Dean&Francis
ISSN 2959-6157

The Impacts and Adaptations of Climate Change-induced Flood Disasters: Case Study of Burkina Faso

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Abstract:

Flooding occurs when water overflows from natural sources including storm surges, heavy rain, and quickly melting ice and snow, raising the water levels in rivers and lakes. Flood disaster is one of the most severe natural disasters affecting Burkina Faso, impacting thousands of people every year, damaging most crops planted by farmers. This study looked at the methodologies used to evaluate the risks of flooding, the causes and impacts of flood disasters in Burkina Faso, and future prediction and adaptation to flooding disasters in Burkina Faso. Through exploring the weather fluctuations, local farming practice, and construction methods, the study found that Burkina Faso floods are caused by both natural and human-induced factors. Reasons of intense flooding in Burkina Faso include harsh wet and dry seasons with erratic high precipitation, an inadequate drainage system, and widespread land use brought on by the country's rapidly increasing population. The research compared the advantages and disadvantages of the most applied risk assessment methods. Future flood projections in Burkina Faso could benefit greatly from the application of techniques like mathematical statistics and machine learning, due to their economic efficiency, accuracy, and practicality. By assessing the urbanization approaches and the monoculture agriculture practice of Burkina Faso, recommendations of future flood management were presented. Along with limiting urbanization and population expansion, aquaponics and more tree planting could enhance people's quality of life during future floods.

Keywords: Flooding; precipitation; agriculture; urbanization; drainage system.

ISSN 2959-6157

1. Introduction

Flooding is the overflow of water caused by natural factors such as heavy rain, storm surge, rapid melting of ice and snow, which causes the water level of rivers and lakes to rise rapidly [1]. Flood disasters are often large-scale and disastrous, destroying millions of homes and properties in various places around the world. According to statistics, 44% of all world disasters are flood related [2]. In 2021, a flood in Zhengzhou, China triggered by extreme rainfall reaching an average total precipitation above 250mm disrupted the local cropland, urban area, and residential sites [3]. The disaster affected more than 14 million people and killed 398 people, submerging 16 million hectares of crops with $20.69 billions of direct economic lost. The 2020 flood in Spain caused by the storm Gloria stroked seafront roads, leaving at least 220,000 homes without power [4-5]. The 2024 Kenya-Tanzania flood due to El Nino induced heavy rainfall and cyclones affected at least 1.6 million people, killed at least 473 people, and displaced more than 410,000 people [6].

Several researchers have studied methodologies to analyze and mitigate the danger of flooding. Marcello Arosio assessed the direct and indirect impacts of floods in urban context. The research utilized a graph-based method that organized the impacts into nodes and investigated the relationships of different nodes across the impact chain. The researcher also carried out hazard reconstruction system by hydrological models of urban drainage system developed by the United States Environmental Protection Agency. The results of the study demonstrated that the number of interacting nodes resulted in indirect impacts, and the extent of lost services in indirect impact is larger than the direct impact. Mitigation measures can be formulated using the graph-based method of accounting the indirect impacts [7].

Another study conducted by Pei et al. evaluated the effects and solutions to urban flooding. The researchers employed a model-based technique with two-dimensional simulations and visualized the risks of flooding at different precipitation rates and low impact development (LID) practices. The LID performance was assessed by an evaluation system in regard to life-cycle cost analysis, the analytic hierarchy process, and regret decision theory. Results of the study imply that the LID combination of bioretention, infiltration trenches, and rain barrels could effectively reduce the urban flooding risk [8].

Kaitano et al. studied the flooding trends in South Africa by analyzing the factors, impacts and solutions to those disasters. Investigating the archival climate data and primary data from key informants and field observations, researchers found that there was a statistically significant increase of flooding rate over the past decade (2010-2020). The research also showcased that factors such as extreme rainfall, overgrown vegetation, pollution, and urbanization contribute and worsen the vulnerability of the area towards flood disasters. Comprehensive approaches were recommended to remediate the skyrocketing flooding risk [9].

An analysis by Ansah et al. on floods in Ghana examined the meteorological dynamics. The researchers utilized the Weather Research and Forecasting (WRF) model and found out that the low surface pressure and the high humidity intensified the thunderstorm, leading to flood disasters over Accra and Kumasi. Data from comparison of 2018 rainfall and historical rainfall suggests that Accra's annual rainfall is increasing, whereas Kumasi had a decreasing trend of rainfall. Accra has fewer days of heavy rain, and Kumasi had a longer period of mild rain [10].

Tazen et al. inquire into the flood trend of Burkina Faso from 1960s to 2000s and its relationship with extreme rainfall events. Fourteen rainfall indices and a frequency analysis of annual maximum daily rainfall series were applied for analysis. Few rainfall indices show significant trends at the 5% level during the period 1961-2015. An analysis of media flood reports highlighted that Burkina Faso experienced about three floods per year over the time 1986-2016 and increased to five per year in the 2000s. Results suggest that human and environmental factors, rather than heavy rainfall, are the causes of increased flood risk in Burkina Faso [11].

