, the Accra Metropolis is characterized by gentle slopes to about 22%. Thus, based on the low-lying nature of Accra Metropolis, runoffs are sent downwards to the Accra Metropolis and its environs, from other municipalities (Adenta, Ga East, La Nkwantanang Madina) in the Accra Metropolis.

Communities within or closer to major rivers in Accra as well as those within the tributaries of these major rivers experience floods in response to any intense rainfalls. For settlers and these settlements, the issue of flooding has become a perennial event. Also, previous researchers indicate that most of the drains in Accra are either undersized, overdue, silted or improperly connected (Rain et al. 2011; Okyere et al. 2013). It is also a fact that the greater population density in Accra has increased the number of impervious surface areas through pavement and buildings (Rain et al. 2011; Okyere et al. 2013).

The attitudinal factor of flooding resulting from siltation is a key component, which many citizens in the capital city refuse to practice (Tabiri 2015). The dumping of waste into drains reduces the capacity of these drains to convey runoff into the sea. Odaw river, Onyasia river, and Korle lagoon

are major water bodies in Accra (Asumadu-Sakodie et al. 2015a, b). These water bodies receive surface runoff from their catchments and channel them into the sea. However, many have turned them into their dumping grounds. On June 3, 2015, a flood combined with an explosion at the Ghana Oil filling station claimed over 152 lives (Asumadu-Sarkodie et al. 2015a, b), thus, totalling 567 lives lost between 1968 and 2015.

Worryingly, the Accra Metropolis has been inundated with perennial flood disasters from 1968 to date (Okyere et al. 2013; Amoako and Boamah 2014; Tengan and Aigbavboa 2016). The metropolis has a population of over 3.86 million and out of these, 415 people lost their lives through flood disasters between the periods of 1968–2014 (Okyere et al. 2013; Amoako and Boamah 2014; Asumadu-Sakodie et al. 2015a, b; Tabiri 2015; Tengan and Aigbavboa 2016; Kwang and Matthew Osei, 2017). One of the major causes of the June 3, 2015, flood was as a result of blockage of the Odaw river's mouth from discharging water into the sea. Many lives and properties were also lost through recurring floods between 2016 and 2019. Some researchers have attributed these recurring floods in the Accra Metropolis to several contested factors such as its low-lying area, poor planning, drainage networks (choke drains, underside drains, etc.), massive expansion of the city, increase impervious surface area, mismanagement of surface water resources through uncontrolled rapid urbanization and the construction of residential and commercial structures on waterways (Twumasi and Asomani-Boateng 2002; Owusu and Agbozo 2019). Other researchers also attributed this perennial havoc to the poor flood management approach in the city's development plan, poverty and climate change variability (Okyere et al. 2013; Amoako and Boamah 2014; Asumadu-Sarkodie et al. 2015a, b; Afornorpe 2016).

Drainage density is a key parameter in flood vulnerability studies. It is the computation of the total length of rivers and or length of stream networks in the watershed or catchment divided by the total area of the drainage basin (Oikonomidis et al. 2015). Drainage density analysis is done to determine how well a catchment or a basin is drained by river networks or streams. Drainage density map is a key component in the analysis of flood and groundwater recharge studies (Yildiz 2004; Lakshamma et al. 2015). It shows the areas where runoff will flow toward and accumulate (Waikar and Nilawar 2014). Runoff normally flows from high-land areas to low-lands areas such as valleys, basins, rivers, lakes, and lagoons. Therefore, areas characterized by high drainage density indicate high surface runoff (Krishnamurthy et al. 2000).

Despite the numerous flood-related incidents in the Accra Metropolis, studies on flood vulnerability assessment in the Accra Metropolis are limited and not readily available in the literature. It is therefore, crucial to determine the drainage

density and elevation patterns of the Accra Metropolis in order to assess the vulnerability of the city to floods. This information will be key for city planners and interventions aimed at addressing the perennial floods in the Accra Metropolis. The study also provides a detailed review of the number of lives and properties lost through flood-related incidents using previous literature.

Materials and methods

Study area

The geographical scope of the study is restricted to the Accra Metropolitan Assembly (AMA) (Fig. 1). The study focused specifically on the drainage density, floodable zones, and contour levels of the AMA. The AMA covers an area of 181 km² with eleven sub-metropolises namely; Okaikoi North, Okaikoi South, Ablekuma Central, Ablekuma North, Ablekuma South, Ashiedu Keteke, Ayawaso Central, Ayawaso East, Ayawaso West Municipal, La and, Osu Klottey. The metropolis is located within latitude 00°06'W and longitude 05°35'N. Toward the northern fringe of the metropolis lies the Ga West Municipality. The metropolis is bounded to the west by the Ga South Municipality and the south shares territory with the Gulf of Guinea (AMA 2015; Attipoe 2014).

According to the 2010 population and housing census, the population of the AMA is over 2.5 million (AMA 2015), with 4.3% of an annual population growth rate between 1984 and 2000. The Ghana Statistical Service in 2012, reported a population of 3 million in Accra (Amoako and Boamah 2014). With this population growth rate, the metropolis has thus been identified to be one of the most rapidly-growing metropolitans in Africa (Amoako and Boamah 2014).

Data acquisition and analysis

The study did not take into consideration any rainfall data and other modeling tools and datasets; however, the Digital Elevation Model (DEM) of the Accra Metropolis was used to assess the drainage density, floodable areas and as well as contour patterns of the area. DEM determines flow direction and accumulation, other hydrological factors of topography and it informs the overland access flow direction and accumulation. Many factors are considered in flood modeling; however, this research focused on the contour patterns, floodable areas, slope patterns and the drainage density of the Accra Metropolis due to the crucial roles that these factors play in flooding in general.

