

Socioeconomic and Environmental Vulnerability to Flooding in the Tamale Metropolis of Ghana Using a Composite Index Approach

Justice Agyei Ampofo

justiceagyei.ampofo@stu.edu.gh

Sunyani Technical University

Research Article

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Abstract

The social, economic and environmental impacts of flooding on city residents are cumulative, but are not often measured in combination at the community level in West African cities. This study examines the impacts of flooding on the social, economic and environmental processes of the Tamale Metropolis, Ghana, through the development of a Flood Vulnerability Index (FVI) based on a household survey of 400 households in communities that are vulnerable to flooding. The sub-indices were constructed using the weighted component indicators scored according to the characteristics of the household and community to follow the compositional approach of Balica et al. (2012) for each sub-index (social, economic and environmental). The Social Sub-Index was 1.6, representing moderate level of awareness and preparedness to flood risks; Economic Sub-Index was 1.95, representing moderate economic development and accessibility; and the Environmental Sub-Index was 1.5, representing moderate physical vulnerability related to water supply, sanitation and proximity to drainage and water bodies. The overall vulnerability index obtained was 4.02 which indicates the moderate flood vulnerability category for Tamale Metropolis as the social sub-index contributed the greatest share of 64% while the economic sub-index contributed 57% and the environmental sub-index 45%. The results suggest that the city is not at the highest level of risk, but a lack of community readiness, access to resources and water and sanitation infrastructure means that people in flood-prone communities are vulnerable to additional harm in the event of a flood. The study suggests that investments in flood-risk reduction in the Tamale Metropolis should be prioritized by social preparedness gaps given that this has the highest contribution to the overall vulnerability while economic accessibility and environmental resilience elements should be continued to be invested.

1. Introduction

Flood vulnerability is a multi-dimensional phenomenon that is determined by the combination of social, economic and environmental factors that influence the extent of the impact as well as the ability to recover from flood events (Mavhura, Manyena & Collins, 2017; Rufat, Tate, Burton & Maroof, 2015). Social vulnerability reflects the demographic and community level factors that determine a population's ability to anticipate and react to flooding, including awareness, preparedness, social cohesion and access to support services. Economic vulnerability is an indicator of the capacity of livelihoods, employment, infrastructure and services available to residents, their ability to absorb and recover from losses as a result of the flood. Environmental vulnerability, on the other hand, reflects the physical vulnerability of a locality, such as water supply and sanitation, topographic position, and proximity to water bodies, which affect the intensity of the impacts of floods.

The growing problem of urbanisation, deforestation, and poor waste management in the Tamale Metropolis, together with the limited infrastructure, has made residents vulnerable to risks from flooding and its associated impacts (Shokri, Sabzevari & Hashemi, 2020). The traditional and local knowledge practices in the community to this susceptibility are the building of mud flood barriers and water-retardation ponds, as well as sensitisation campaigns by the Tamale Metropolitan Assembly and the

National Disaster Management Organisation (Macnight Ngwese, Saito, Sato, Agyeman Boafo & Jasaw, 2018). However, the relative role of social, economic and environmental factors in the overall vulnerability to floods in the metropolis have not been systematically quantified.

This study aims to fill the gap by developing a composite Flood Vulnerability Index (FVI) for the Tamale Metropolis with social, economic and environmental sub-indices in order to identify the impact of flooding on Tamale flood-prone communities environmental, social and economic vulnerability and to determine the most urgent dimension of vulnerability that can merit policy attention.

2. Materials and Methods

2.1 Study Area and Sampling

It was carried out in the communities in the Northern Region of Ghana, the capital of the Northern Region, which are prone to flooding. The structured household questionnaires were administered to 400 households selected using purposive sampling, simple random sampling and convenience sampling in the three (3) metropolitan zones namely, Tamale North, Tamale Central and Tamale South. The sample size was computed using Cochran's (1977) formula for the estimated population of the metropolis of 730,000 people at a 5% margin of error.

2.2 Flood Vulnerability Index Construction

The Flood Vulnerability Index (FVI) was developed using the approach of the compositional index developed by Balica et al. (2012) to formulate an index from a set of sub-indices, each of which is a weighted combination of component indicators that are scored by the respondents and based on field observation. A weight (reflecting the relative contribution of each component to that sub-index) and a score (reflecting the observed or perceived condition of that component in the study area, on an ascending scale) were assigned to each component with the product of the two then summed across components to give the sub-index value. The three sub-indices were then summated (using the weights associated with each index) to arrive at an Overall Vulnerability Index:

Flood Vulnerability Index (FVI) = Social Sub-Index + Economic Sub-Index + Environmental Sub-Index