Nevertheless, flooding is still a major issue affecting the locals and the economy of Burkina Faso. Every year, heavy summer rainfall in Burkina Faso lead to numerous flood disasters that submerge the land. Along with unsustainable monoculture agriculture strategies, the flood devastates houses, kill crops on farmland, and make thousands of people homeless and hungry. This paper investigated the situation of flood disasters in Burkina Faso by analyzing the factors causing the disaster and its impact to people living in Burkina Faso. The study examined four risk assessment methods for rainstorm flood disaster. Possible mitigation strategies for flood management were suggested based on the environmental, economic, and political situations in Burkina Faso.

2. Research Background and Current Situation

The northern and the central part of Burkina Faso are most prone to flood disasters. Natural precipitation patterns and human activity both directly and indirectly contribute to the disaster. This results in the decline in population, food, and economy in the affected areas.

2.1 Causes of Burkina Faso Flood

Nothern and central areas of Burkina Faso experience successive drought from November to March with a lower than 10 millimeters average precipitation. The arid season was followed by unpredictable extreme rainfall during summertime. The precipitation reaches 176.81 millimeters in July and 240.86 millimeters in August. This increases the chances of flooding because the soil's ability to absorb water was reduced during the dry season. When sudden heavy rain occurs, closely compacted particles in soil prevent water from being absorbed, forcing the rainwater to run off from slopes or pools, causing extensive floods.

In addition to precipitation, human activities such as unstable hydraulic structures and urbanization are also a factors of flood disaster. The dams on the minor tributary of the Massili river system were built on marshy soil with limited water filtration capacity [12]. Moreover, informal bare soil roads with no storm drainage provision restricted water from leaving the city. The major channel that runs through Ouagadougou is sporadic. The channel has little apparent shape and is eroding and unstable. Thus, during heavy rain, water inevitably builds up, flooding the city. Rapid urbanization with extensive land-use increases the risk of flood disaster. The city of Ouagadougou in Burkina Faso experienced a skyrocket of population growth since the 1960s. The population growth rate has reached 5.6% annually since 2000 [12]. The dwellings built in unplanned areas with "mud walls" were easily damaged by rainwater, making houses extremely vulnerable to floods.

2.2 Effects of Burkina Faso Flood

The floods in Burkina Faso affects thousands of locals each year, forcing them to relocate, threatening their lives. More than 150,000 people were affected due to the flood events in September 2009, and displaced people must live in rescue chambers where food and water are very limited. The disasters not only pose short-term influence on humans, but also worsen their living condition for years. The flood in September 2009 washed away 22,220 hectares of farmland, damaged 15 dams and 42,000 residential buildings, causing an economic loss of $130 million. Reconstruction projects and living supplies were needed years after the flood, requiring even more money to be used. According to the case study by Charlotte Müller et al., it was reported that 49% of interviewed farmers had at least one of their fields damaged by flood; some fields even had no harvest throughout the year. The reduction of agriculture due to unsustainable monoculture farming system tremendously lowered the annual food yield, leading to the starving of local people and the decline of economy as a very limited amount food could be sold.

2.3 Risk Assessment Method of Flood Disasters

Flood disasters often occur for multiple reasons. Due to the complexity and uncertainty of different factors influencing the risk of flood disaster, several risk assessment methods were developed. Currently, researchers have adopted methods including mathematical statistics for historical disasters, multi criteria indicator system, hydrological and hydrodynamic modeling, coupling of remote sensing and GIS, and machine learning.

Mathematical statistics analysis is a method that investigates data on the number of affected people, the area submerged, and loss of life and property from historical flood disasters. The patterns and trends of flood risk are then determined and evaluated. Multi criteria indicator system technique analyzes the natural and social factors of flooding. Appropriate indicators like rainfall, vegetation coverage, slope, impermeable surface, population density, GDP, etc. were selected to form a flood risk assessment system. Hydrological and hydrodynamic modeling is a scenario simulation of hydrological events in a watershed using a watershed runoff model. Through calculation and prediction of hydrological factors such as the size, depth, historical duration, and flow velocity of flood inundation areas, the risk of flooding could be assessed. Remote sensing and GIS coupling method utilize remote sensing platforms to calculate and extract information on flood inundation range, inundation time, land use, etc. The information will then be input into GIS for comprehensive analysis of flood risk. Machine learning also began to emerge as an objective and flexible analysis technique for flood disasters. In this method, algorithms could learn the characteristics of flood risk and automatically obtain the input-output relationship between flood risk and driving factors. The benefits and the downsides of each method are compared in Table 1.

