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Introduction

One of the most common and damaging natural disasters in the world, flooding causes a great deal of death, damage to infrastructure, and environmental deterioration. According to the World Bank, flooding affects over 2 billion people annually, with annual economic losses exceeding $100 billion and a yearly death toll in the thousands (Rentschler & Salhab, 2020). Rapid urbanization, coupled with inadequate surface drainage infrastructure and intense rainfall events, exacerbates the risk of flooding, particularly in urban areas, where it threatens public safety, health, and infrastructure (Mukwaya et al., 2012).

Kampala, Uganda's capital city, has a current population of 4 million and a predicted population of 21 million by 2040. It is highly vulnerable to floods, particularly during the two rainy seasons (March-May and October-December) (International Rescue Committee, 2018). While Kampala lacks significant rivers, it is specifically prone to pluvial flooding. Pluvial flooding, also known as flash flooding or overland flooding, occurs when rainfall exceeds the ability of both the soil to absorb it and the stormwater drainage systems to withstand it.

The Nakivubo Channel, Kampala's major drainage system, was constructed in the 1950s to prevent pluvial floods by diverting stormwater and wastewater away from industrial and residential areas. It is a 9-kilometer-long river that drains waste and storm water into Nakivubo Swamp, which in turn flows into Lake Victoria. Recent fast urbanization and floodplain expansion, spurred by population pressure and lax enforcement of wetland preservation legislation, have increased runoff into the channel (Gideon & Bernard, 2018). The issue is exacerbated by the accumulation of garbage and sediment in the channel and its tributaries, which obstructs drainage and reduces the capacity of both the channel and the surrounding drainage system. These compounding issues ultimately cause the entire system to become overwhelmed during heavy rainfall events (Abo, 2024; Olsson, 2024). In flood-prone areas of Kampala, 69% of households have experienced flooding due to the current infrastructure and urban planning deficiencies (Olsson, 2024).

Despite ongoing efforts by the Kampala Capital City Authority (KCCA) to improve drainage infrastructure, the city continues to experience significant flood-related disruptions. Between January 2019 and November 2024, the UN’s Global Disaster Alert and Coordination System (GDACS) recorded six major flooding events in Kampala, along with one landfill slope failure that resulted in substantial loss of life in 2024 (GDACS, 2019-2024). As climate projections suggest an increase in future rainfall intensity, the frequency of pluvial flooding in Kampala is expected to rise unless adequate infrastructure is developed to manage these extreme weather events (Mukwaya et al., 2012).

For flood predictions, Uganda currently uses the Global Flood Awareness System (GloFAS). GloFAS was created by the European Union's Copernicus Program and is run in Uganda by the Uganda National Meteorological Authority (UNMA) and the Ugandan Red Cross Society (URCS). Forecasting pluvial flood events in urban settings is thought to be beyond the scope of the GloFAS model, which is largely focused on river flooding. In addition, the model's low temporal coverage and coarse geographical resolution make it difficult to produce the localized, real-time predictions needed for efficient urban flood risk management (Boelee et al., 2018; Umer et al., 2018). GloFAS is not suitable for smaller urban systems like Kampala, even though it works well for catchments with a larger scale. The current flood forecasting capabilities for the city's urban landscape are therefore seriously lacking (Mulangwa, 2023).

A promising answer to this problem is provided by recent developments in machine learning (ML). ML models can identify intricate patterns in real-time by evaluating vast amounts of hydrological and meteorological data, which increases the precision of flood forecasts. The goal of this project is to use information from the Trans-African Hydro-Meteorological Observatory (TAHMO) network to create an ML-based forecast model for Kampala. Five weather stations run by TAHMO in Kampala gather comprehensive data on wind speed, surface air temperature, relative humidity, precipitation, atmospheric pressure, lightning, soil moisture, and temperature. To increase the precision and promptness of flood forecasts in Kampala, this data will be used as input for a deep learning model that looks for relationships between meteorological factors and pluvial flood events. The absence of stream gauge data in Kampala, however, is a significant project drawback (Musoke et al., 2022). Several instream monitoring stations were formerly present on the Nakivubo Channel, but they have since been badly maintained and are no longer functional. Several new stations that were sponsored by the UN in 2019 had not yet been deployed as of 2022 (Musoke, 2022). Another possible source of data is the URCS, which has set up stream gauge stations in rural areas as well. However, there aren't any of these stations in Kampala's urbanized districts now. The capacity to accurately forecast urban flood events may be hampered by this data deficit. In order to tackle this issue, this study will investigate two different data sources: (1) Dr. Seith Mugume's intensity-duration-frequency (IDF) curves for Kampala, and (2) flood event records from the GDACS database (Olsson, 2024; GDACS, 2019-2024). The installation of a more accurate flood forecasting system than GloFAS now provides might greatly lessen the effects of flooding and save lives in Kampala's flood-prone districts, even as KCCA's continuing infrastructure improvements work to ease the city's water management issues. The main goal of this study is to develop an early flood warning system.

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