The study analyzed up to a point, where the natural breaks or arrangements of the land explain the phenomenon of the annual floods in the Accra Metropolis and

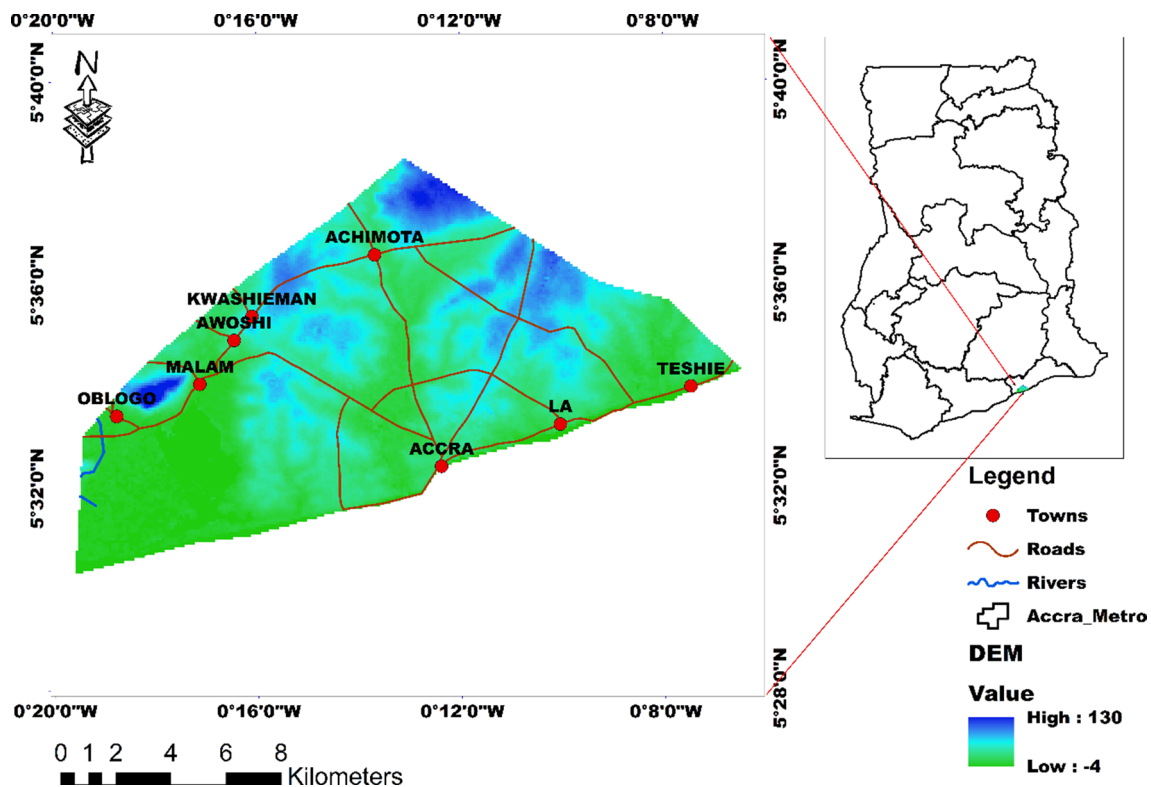


Fig. 1 Location map of the study area

along with the connection of drainage density and elevation patterns of Accra. The elevations and slopes are important elements that contribute to the determination of flow direction and flow accumulation resulting from impervious surface areas, which reduce infiltration and give vital information about the vulnerability of the area to floods (Okyere et al. 2013) as well as excess overland flow emanating from precipitation exceeding infiltration. Flow direction shows how overland flows are shared within the catchment area (Ghebremariam 2017). The infiltration rate and the surface flow velocity of the area depend mainly on the elevation patterns and sloppiness, soil characteristics and the level of infrastructural development in the city. A DEM was used to determine the flood-prone areas in the metropolis.

Secondary data on the death tolls and illegal structures on waterways were obtained from the literature. These data were sourced to establish the trend of lives lost as a result of flash floods in the metropolis. The initial flood map generated was classified into four zones; not floodable, less floodable, medium floodable, and highly floodable. This same map was further classified into three zones such as natural flood-prone areas, flood-prone areas, frequent flood-prone areas, and no flood. The DEM used for flood maps was further used to generate the drainage density of the area.

Drainage density

The Digital Elevation Model (DEM) of the study was used to analyze the direction of flows and flow accumulation in the area. The drainage density map of the area was generated from the DEM using the ArcMap environment through the Line Density tool. The Line Density file generated was further reclassified into four classes from low to very high (from low converging to very high converging areas) using the equation below.

$$DD = \frac{\sum Le}{A} \quad (1)$$

where Le is the total distance of all the streams and rivers, and A is the total area of the drainage basin or the watershed.

Contour characteristics in Accra

The contour map of the study was generated using the Digital Elevation Model in the ArcMap environment, using the contour command tool. The output polyline assigned was 10 m, which generated five classes of the contour lines. The five classes were further reclassified into three classes.

Geology

The geology map of the study area was extracted from the geological map of Ghana. Three series of geological compositions were found namely; Accraian (Mid-Devonian), Dahomeyan and Togo series (Neoproterozoic).

Lineament density (LD)

The DEM was used to extract the lineament networks using PCI Geomatica trial version. The lineament networks were then overlaid on the geological map.