ISSN 2959-6157

Table 1. Benefits and downsides of flood risk analysis methods

Method	Benefits	Downsides
Mathematical statistics of past disasters	Relatively simple calculation of past trends, no need to consider other flood factors, accurate results.	Only applicable to large-scale areas, requires high-precision historical disaster data, sensitive to missing data.
Multi criteria indicator system	Applicable to a wide range of scales, flexibly select indicators that affect flood disasters for flood risk assessment.	Selection of indicators affected by data availability and accuracy, no unified indicator selection standard, calculation of weights greatly affected by subjective influence of experts.
Hydrological and hydrodynamic modeling	Directly and accurately reflect the scope and extent of flood disasters.	High requirements for geographical data, application scope mainly concentrated on the watershed scale, difficult to use on a larger regional scale.
Remote sensing and GIS coupling	Provide continuous data, easy obtain of data, fast-processing speed, more suitable for large-scale flood disasters.	Images of small floods cannot be captured in time from satellites due to the short duration, errors may occur when identifying flood areas (depending on the algorithm used in the image).
Machine learning	High accuracy, continuously improving.	Relies heavily on the integrity and accuracy of data, directly affects results of flood disaster risk assessment.

3. Suggestions for Future Flood Control

Flooding was an enduring issue in Burkina Faso, affecting both the citizens living there and the natural environment. Future flood controls could focus on flood prediction and adaptation. This allows the alarm of locals prior to the flood so that they could be prepared in terms of supplies and settlements, and a modification for a more flood resilient agriculture system.

3.1 Flood Prediction

Mathematical statistics could be a feasible way to predict future flood events in Burkina Faso. This method is relatively simple to calculate, and it does not require expensive technologies and models, given that Burkina Faso was ranked 184th out of 191 countries in the 2021-22 report of United Nations Development Programme. Considering that flooding was already a long-term issue for Burkina Faso, and extensive research of Burkina Faso flood every year were implemented, precise historical data about the area submerged, the amount of people affected, and the property lost from each year could be easily collected. This allows the calculation of a relatively accurate result regarding the prediction of the time and extent of the flood.

As computer technology and machine learning algorithms began to advance, machine learning may also be a sustainable approach for flood prediction in the future. Through the learning of characteristics of past events, machine learning could automatically obtain the relationship between flood risks and driving factors. This creates a reliable and sustainable prediction of long-term flood disasters in the future, enabling the local government to propose a long-term plan for future disasters.

3.2 Flood Adaptation

Adaptation to the flood in Burkina Faso involves the improvement of agriculture system and the execution of new policies.

Due to the unpredictable nature of the flood, the current agricultural practice of Burkina Faso, monoculture farming, is too vulnerable for crop growth. Other farming methods such as aquaponics, an incorporation of fish to the cultivation of plants with water, could be utilized by filtering the isolated flood water once per two weeks. This makes the introduction of additional water supply unnecessary, and it avoids the increased pH of soil after the flood because no soil is used. Since the system contains an abundance of aquatic animals like tilapia, carp, and perch, the fish feces could serve as nutrients, such as nitrates, for the crops. The plants purify the water for fishes, and their photosynthesis ensures oxygen for fish respiration. Aquaponics also saves money because additional fertilizers or pesticides are not required; there will be few weeds or pests as other conditions are controlled. Additionally, job opportunities can be created, boosting the employment rate and national economy.

To enhance the drainage system in Burkina Faso so that water could penetrate after heavy precipitation, more trees should be planted, and policies limiting logging should be applied. The growth of trees will increase the rate of plant uptake and evapotranspiration, reducing runoff and accumulation of rainwater. The roots of the trees also loosen and deepen the soil, increasing infiltration, removing the rainwater on land. Additionally, urbanization should slow down, and the rapidly increasing population should be restrained. Laws regarding the maximum number of children a family could have should be generated. As the population increased, more houses were built, meaning that trees would be cut down. Therefore, to stop deforestation, less buildings should be constructed, and more trees should be planted.

4. Conclusion

This paper studied the causes and effects of flood disasters in Burkina Faso, evaluation methods of flooding risks, and future prediction and adaptation to flood disasters in Burkina Faso. The results of the study show that causes of Burkina Faso flood include extreme wet and drought seasons with unpredictable heavy precipitations, underdeveloped drainage system with eroded main channel and informal bare soil roads, and the extensive land use due to the rapid population rise. The disaster affects thousands of people each year, forcing them to relocate, destroying their crops, and damaging their possessions. Methods such as Mathematical statistics and machine learning could be effectively used for future flood predictions in Burkina Faso because of their feasibility, accuracy, and economic efficiency. People's quality of living after future floodings could be improved through aquaponics and increased planting of trees, along with the restriction of population growth and urbanization. This study contains drawbacks. The causes and effects of Burkina Faso flood were not thoroughly analyzed: additional factors triggering specific flood events were neglected, the long-term impact to the environment was disregarded, and the severity of each flood event was not examined. Trends of past disaster events were not considered, so there were no investigations into the changes in flood pattern. Details like the economic status, the capability of the population, and the time and energy needed to achieve those predictions and adaptation suggestions were not considered.

Future research on Burkina Faso flood could involve field investigations of climate, terrain, constructions, and agriculture in Burkina Faso. Real-life applications of various flood risk examination methods could also be added, empowering a better understanding of the mechanisms as well as benefits and downsides of those approaches. This allows a more in-depth and objective evaluation of the flood risk, and the problems Burkina Faso is facing, which contributes to a more attainable, well fitted, and timely flood management plan.

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