The Social Sub-Index included awareness campaigns and educational programmes which involved flooding; community-level awareness and preparedness; community-led initiatives and organisations; and community resources for income, employment or education. The Economic Sub-Index included the level of economic activity, access to jobs, educational facilities, access to health care, access to transportation, economic development projects, land use zoning, and development project impacts. The Environmental Sub-Index included access to reliable and safe water supply, water quality, sanitation facility access, proximity to low-lying or valley areas that are prone to water accumulation, and proximity to major water bodies and drainage. The resulting index values were interpreted based on the scale of Balica et al. (2012) which was adapted here to be applied to the sub-index and overall totals reported in

Section 3, as follows: very small vulnerability, index value below 0.1; small vulnerability, index value between 0.1 and 0.25; moderate vulnerability, index value between 0.26 and 0.50; high vulnerability, index value between 0.51 and 0.75; very high vulnerability, index value above 0.76.

Ethical considerations: The household survey was conducted as part of a graduate school graduation requirement under the University for Development Studies Graduate School Guidelines and Regulations. The research proposal received academic (departmental) review and approval from the Department of Environment and Sustainability Sciences, University for Development Studies. Formal ethical review was separate from this academic review: the study protocol was reviewed and approved from ethical review by Professor Ebenezer Owusu-Sekyere the Head of Department of Environment and Sustainability Sciences in accordance with the University for Development Studies Graduate School Guidelines and Regulations and the ethical principles of the Declaration of Helsinki. Freely given, informed consent was obtained from every participant before data collection, as stated in the Declarations section.

3. Results and Discussion

3.1 Social Vulnerability

The Social Sub-Index for the Tamale Metropolis was 1.6 (Table 1) which shows moderate awareness and preparedness for floods. Awareness campaigns and educational programmes (0.8) and general level of awareness on flood risks and preparedness (0.9 on a single basis) were the most significant contributors to this sub-index, followed by community-led initiatives (0.4) and community resources supporting income, employment or education (0.2). This medium score indicates that awareness and preparedness campaigns are implemented in the metropolis, such as promoting resilient design, traditional flood mitigation practices (e.g., mud barriers, drainage channels) and disaster-preparedness education (Macnight Ngwese et al., 2018), but there is not a uniform application of these in all communities. This is a call for more comprehensive and stakeholder-based flood-risk management that has been echoed in the country of Ghana (Atanga, 2020; Tasantab, Gajendran, von Meding & Maund, 2020).

Table 1
Social Vulnerability Index for the Tamale Metropolis

Social Sub-Index Component	Weight	Score	Contribution
Flood-related awareness campaigns or educational programmes	0.4	2	0.8
Level of awareness regarding flood risks and preparedness	0.3	3	0.9
Community-led initiatives or organisations for flood risk awareness and preparedness	0.2	2	0.4
Community resources or organisations providing support related to income, employment, or education	0.1	2	0.2
Total			1.6
Source: Field survey data, 2023			

3.2 Economic Vulnerability

The Economic Sub-Index had the highest score of the three sub-indices with 1.95 (Table 2), reflecting moderate level of economic development and accessibility that are below residents' needs, especially in employment, education, health care and transportation. The largest share (0.6) was generated by economic activities, indicating that Tamale's economic location as the market district of the Northern region, is well developed, whereas the smallest share (0.15) was provided by economic development initiatives, revealing a comparative lack of targeted investments. The metropolis has the potential to increase population and economic development but the current infrastructure and resilient design is not adequate to significantly mitigate the economic cost from floods (Owusu, 2014).

Table 2
Economic Vulnerability Index for the Tamale Metropolis

Economic Sub-Index Component	Weight	Score	Contribution
Economic activities	0.20	3	0.60
Accessibility of employment	0.15	2	0.30
Accessibility of educational institutions	0.10	2	0.20
Economic development initiatives	0.15	1	0.15
Accessibility of healthcare facilities	0.10	2	0.20
Transportation network and services	0.15	2	0.30
Land use pattern and zoning regulations	0.10	2	0.20
Development projects impact	0.05	1	0.05
Total			1.95
Source: Field survey data, 2023			

3.3 Environmental Vulnerability

The Environmental Sub-Index showed a score of 1.5 (Table 3) which was the lowest of the three sub-indices, but represented moderate physical vulnerability to flooding. The availability of drainage systems or streams that could impact the flow of water during heavy rains (0.4) and water quality and sanitation facilities (0.3) were the next greatest contributors. This is driven by both natural drivers climate variability and anthropogenic drivers poor land use and unplanned settlements (Asiedu, 2020). During floods, the contamination of water sources is another health risk for affected people and damage to roads, bridges and utilities is another challenge to access and services during and after floods.