Results and discussion

Delineation of flood-prone areas

From Fig. 2, the study indicates that about 32% of the study area is covered by natural flood-prone zones, with flood-prone zones covering 33%, and frequent flood zones representing 25%

while the no floodable zone covers 10%. Natural flood-prone zones constitute swamps, marshy areas, valleys, rivers, basins, and lagoons. These areas are naturally liable to flood. Frequent flood-prone zones represent areas that will often experience floods due to the expansion of the city. Flood-prone areas are also those areas within the catchment that are susceptible to floods due to the connection of these areas with natural flood-prone areas as well as city rebranding. However, a study by Okyere et al. (2013) reports that areas within 350 m contour were found to be flood potential zones that are bound to experience episodic floods with little input of rainfall. From Fig. 1, Accra is located in a low-land area with slope ranging between -4 and 130 m. According to the World Bank (2012) and Attipoe (2014), low-lying areas

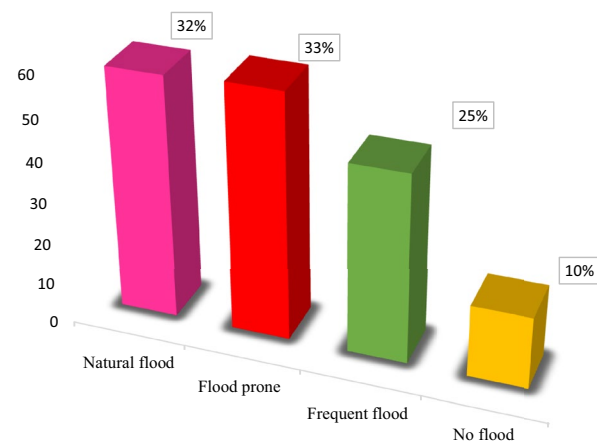


Fig. 2 Percentages of flood areas

are often flood-prone with many houses within these areas being besieged by floodwaters during and after torrential downpours. According to Amoako and Boamah (2014), in Accra, there are many low-lying areas, which are subjected to annual flooding due to insufficient culverts sizing and blockage of the major drains in the city due to the accumulation of silt and as a result of the poor culture of maintenance. Also, many areas in the Accra Metropolis experience flood as a result of rapid runoffs being generated from low-lying areas, which in turn flow to join drains with inadequate capacity located within the residential and commercial areas of the city.

Floods and drainage density

Figure 3 shows the floodable areas and the high and low water converging areas within the watershed. Very high drainage density values range between 149 and 1117 m/m² and showed high runoff converging areas. High drainage density was also found to be in the range of 1117–1702 m/m², which defined the area as a high runoff converging point. Water flows from high-land areas to low-lying areas in the metropolis and this increases surface runoff. The medium and low converging points of runoff were also found to be ranging between 1702–2563 m/m² and 2563–4070 m/m², respectively. The very high converging points were found to be within the most floodable areas (Fig. 3a and b), and

these areas with very high or high drainage density increase surface runoff (Kumar et al. 2007). However, areas with low drainage density influence less surface runoff due to infiltration of the surface runoff (Manap et al. 2011; Rahmati et al. 2014). Nevertheless, these areas have been encroached by infrastructure (Karley 2009; World Bank 2012; Amoako and Boamah 2014; Amoako and Inkoom 2017). Runoff flowing toward these low-lying areas increases in velocity due to slope gradient, which controls drainage density (Das and Mukhopadhyay 2018). This further confirms the fact that the runoff flows toward the low-lying areas within the metropolis, resulting in the high flash floods in those areas as identified.

Contour slopes

The contour of the metropolis (Fig. 4) ranges between 0.00 and 120.00 m. Figure 4 shows that the gentle slopes contour zones range between 0.00 to 20.00 m, while the steep slope contour zones range from 60.00 to 120.00 m. Observation from both Figs. 3b and 4 indicates that the natural floodable and flood-prone zones occur within the gentle slope contour ranges (Fig. 4). The no floodable areas (Fig. 3b) were also observed within the contour ranges of 60–120 m (Fig. 4). This shows that the surface runoffs from the steep slope areas flow toward the gentle slope zones, which are serving

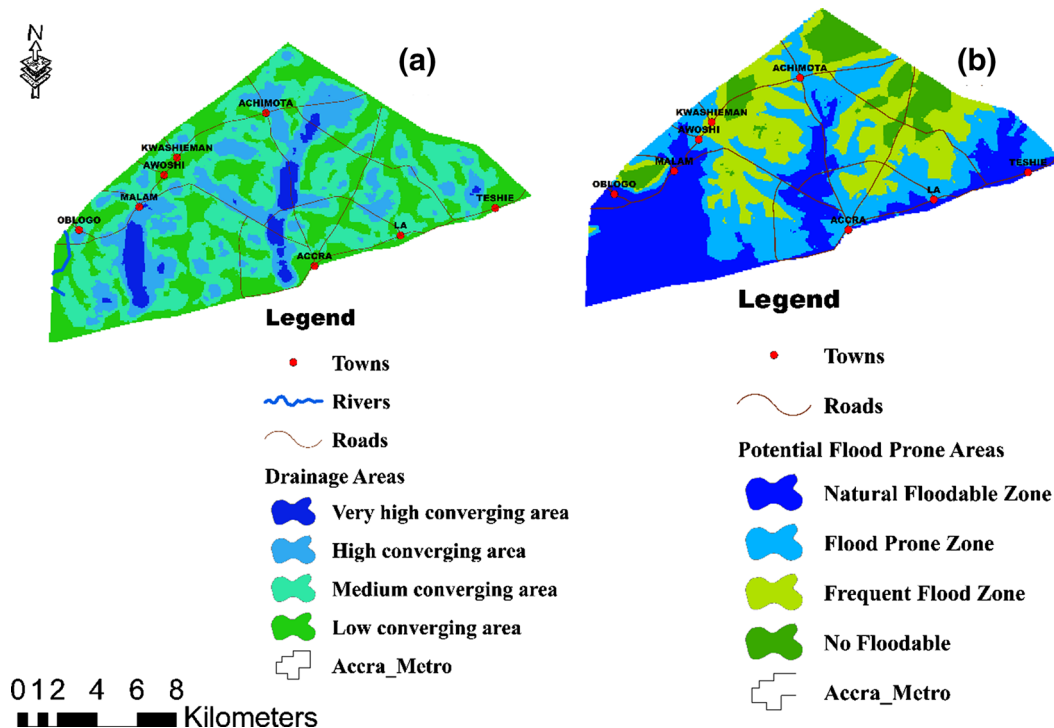


Fig. 3 a Drainage density map and b map of floodable areas map

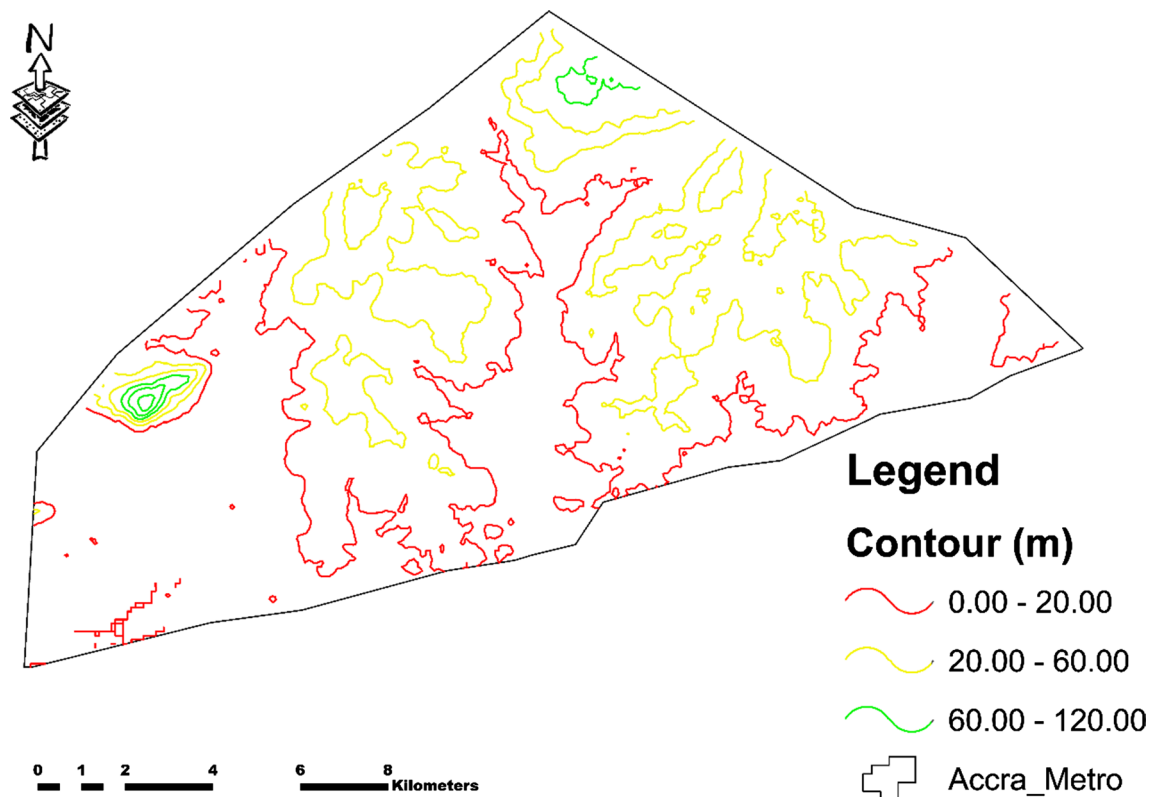


Fig. 4 Contour map

as high convergence zones (Fig. 3a) of the runoffs leading to the occurring floods.

Geological characteristics

From Fig. 5, the geology of the Accra Metropolis is dominated by Dahomeyan (Neoproterozoic) series of about 58% of the total area, which comprises acidic, ortho, paragneiss, schist and migmatite, and many of which are rich in garnet, hornblende, and biotite. The Accraian (Mid-Devonian) series covers an area of about 25% in the central part of the metropolis comprising sandstone, grit, and shale. The Togo (Neoproterozoic) series covers 17% of the total area in the western part of the metropolis consisting of quartzite, sandstone, shale, phyllite, schist, and silicified limestone. Rocks belonging to the Togo series are generally weak and loosely bound together and are poorly consolidated and unconsolidated as a result of sediment depositions (Addo 2010). Observation from Fig. 4 showed that the patterns of the Togo and Accraian series in the western and central parts fall within the gentle slopes where high and medium floods occur perennially. The Dahomeyan series experiences fewer flash floods as compared to the Accraian and the Togo series due to the steep contour slopes and a thin overburden, which impedes groundwater recharge (Erdélyi 1965). Addo (2010)

also reported that the Dahomeyan (Neoproterozoic) series is characterized by metamorphic basement rocks overlain by clay and laterite. However, it was also observed that the lineament networks (geological structures) were dominated in the Dahomeyan (Neoproterozoic) series. This implies that the geological structures in the Dahomeyan (Neoproterozoic) series channel the runoffs into the low-lying areas contributing to the perennial flooding in the Accra Metropolis.