Table 3
Environmental Vulnerability Index for the Tamale Metropolis

Environmental Sub-Index Component	Weight	Score	Contribution
Access to a reliable and safe water supply system	0.20	1	0.20
Quality of the water supply in terms of safety and cleanliness	0.15	2	0.30
Availability of proper sanitation facilities (toilets, waste disposal)	0.15	2	0.30
Located in a low-lying area or valley prone to water accumulation	0.20	1	0.20
Proximity to the nearest major water body	0.10	3	0.30
Proximity to drainage systems or streams affecting water flow	0.20	2	0.40
Total			1.5
Source: Field survey data, 2023			

3.4 Overall Vulnerability Index

When the three sub-indices are combined an Overall Vulnerability Index is obtained at 4.02 for Tamale Metropolis (Table 4), which falls in the moderate flood-vulnerability category. The social sub-index had the highest contribution to overall vulnerability (64%), followed by the environmental (45%) and the economic (57%). The ordering is useful because, while the environmental sub-index was the lowest in absolute values, the social sub-index (which indicates the pressure of the environment, social cohesion and information access) had the highest impact on the overall vulnerability of the metropolis. The social contribution to vulnerability is increased by high population growth rates, lack of education for certain groups and unequal access to information about floods (see companion analysis on information-access patterns of surveyed households). The significant role played by the economic sub-index is due to the growth of informal settlements, poor infrastructure and restricted availability of financial resources in vulnerable communities (Rufat et al., 2015).

Table 4
Overall Vulnerability Index for the Tamale Metropolis

Sub-Index	Weight	Score	Contribution
Social Flood Vulnerability Index	0.4	1.6	0.64
Economic Vulnerability Index	0.3	1.9	0.57
Environmental Vulnerability Index	0.3	1.5	0.45
Total			4.02
Source: Field survey data, 2023			

At the overall level, the Tamale Metropolis is moderately vulnerable, but not at crisis levels, suggesting that although residents of the flood-prone communities may not be particularly susceptible to flooding, they may be quite vulnerable to harm when flooding does occur because of the combination of social, economic and environmental gaps. These results are aligned with regional studies which found that in similar West African urban environment, high composite vulnerability to floods is associated with rapid urbanisation, deforestation and poor waste management (Shokri, Sabzevari & Hashemi, 2020).

4. Conclusion

The area of Tamale Metropolis was used to assess the flood vulnerability of the communities based on the Social, Economic and Environmental dimensions of flood vulnerability in the area using a composite Flood Vulnerability Index. The Overall Vulnerability Index for the metropolis was moderate (4.02) and social sub-index (0.64 contribution) was the most influential sub-index that determines the overall vulnerability, followed by the economic (0.57) and environmental (0.45) sub-indices. The results imply that policy efforts for preparedness and awareness raising at the community level and socio-economic access to critical services should be given the same priority as investment in physical infrastructure to create a flood-risk reduction strategy for the metropolis. The Tamale Metropolitan Assembly and its partner agencies should focus on regular flood awareness campaigns that are community-led, provide access to income, employment and educational opportunities in flood-prone communities and continue to invest in the development of resilient water supply, sanitation and drainage systems to decrease the overall flood vulnerability of the metropolis.

Declarations

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Author Contributions: Justice Agyei Ampofo had the concepts of the study, developed the methodology, did the systematic literature search and review, analysed and synthesized the findings, and wrote the

original draft. Justice Agyei Ampofo made the manuscript revisions and edited it, as well as reviewing and approving the final version and accepting responsibility for the content of the work.

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Data availability: The datasets generated and analysed during the course of the study are included in this published article. The underlying survey data (household responses and the variables used to compute the composite vulnerability index) are also available from the corresponding author, Justice Agyei Ampofo, on request.

Code availability: Not applicable

Ethics approval and consent to participate

This study involved human participants. The research proposal received academic (departmental) review and approval from the Department of Environment and Sustainability Sciences, University for Development Studies, as part of the requirements of the University for Development Studies Graduate School. This academic review is distinct from the formal ethical approval. The study protocol was reviewed and approved from ethical review by Professor Ebenezer Owusu-Sekyere the Head of Department of Environment and Sustainability Sciences in accordance with the University for Development Studies Graduate School Handbook and Guidelines and Regulations and the ethical principles of the Declaration of Helsinki and its later amendments. All procedures performed in this study involving human participants were carried out in accordance with the relevant institutional guidelines and regulations and with these ethical principles.

Consent to participate

Freely given, informed consent to participate in the study was obtained from all participants before data collection. Participants were informed of the purpose of the study, that their participation was voluntary, and that their responses would be treated confidentially and used for research purposes only.

Competing interest

The author declared that he has no competing interests.

Clinical Trial Number: Not applicable

Consent to Publish Declaration: Not applicable

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