Illegal structures on waterways and impact of perennial flooding on human lives in the Accra Metropolis

According to the UNCT Ghana (2015), there are 8470 settlement structures built on waterways within various parts of the metropolis (Fig. 6). This could be attributed to the fact that settlers acquired parcels of land illegally without proper documentation. This is generally dominated by squatters in the slum areas, which are within the low-lying areas, where most of the major drainage networks are suited (Oppong et al. 2020). Circle, Nima, Alajo, Old Fadama, and Agbogboloshe are among communities located within the major drainage network and hence often experience flood-related incidents. Also, communities like Nima, Old Fadama, and Agbogboloshe are the most slum-dominated areas within

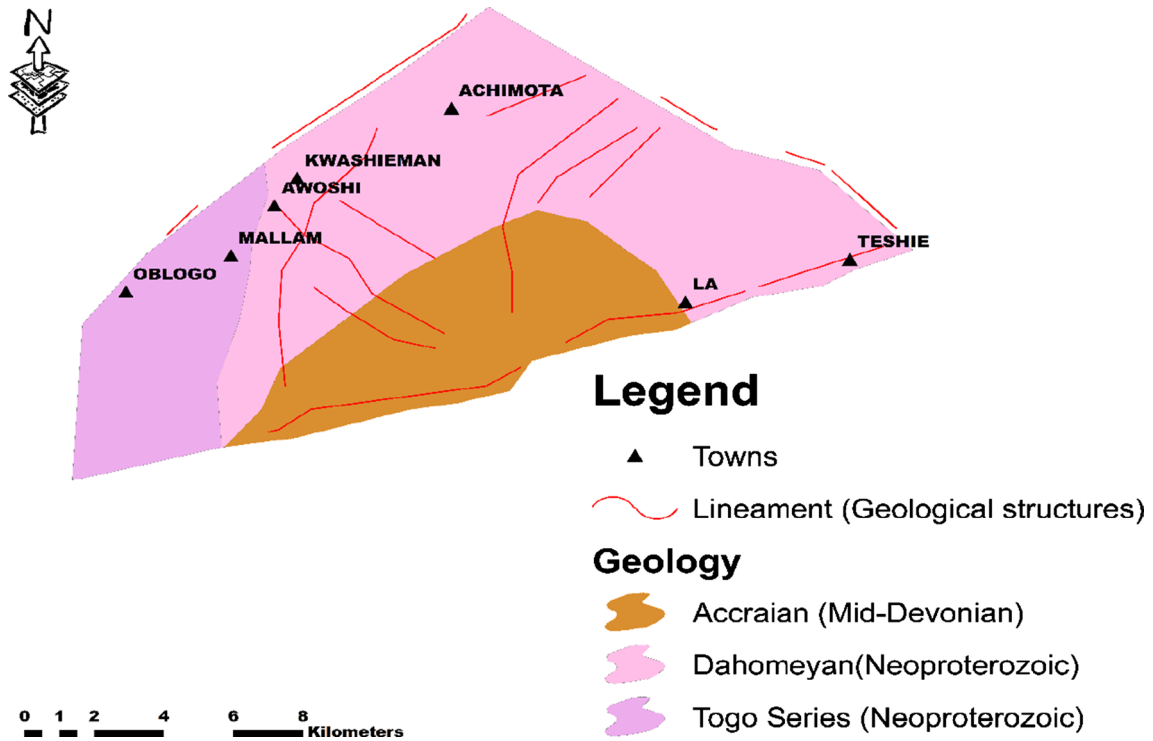


Fig. 5 Geology map

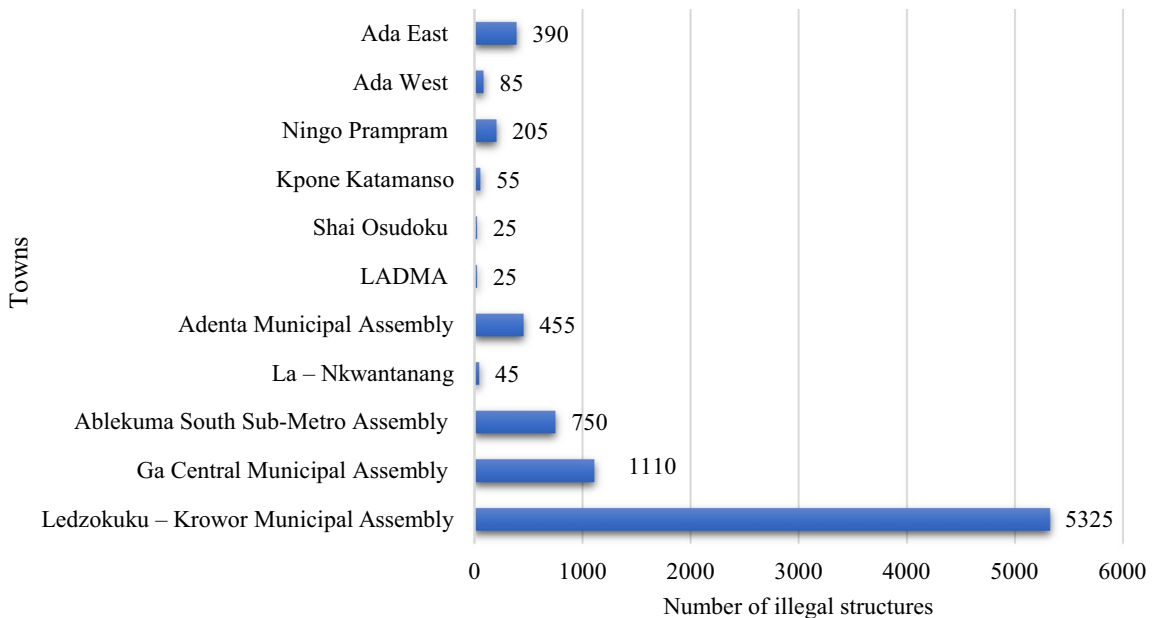


Fig. 6 Illegal structures on waterways (UNCT GHANA 2015)

the city (Oppong et al. 2020; Owusu and Agbozo 2019). Apart from the geographical location of the metropolis which exposes part of the metropolis to flood disaster, solid waste disposal attitude among many is also one of the key contributory factors of flood occurrences (Oppong et al.

2020). In Accra, 608 people have lost their lives between 1968 and 2018 as a result of flash floods. Out of which, 415 died between the period of 1968–2015 (Asumadu-Sakodie et al. 2015a, b) and 193 also died between 2010 and 2018 (Fig. 7). On June 3rd 2015 alone, 152 people lost their lives

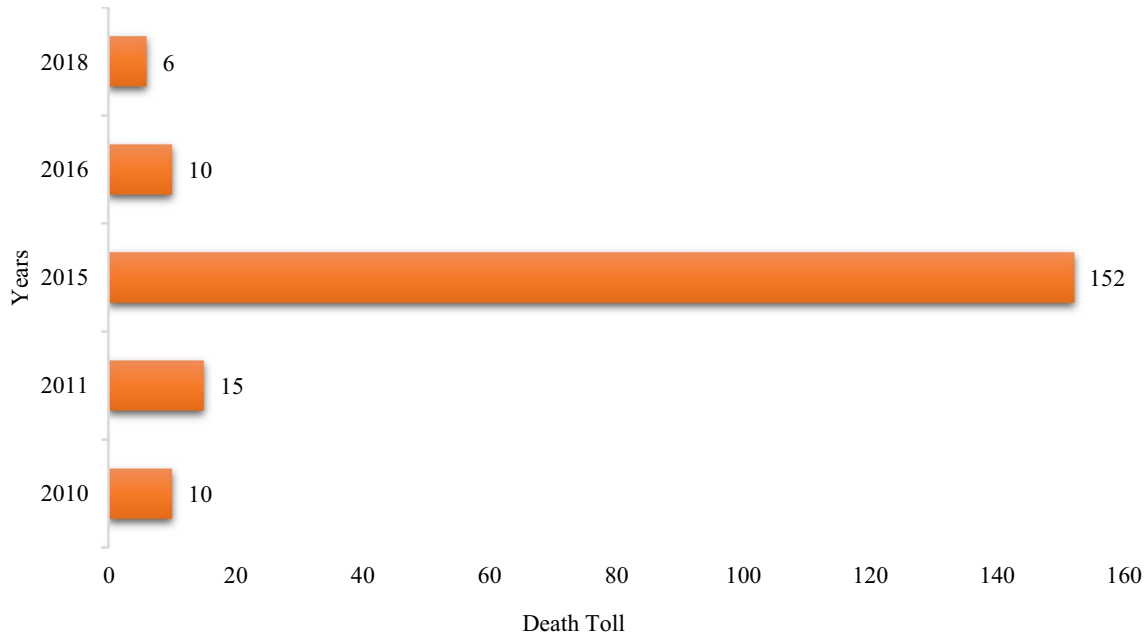


Fig. 7 Death Tolls (Okyere et al. 2013; Amoako and Boamah 2014; Asumadu-Sakodie et al. 2015a, b; Tabiri 2015; Kwang and Matthew Osei 2017)

through a flood-related disaster and several properties were also destroyed.

For a nation to develop, it depends on the output of its citizens. However, these lives lost through this recurrent natural disaster have impacted the nation’s economy and the psychological stability of the citizens. It is reported that after the June 3rd 2015 disaster, many families and citizens went through a lot of psychological trauma (Quarshie et al. 2018). Many could not stand the sight of dead bodies that

were displaced after the floodwaters receded. To date, the pictures of the dead bodies still echo in the memories of many citizens.

Annual population estimations

Flooding death tolls of 10 and 152 were recorded in 2010 and 2015, respectively (Fig. 7), largely due to the increasing population. The population of the Accra Metropolitan

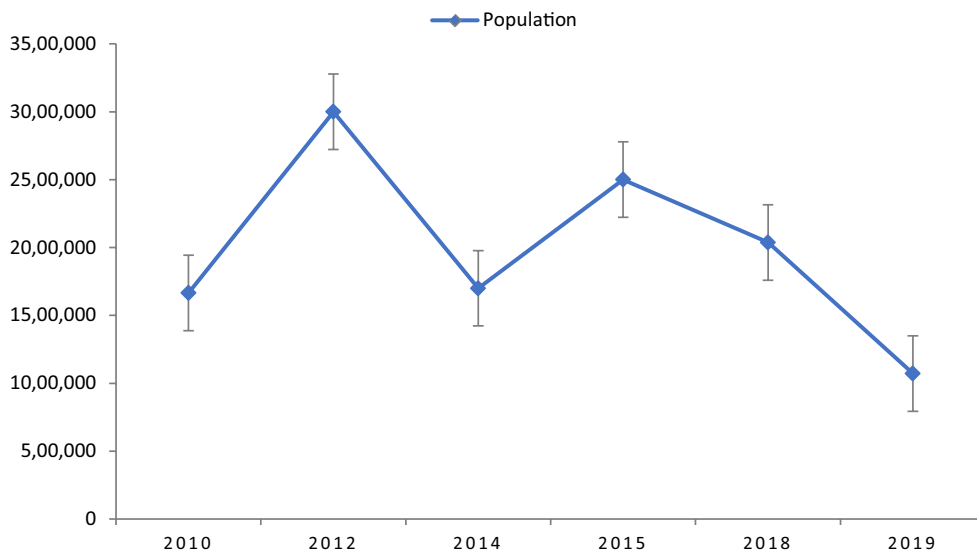


Fig. 8 Annual population estimations (AMA 2014, 2015, 2019; Amoako and Boamah 2014)

Assembly has been increasing at a high rate (Fig. 8). Because Accra serves as the national capital of the country, about 1 million people commute daily to the city for various services (AMA, 2014, 2015, 2019, 2020). From Fig. 8, the population of the metropolis was estimated as 3 million in the year 2010. It was also reported that the 2014 and 2019 annual population estimations were the least. In all, the increase in population has impacted the AMA hydrological pattern and drainage system, due to the siting of several infrastructures on waterways and the depletion of the swamps and surface runoff retention zones.

Conclusion

This study assessed flood vulnerability in the Accra Metropolis using the Digital Elevation Model (DEM) of the area. The study revealed that the very high drainage density and high drainage density areas were found to be within the most floodable areas. Such an observation is consistent with the fact that all the runoffs flow from the high-land areas to the low-land areas to cause floods. The gentle contour slopes were also found to coincide with the natural floodable and flood-prone zones within the metropolis. Areas within the Accra Metropolis that fall under geological formations such as the Accraian and Togo series also experience high floods as compared to the Dahomeyan series. A couple of other factors were also contested by several researchers which include; illegal structures on waterways, climate change impact and variability, inadequate culverts sizes, blockage of the major drains due to the accumulation of solid waste, the immense expansion of the city due to a constant increase in population, increase in impervious surfaces and poor national flash flood management plans and weak engineering works. These expose the city to the consistent perennial episodes of floods. Therefore, the Accra Metropolis requires a paradigm shift from its usual development plans to improved and sustainable city planning. Urban planners and city engineers will need to approach city planning and development in a holistic manner taking into consideration multiple factors.

In a nutshell, this study used ArcGIS and spatial data to map flood risk zones in the AMA which could be seen as the simplest way of modeling flood risk zones. However, it may not be fully accurate, since there are other hydrological modeling methods, near-real-time datasets and tools for computing and routing floods. The use of the literature and single data such as DEM may limit more detailed analysis. Therefore, this study recommends that further studies could focus on flood routing per the land use land cover dynamics of the metropolis and taking into consideration the populace who live close to all the major drains in the metropolis. In addition, the government's interventions to mitigate these

perennial floods should take into account the Riparian Buffer Zone Policy in order to address the problem of encroachment. Organizations such as NGOs and other key stakeholders should ensure community engagements and sensitization on the consequences of encroaching on waterways.

Acknowledgements The authors thank the Reviewers and Editor for the valuable comments that improved the quality of the paper.

Author contributions Benjamin Wullobayi Dekongmen was involved in conceptualization, resources, methodology, writing—original draft preparation, writing—review and editing. Amos Tiereyangn Kabobah contributed to resources. Martin Kyereh Domfeh and Emmanuel Daanoba Sunkari were involved in formal analysis and investigation, writing—review and editing. Yihun Taddele Dile, Rita Akosua Anima Gyimah, and Eric Ofosu Antwi were involved in supervision.

Funding The authors received no specific funding for this work.

Availability of data and material All data used in the study will be readily available to the public upon request.

Declarations

Conflict of interest The authors declare no conflicts of interests.

Ethical approval The authors declare that the submitted manuscript is original. Authors also acknowledge that the current research has been conducted ethically and the final shape of the research has been agreed upon by all authors. Authors declare that this manuscript does not involve researching about humans or animals.

Code availability (software application or custom code) All software applications used in this study were the licensed software applications used by the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

Consent to participate The authors consent to participate in this research study.

Consent to publication The authors consent to publish the current research in Applied Water Science.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Accra Metropolitan Assembly (2014) The Composite Budget of the Accra Municipal Assembly 2014 Fiscal Year.
- Accra Metropolitan Assembly (2015) The Composite Budget of the Accra Metropolitan Assembly (AMA) 2015 Fiscal Year.
- Accra Metropolitan Assembly (2019) Composite budget for 2019–2022, Programme based budget estimates for 2019.
- Accra Metropolitan Assembly (2020) Composite budget for 2020–2023, Programme based budget estimates for 2020, Accra Metropolitan Assembly.
- Addo KA (2010) Changing morphology of Ghana's Accra coast. *J Coast Conserv*. <https://doi.org/10.1007/s11852-010-0134-z>
- Aforonpe EK (2016) Flood Vulnerability and Adaptation in Accra: Examining Aspects of both Climate and Non-Climate Factors, University of Ghana. University of Ghana. Available at: <http://ugspace.ug.edu.gh>.
- Amoako C, Boamah EF (2014) The Three-dimensional causes of flooding in Accra, Ghana. *Int J Urban Sustain Develop* 7(1):109–129. <https://doi.org/10.1080/19463138.2014.984720>
- Amoako C, Inkoom BKD (2017) The Production of Flood Vulnerability in Accra, Ghana: Re-thinking Flooding and Informal Urbanisation. *Urban Studies Journal Limited*. <https://doi.org/10.1177/0042098016686526>.
- Asumadu-Sarkodie S, Owusu PA, Jayaweera HMPC (2015a) Flood risk management in Ghana: a case study in Accra. *Adv Appl Sci Res* 6(4):196–201
- Asumadu-Sarkodie S, Owusu PA, Rufangura P (2015b) Impact analysis of flood in Accra Ghana. *Adv Appl Sci Res* 6(9):53–78
- Attipoe, SK (2014) An Assessment of Flood Mitigation Measures in Accra, Ghana.
- Avand M, Moradi HR, Lasboyee MR (2021) Spatial Prediction of future flood risk: an approach to the effects of climate change. *Geosciences* 11(25):1–20. <https://doi.org/10.3390/geosciences11010025>
- Bempah SA, Øyhus AO (2017) The role of social perception in disaster risk reduction: beliefs, perception, and attitudes regarding flood disasters in communities along the Volta River, Ghana. *Int J Disaster Risk Reduct* 23:104–108. <https://doi.org/10.1016/j.ijdrr.2017.04.009>
- Das N, Mukhopadhyay S (2018) Application of multi-criteria decision making technique for the assessment of groundwater potential zones: a study on Birbhum District West Bengal India. *Environ, Develop Sustain*. <https://doi.org/10.1007/s10668-018-0227-7>
- Erdélyi M (1965) The hydrogeology of Ghana. *Int Assoc Sci Hydrol Bull* 10(1):44–52. <https://doi.org/10.1080/02626666509493370>
- UNCT GHANA (2015) Ghana – Floods Situation Report.
- Ghebremariam MA (2017) Urban Flood Modelling: A GIS Based Approach in Lomma. Lund University, Skåne Region
- Hirabayashi Y, Mahendran R, Koirala S, Konoshima L, Yamazaki D, Watanabe S, Kim H, Kanae S (2013) Global flood risk under climate change. *Nat Clim Change* 3(9):816–821. <https://doi.org/10.1038/nclimate1911>
- Karley NK (2009) Flooding and physical planning in Urban Areas in West Africa: situational analysis of Accra, Ghana. *Theor Empir Res Urban Manag* 4(13):25–41
- Kim J, Kang J (2021) Analysis of flood damage in the Seoul Metropolitan government using climate change scenarios and mitigation technologies. *Sustainability* 13(105):1–28. <https://doi.org/10.3390/su13010105>
- Krishnamurthy J, Mani A, Jayaraman V, Manivel M (2000) Groundwater resources development in hard rock terrain—an approach using remote sensing and GIS techniques. *Int J Appl Earth Obs Geoinf* 2(3/4):204–215. [https://doi.org/10.1016/S0303-2434\(00\)85015-1](https://doi.org/10.1016/S0303-2434(00)85015-1)
- Kumar PKD, Gopinath G, Seralathan P (2007) Application of remote sensing and GIS for the demarcation of groundwater potential Zones of a River Basin in Kerala, Southwest Coast of India. *Int J Remote Sens* 28(24):5583–5601. <https://doi.org/10.1080/01431160601086050>
- Lakshamma DN, Balasubramanian A, Siddalingamurthy S, Sumithra S (2015) Estimation of Groundwater Recharge studies in Gundal Watershed, Gundlupet Taluk, Chamarajanagar District, Karnataka, India using remote sensing and GIS. *Int J Curr Eng Technol* 5(3):2138–2148
- Manap MA, Sulaiman WNA, Ramli MF, Pradhan B, Surip N (2011) A Knowledge-driven GIS modeling technique for groundwater potential mapping at the upper Langat Basin Malaysia. *Arab J Geosci* 6(5):1621–1637. <https://doi.org/10.1007/s12517-011-0469-2>
- Oikonomidis D, Dimogianni S, Kazakis N, Voudouris K (2015) A GIS/Remote sensing-based methodology for groundwater potentiality assessment in Tirnavos Area, Greece. *J Hydrol* 525:197–208. <https://doi.org/10.1016/j.jhydrol.2015.03.056>
- Okyere CY, Yacouba Y, Gilgenbach D (2013) The problem of annual occurrences of floods in Accra: an integration of hydrological, economic and political perspectives. *Theor Empir Res Urban Manag* 8(2):45–79
- Opong BE, Asomani-Boateng R, Fricano RJ (2020) Accra's Old Fadama/Agbogbloshie settlement to what extent is this slum sustainable?. *African Geographical Review* 39(4), 289–307 <https://doi.org/10.1080/19376812.2020.1720753>.
- Owusu AB, Agbozo M (2019) Application of geographic information systems for flood risk analysis: a case study from Accra Metropolitan Area. *Present Environ Sustain Develop* 13(1):81–97. <https://doi.org/10.2478/pesd-2019-0007>
- Quarshie EN, Peprah J, Asante PY, Verstraaten-Bortier M, Abbey EA, Agyei F (2018) “It was touching”: experiences and views of students in the June 3 flood and fire disaster relief response volunteerism in Accra Ghana. *Cogent Psychol* 5(1):1489481. <https://doi.org/10.1080/23311908.2018.1489481>
- Rahmati O, Samani AN, Mahdavi M, Pourghasemi HR, Hossein Z (2014) Groundwater potential mapping at Kurdistan Region of Iran using analytic hierarchy process and GIS. *Arab J Geosci* 8(9):7059–7071. <https://doi.org/10.1007/s12517-014-1668-4>
- Rain D, Engstrom R, Ludlow C, Antos S (2011) Accra Ghana: A City Vulnerable to Flooding and Drought-Induced Migration. Available at: <http://www.unhabitat.org/grhs/2011>.
- Tabiri MO (2015) Perennial problem of floods in Accra: What is the way forward? *Int J Adv Res Edu Technol (IJARET)* 2(3):198–201
- Tengan C, and Aigbavboa CO (2016) Addressing flood challenges in Ghana: a case of the Accra Metropolis. International Conference on Infrastructure Development in Africa, 498–504.
- Twumasi YA, Asomani-Boateng R (2002) Mapping seasonal hazards for flood management in Accra, Ghana using GIS. International Geoscience and Remote Sensing Symposium (IGARSS). IEEE, 5(C), 2874–2876 <https://doi.org/10.1109/igarss.2002.1026807>.
- Waikar ML, Nilawar AP (2014) Identification of groundwater potential zone using remote sensing and GIS technique. *Int J Innov Res Sci, Eng Technol* 3(5):12163–12174
- World Bank (2012) Ghana - Sanitation and Water Project for the Greater Accra Metropolitan Area (GAMA): environmental assessment: Environment and social management framework. Available at: <http://documents.worldbank.org/curated/en/176011468250869848/Environment-and-social-management-framework>.
- Yildiz O (2004) An investigation of the effect of drainage density on hydrologic. *Turkish J Eng Env Sci* 28:85–94

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations