Developing a Climate-Smart Web GIS App for Multi-Hazard Early Warning against Climate-Based Disaster Risks

Anastazia Daniel Msusa [1], Dorothea Deus [1], Octavian Gasper Nyalali [4], Anthony Gidudu [2], Engelbert Wangabo [1], Salma Makuti [3], Gideon Marandu [1]

[1] Dept of Geospatial Sciences & Technology, Ardhi University, Dar es Salaam, Tanzania
[2] Dept of Geomatics and Land Management, Makerere University, Kampala, Uganda
[3] Dept of Geotechnical Engineering, University of Dar es Salaam, Dar es Salaam, Tanzania
[4] Ability First Tanzania (AFTA), Dar es Salaam, Tanzania

Keywords: Climate, Climate-Smart Application, Web GIS, Multi-Hazard Early Warning, Disaster Risk Reduction

Abstract

Floods and drought are one of the most recurring and devastating natural hazards threatening life and economy. Early warning of the likely occurrence of flood and drought disaster risks and impacts could assist in decision making to support proper disaster risk responses, management and formulation of informed Climate Change adaptation and mitigation strategies for enhanced resilience and disaster risk reductions. Globally and across Africa various initiatives and innovations of multi-hazard early warning systems based on web and mobile information platforms have been developed, however, none fit in the Tanzanian and East African environment. Developing a localized multi-hazard early warning for climate related hazards is essential in reducing loss of life and damage to property. This study aimed at developing an innovative multi-hazard early warning Web based Geographical Information System (GIS) App for flood and drought disaster risks in East Africa, Case of Tanzania. We used Palmer Drought Severity Index (PDSI) and deep learning neural networks based on geospatial weather data using a convolution long-short-term memory (ConvLSTM) model to predict drought in Dodoma. Global Flood Awareness System (GloFAS) flood prediction data were streamed to show the flood occurrence forecasted for Dar es Salaam. The Web based GIS App was designed and developed using the Rapid Application Development (RAD) methodology in Microsoft .NET framework to capture and disseminate information on flood and drought disaster risks. From analysis we identified areas which are highly prone to flooding. The results were validated using observed flood points identified and mapped using the participatory approach by vulnerable community members. On the other hand, the analysis of drought conditions in Dodoma region depicts Chamwino, Bahi and Central Dodoma to be highly prone to drought risks. Thereafter, the Web-based GIS App for dissemination of climate related early warning information for flood and drought disaster risks was successfully developed. We recommend integration of GIS and Early Warning Tools into Existing Policies, Establish Monitoring and Evaluation Frameworks and further Improvement of the Developed App for enhanced Disaster Risk reductions (DRR).

1. Introduction

Disasters resulting from climate change related natural hazards like floods and droughts accounts for casualties, human displacement and property damage are on an appalling scale around the world (Thomas, 2017). At global level, flooding is one of the most significant natural disasters among meteorological hazards leaving widespread devastation in its wake (Dewan, 2013; Grimaldi et al., 2016; Blöschl, 2022; Olanrewaju & Reddy, 2022; Alsahhan et al., 2023). In many parts of the world, about 1.81 billion people, which is 23% of world population are straightforwardly exposed to 1-in-100-year floods (Rentschler et al., 2022). East Africa is burdened by the dual pressures of climate change and the rapid, uncontrolled transformation of its cities and megacities (Gosset et al., 2023). For instance, in March 2020 more than 1.3 million people were affected by floods in East Africa. In 2024, severe flooding in East Africa caused several casualties while destroying infrastructure, crops and killing livestock and wildlife. Tanzania experiences the highest incidence of flooding in East Africa (Erman et al., 2019). Between 2013 and 2020, Tanzania reported 34 natural disasters such as floods and storms. Such weather hazards led to destruction, deaths, and thousands of people forced to leave their homes (World bank Group, 2022). The cost of flooding has been increasing over the years, and its effects are felt by everyone to varying degrees (Cruz-Bello & Alfie-Cohen, 2022), causing disruption, displacement and endangering of properties. Besides causing damage to infrastructure and threatening lives, floods cause decline of the economy (Mioc et al., 2008; Motta et al., 2021; Ajibade et al., 2021; Li et al., 2023; Zao et al., 2023). Floods are the main natural hazard that the country experiences on regular bases (Olorunfemi, 2011). Specifically, Dar es Salaam region is highly vulnerable to floods, coastal erosion, water scarcity, and disease outbreaks (Kebede & Nicholls, 2012). Each year, the region faces severe flooding that devastates roads and destroys homes posing significant risks to both lives, infrastructure and economy.

On the other hand, droughts rank among the most destructive and expensive natural disasters with a profound impact on agriculture, water resources, the economy, society and the environment (Mckee et al., 1993; Li et al., 2019; Pei et al. 2020; Hoque et al., 2020). Economic losses from drought-related disasters and their negative effects on human society surpass those of any other meteorological disaster (Hoque et al., 2020). Globally, drought-related disasters cause an estimated economic loss of \$6–8 billion annually (Pei et al. 2020). Frequently droughts in Tanzania cause devastating impacts on economy, agricultural output, food security, hydropower generation and domestic water supply (World bank Group, 2022).

Despite the effects of flood and drought hazards on the Tanzanian population, still the majority do not have enough information about the changes in weather, climate and associated hazards (Garcia-Aristizabal et al., 2017). Many

https://doi.org/10.5194/isprs-archives-XLVIII-4-W16-2025-59-2025

people do not have access to clear, correct, reliable and up-to-date information about the possibility of flood or drought disasters occurrences. This underlines the need for Early Warnings for all.

Considering the availability of early warning climate related multi-hazard tools or platform in the world (for instance, the World Meteorological Organization (WMO) and Global Multi-hazard Alert System (GMAS)) and the tools utilized for climate related information dissemination in Tanzania (like radio, TV and newspaper), there is still no reliable multi-hazard early warning tool that can easily inform the vulnerable communities with precise details about some natural disaster about to happen shortly or soon. The actual spatial information about areas vulnerable to flood and drought disaster risks are also unknown. Therefore, in order to address these challenges, an innovative Web Geographical Information System (GIS) App to enable accessibility to and dissemination of multi-hazard related risks information particularly flood and drought is vital. This information will support local government officials, community-based disaster management committees, residents and farmers by providing timely alerts and actionable information for preparedness, response, reduction and formulation of sound climate change adaptation and mitigation plans.

Consequently, the objectives of our study were to: (1) identify and map flood and drought prone areas, (2) predict occurrences of flood and drought events and (3) design and develop a Climate-Smart Web GIS App for Multi-Hazard Early Warning against Climate-Based Disaster Risks.

2. Materials & Methods

2.1 Description of the Study Area

The study was conducted in Dodoma (latitude 04°18'55"S to 07°22'46"S and longitude 35°03'13"E to 36°57'54"E) a drought-prone region and Dar es Salaam (latitude 06°33'59"S to 07°10'54"S and longitude 39°00'26"E to 39°33'09"E) a flood-prone region in Tanzania (Figure 1).

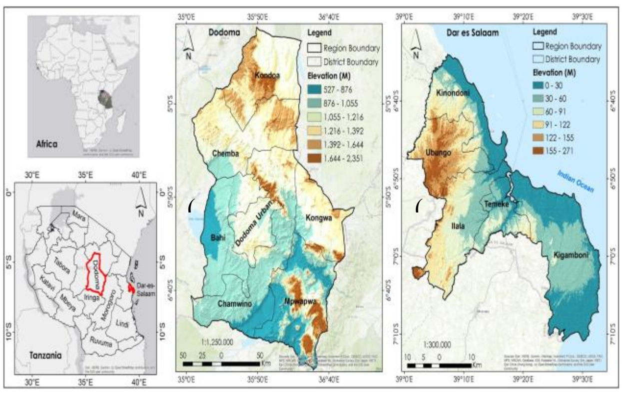

Figure 1: Location of the Project Area

Dodoma covers an area of 41,941km^2 and the population of Dodoma Region was approximately 3.1 million according to the 2022 national census. The region experiences a semi-arid climate with irregular rainfall patterns, primarily concentrated between November and April. Average annual precipitation ranges from 500 to 800 mm, and temperatures can vary significantly between day and night. Dodoma region was selected for this study based on its semi-arid nature and it is one of the regions in Tanzania with high risk of drought.

In contrast, Dar es Salaam region covers an area of about 1630 square kilometres and has a population exceeding five million, making it one of the fastest-growing cities in the world. The climate is hot and humid, with annual rainfall averaging between 1,000 to 1,400 mm, primarily occurring from March to May. Flood events in Dar es Salaam city are recursive and affect many places. In most cases the effects include deaths, loss of properties and many people abandoning their settlements. Major service delivery systems such as roads, water and sewage systems are also impacted. The city is prone to regular flooding and that is why the region was selected for this study.

2.2 Data Acquisition

We collected both GIS and RS based datasets (Table 1) that were used for flood and drought risk assessment and prediction. The GIS datasets were critical for mapping exposure and vulnerability while remote sensing datasets provided dynamic environmental variables necessary for climate-based hazard detection and monitoring. These datasets were then pre-processed and integrated within a spatial database to support multi-hazard analysis workflows. Additionally, temporal datasets were analysed to detect seasonal and inter-annual variations relevant to flood inundation and drought severity.

2.3 Identification and mapping of flood and drought prone areas

A geospatial based Height Above Nearest Drainage (HAND) model was used to translate elevation data from height above mean sea level to height above the nearest river (Aristizabal et al. 2023). This was done in the QGIS software with GRASS plugin and the processing step involved the generation of DEM derivatives, particularly the height above the nearest drain, generation of the hand map, cartographic manipulation and changing the style of a hand map to generate the 10m flood extent. Then, an overlay and proximity analysis of buildings was done to show the extent of community and infrastructure vulnerability. To check the performance of the HAND model, a Participatory Community mapping was conducted to identify and map areas vulnerable to flooding in Hananasifu and Msasani wards. We printed Landsat satellite images and people living in areas vulnerable to floods marked the areas where flood events recur. To identify drought prone areas we used the Vegetation Condition Index (VCI). VCI was computed by comparing the current NDVI with the historical minimum and maximum NDVI values (Equation 1). This index indicates how healthy the vegetation is relative to its historical range.

$$VCI = (NDVI - NDVI\_min) / (NDVI\_max - NDVI\_min) \quad (1)$$

2.4 Flood and Drought Prediction

We employed a predictive modelling approach to forecast flood levels by utilizing the API that integrates reanalysis and forecast data from the Global Flood Awareness System (GloFAS). Specifically, we utilized GloFAS version 4, which offers seamless river discharge data spanning from 1984 and provides forecasts extending up to seven months into the future. The methodology began with establishing a connection to the Global Flood API to collect the necessary historical river discharge data.

The Palmer Drought Severity Index (PDSI) was then used as a drought indicator to identify areas with drought conditions. The

https://doi.org/10.5194/isprs-archives-XLVIII-4-W16-2025-59-2025

PDSI values were downloaded from TerraClimate using Google Earth Engine. The datasets were from 1958 to 2023. During model training, a threshold value of -2 was used to create a binary classification of those areas affected by drought. Drought prediction was done using deep neural networks based on geospatial weather data using a convolution long-short-term memory (ConvLSTM) model (Alexander, et al., 2023). The ppConvLSTM model blended Recurrent Neural Networks (RNNs) with Long-Short-Term Memory (LSTM) to capture temporal dependencies. For drought prediction we used 12 months history length and a horizon period of 3 months, whereby, the ConvLSTM model was trained with (i) PDSI data range from January 1958 to October 2022 and predict drought condition for January 2023, and (ii) PDSI data from January 1958 to march 2023 to predict drought conditions for June 2023.

SN	Data	Source	Format	Spatial resolution
1	Dar es Salaam and Dodoma region administrative boundary and river network	Ministry Lands Housing and Human Settlement Development	Shapefile	
2	Buildings	Open Street Map	Shapefile	
3	SRTM DEM (30 m)	https://earthexplorer.usgs.gov/	Raster	30
4	Drone DTM for Dar es Salaam	Climate Risk Database (CRD), Resilience Academy. https://geonode.resilienceacademy.ac.tz/	Raster	20
5	Flood validation data	Climate Risk Database, Resilience Academy https://geonode.resilienceacademy.ac.tz/ and Wami-Ruvu Basin Water board	shapefile	
6	Sentinel-1 SAR	https://scihub.copernicus.eu/	Raster	10m
7	Terra Vegetation Indices 16-Day Global (MODIS)	MODIS, https://lpdaac.usgs.gov/ MODIS/006/MOD13Q1	Raster	250m
8	Terra Land Surface Temperature and Emissivity Daily Global (MODIS)	MODIS, https://lpdaac.usgs.gov/ MODIS/061/MCD12Q1	Raster	1km
9	Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS)	https://www.chc.ucsb.edu/data/chirps	Raster	5km
10	TerraClimate	http://www.climatologylab.org/terraclimate.html	Raster	4km
11	Landcover	MODIS, https://lpdaac.usgs.gov/ MODIS/061/MCD12Q1	Raster	500m
12	Landsat satellite images	United States Geological Survey (USGS) website https://glovis.usgs.gov/	GeoTIFF	30m
13	Flood prediction (River Discharge)	GloFAS https://open-meteo.com/en/docs/flood-api#	CSV	5km

Table 1: Data and Sources

2.5 Web based GIS App Architecture

The development of web-based GIS App architecture was based on the Three-tier client-server architecture as illustrated in Figure 2. This architecture logically partitions major functions into three layers. These three layers are:

I. Presentation layer – which provides the user interface. To provide an interactive dashboard for data visualization, this layer was developed using web-mapping libraries. APIs were used for communication between this layer and the processing module hence enabling real time updates and interactive map exploration.

II. Application layer – which performs data processing and information generation rules. It's in this layer where the hydrological models and drought prediction models are run. It included geospatial tools (e.g., GDAL) for data analysis and supported algorithm execution for multi-hazard risks assessment.

III. Data access layer – composed of the OpenStreetMap provider which provides the background of the application, Web data, Weather APIs and local database.

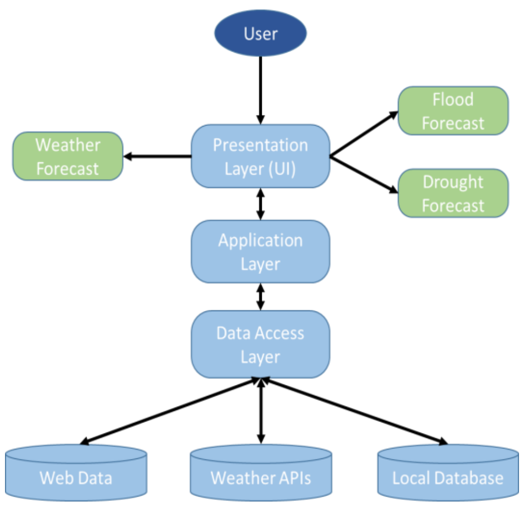

Figure 2: Three-tier client-server architecture

2.6 Development of the Web GIS App

Development of the web-based GIS App was based on the Rapid Application Development (RAD) Methodology. This approach is crucial for developing a web-based GIS App for multi hazard early warning against climate-based disaster risks. This is due to its emphasis on quick prototyping and iterative development, allowing different developers (same time) to build the core functionalities of the GIS App, such as data integration, hazard modelling, and real-time visualization. However, early in the processing stage, developers can incorporate user feedback from disaster stakeholders, hence enabling adjustments and enhancements to the App's features based on practical needs. On the other hand, RAD facilitates integration of advanced analytical models and diverse data sources while ensuring the system remains adaptable to the evolving requirements of climate risk monitoring, hence a robust, user-centred application that can provide timely and effective early warnings. Figure 3 illustrates the Web based GIS App development based on RAD methodology

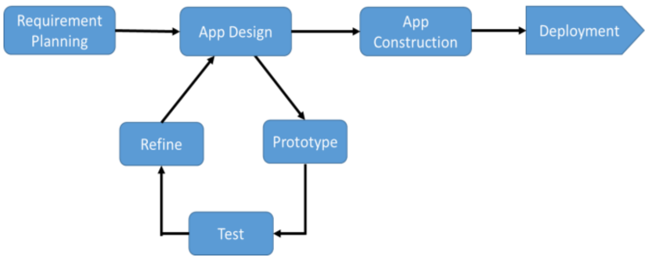

Figure 3: Web based GIS App development based on RAD approach

2.6.1 App Development: The Web based GIS App was developed within the Microsoft cross-platform framework ".NET MAUI (Multi-Platform App UI)". C# (C-Sharp) and XAML (Extensible Application Markup Language) were used to program the App. This included creating a full functional User Interface that was interactive and responsive, allowed for internal computations of data, and display of outputs. The App's early warning/alerts module used algorithms to analyse special (Spatial?) and climate data to predict potential flood /drought hazards. Push notifications and alarms systems were used to notify users about the potential hazards. It was designed such that regular users wouldn't need to register/login to access the app.

2.6.2 Data Visualization: The App used a dashboard, labels, images and interactive maps to show overview status, real-time and historical hazard data, weather conditions and risk areas, warnings and risk levels. Other visualization tools such as graphs and charts were used to display temporal data, trends and prediction models. With the help of various visualization tools, the user could easily access past/historical, current and future predictions data related to weather conditions and related hazard warnings.

2.6.3 Testing: Upon completion the App's components including location precision, data integration and processing, response and visualization, and alert mechanism were tested. This stage involved various stakeholders including users, developers and administrators. Also, simulations using multiple users to access the App simultaneously (Load testing) to ensure its handling of high traffic especially during emergency situations was performed. Thereafter, the provided feedback on use and performance was used to improve the App before final release.

2.6.4 Deployment: After testing and bug fixing the app was deployed for public consumption in various platforms such as online Android markets and websites. It involved creation of installer packages that could be distributed to users. This was done by adding a Setup project to the App's solution. To install, the user was able to run the setup file from the installer package and follow all steps through a wizard to install the application. Thereafter, the application would be ready for use.

3. Results

3.1 Identified Flood and Drought prone areas

The identified flood risk areas for the Dar es Salaam region are presented in Figure 4. It was observed that, Magomeni, Kigogo, Mchikichini, Mburahati, Mabibo, Ndugumbi, Kijitonyama Makumbusho, Mikocheni, Kipawa, kiwalani, Kawe, Kunduchi, Mbweni, Chanika, Pembamnazi, Kisarawe II and Mjimwema, Somangila, Hananasifu, Tandale and Msasani wards have higher flooding risks. Also, the areas marked by residents as flood affected corresponded closely with the HAND model results revealing a strong spatial agreement. Likewise, the identified drought risk areas using the vegetation condition index are presented in Figure 5 where we observed that many districts experience significant drought conditions. In the drought year of 2019, central Dodoma (Dodoma Urban), the western region (Bahi), and the southwest (Chamwino) were severely affected by moderate to extreme drought. Meanwhile, the eastern part of Dodoma (Kongwa) experienced light to severe drought conditions. In contrast, northern Dodoma (Kondoa), the northwest (Chemba), and the southeast (Mpwapwa) were largely unaffected and fell within the no-drought category.

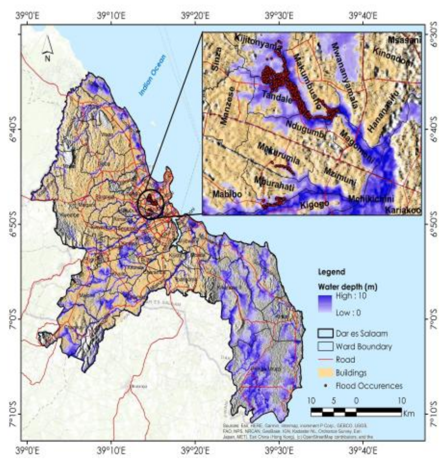

Figure 4: Identified flood vulnerable areas and Validation using observed flood events in Tandale ward in Dar es Salaam region.

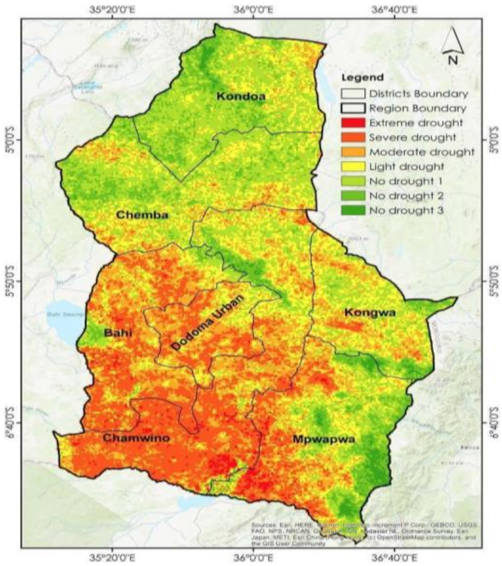

Figure 5: Drought risk areas in Dodoma region

3.2 Drought Events Prediction and Validation

The results from model validation showed that the ConvLSTM model has a good median Receiver Operating Characteristic - Area Under the Curve (ROC AUC) score of 0.87 and median F1 score of 0.81 showing how good its predictive capabilities are over long-term drought predictions. Additionally, the drought conditions in the region are spatially variable with the predicted drought areas (B and D) closely aligning with the original reclassified PDSI data (A and C), showing persistent drought in northern and southern districts, particularly in June 2023 (refer Figure 6a). The monthly drought prediction (refer Figure 6b) show that drought severity fluctuated across the region from January to August, with higher drought risk (yellow areas) becoming more prominent in the northern and southern districts, particularly in May, June, and August 2025.

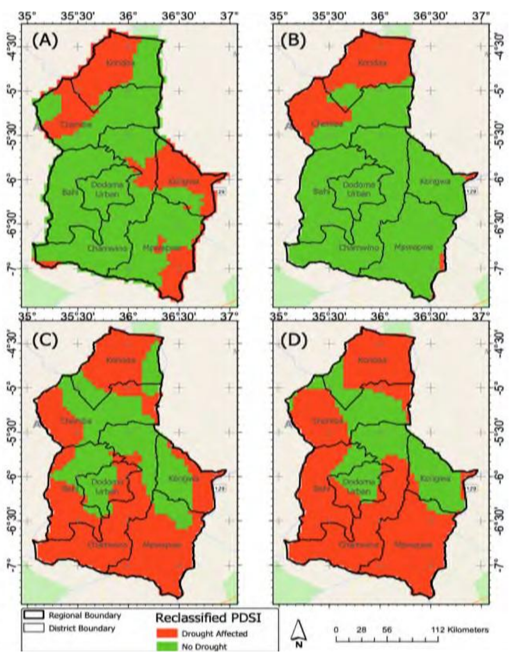

Figure 6: Spatial distribution of the predicted drought conditions in Dodoma region. A and C are the original reclassified PDSI values. B and D are drought predictions for January and June 2023 respectively.

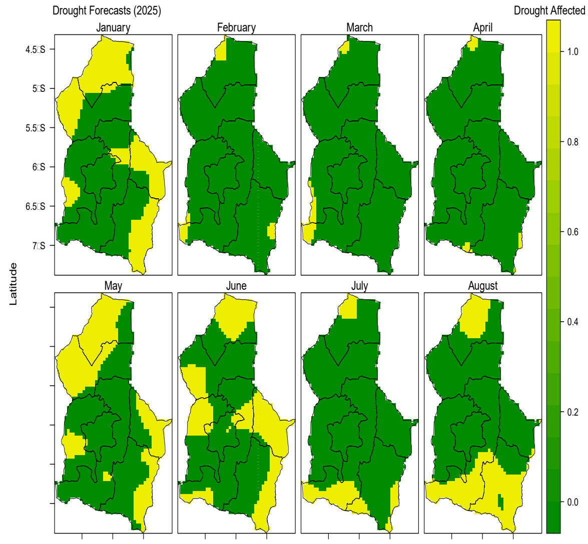

Figure 6b. Spatial distribution of the predicted drought conditions in Dodoma region for January to August 2025

3.3 The Web based GIS App

The main objective of this study was to design, develop and finally implement a web-based GIS App, using Microsoft cross-platform framework ".NET MAUI (Multi-Platform App UI)", C# (C-Sharp) and XAML.The app consiststs of a presentation layer (user interface), application layer and the data access layer. The web-based GIS App interface initially requests permission to access a user's location (refer Figure 7 (A)) thereafter, displays three major layers which are Weather Forecast layer, Flood Forecast layer and Drought monitor layer as described below:

I. The *weather forecast layer* is the first layer to open. This layer displays the weather condition (like Day, date and data request time, City name, Location (latitude & Longitude), Temperature, Humidity, Wind speed, Min & Max Temperature, What the temperature feels like, Pressure, Visibility) and forecast (Weather forecast for three days with 3 hours interval time) of the user's location as in Figure 9(B). The App user can also type in the name of a place he/she wants to access the weather condition and forecast. For example, Figure 7(B) the user has typed in Dodoma to view/access weather conditions and forecast at Dodoma.

II. The *Flood forecast layer*, provides a user with a range of visualizations that aid in understanding flood risks, dynamics, and potential impact areas like Flood Risk Zones, Real-time and Forecasted Water Levels, Rainfall Intensity and Accumulation, Terrain and Flow Path Analysis, Vulnerable Areas, Flood Forecast Timeline and Flood Alerts and Warning Zones. Figure 7 (C) Displays OpenStreetMap of Dar es Salaam city in the Flood forecast layer which is used as a background layer for flood prediction, the user could also explore and see the flood prone areas in their vicinity.

III. The *Drought monitor layer* provides users with information of Drought Severity Index, Soil Moisture Levels, Precipitation Deficit, Vegetation Health and Stress (Vegetation condition Index), Temperature Anomalies, Drought Risk Zones, Temporal Changes & Forecasts and Drought Alerts. Figure 7(D) displays drought monitor layer with initially loaded VCI layer for Dodoma.

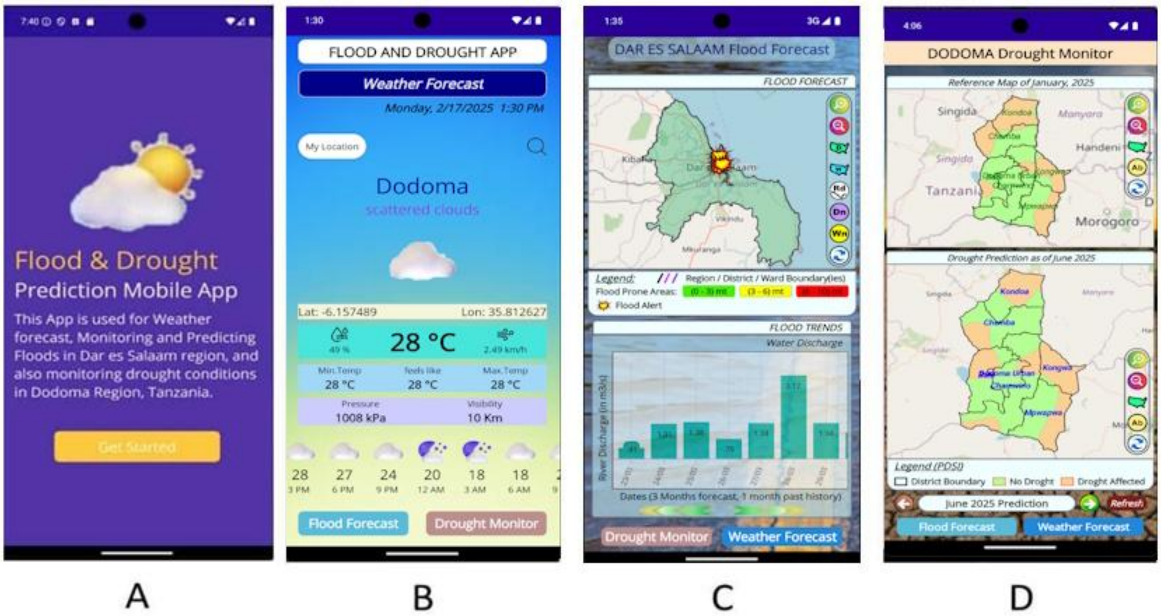

Figure 7. Web-based GIS App (A) First time launch description layer (B) Weather forecast layer (C) Dar es Salaam Flood forecast layer (D) Dodoma Drought Prediction layer

4. Discussion

4.1 Flood and Drought Hazard Risk Areas Identification

Our analysis provided critical insights into the specific patterns of flood and drought risks affecting Dar es Salaam and Dodoma respectively. Based on the analysis of flood prone areas, we mapped areas which are likely to experience flooding during extreme rainfall events. The results reveal that severe flooding is most likely to occur in low-lying areas, poor drainage facilities and rapid urbanization as a result major disruptions to road networks occur which significantly affects transportation and other business activities. In Dodoma specifically at Chamwino, Bahi and Central Dodoma, our data indicated a recurring trend of drought conditions characterized by prolonged dry spells and diminished rainfall. Dodoma region relies heavily on agriculture for its economic stability and food security hence the study suggests that even slight fluctuations in precipitation can have severe repercussions for farmers, threatening their livelihoods and exacerbating food shortages. In understanding how climate change is influencing extreme weather events, both regions serve as important case studies highlighting the urgent need for comprehensive risk assessments and targeted interventions.

4.2 Dynamic Risk Monitoring

The importance of dynamic risk monitoring in enhancing resilience to climate-based disasters was another key theme that emerged from this analysis. The Web based GIS App was designed to integrate real-time data making it capable of monitoring evolving hazard conditions. Residents and local authorities can timely be updated on flood forecasts and drought severity on a near real time basis in Dar es Salaam and Dodoma respectively. Similarly, the dynamic risk assessment tool supports formulation and adoption of proactive decision-making in climate adaptation strategies as it enhances situational awareness that fosters community engagement. Additionally, this proactive approach is vital for minimizing the impacts of climate-related disasters and improving overall community resilience (Khan, 2013; Jiang et al., 2024).

4.3 Design and Development of the Application

The design and development of the web-based GIS App for Multi-hazard Early Warning against climate-based disaster risks represented an invention in Tanzania. The RAD approach used to design and develop the App played a critical role in shaping the application's features, ensuring that it is not only functional but also accessible. However, the Web based GIS App was designed to fit the Tanzanian environment, but it can be used in areas with an environment similar to Tanzania. Additionally, its dynamic monitoring nature is particularly crucial for regions that experience rapid weather changes, where timely information can be the difference between safety and disaster.

5. Conclusion

This study focused on the development of a web-based GIS App for Multi-hazard Early Warning against climate-based disaster risks. The study integrated historical data, real-time data and geospatial analysis seeking to provide critical early warning information, ultimately enabling communities to make informed decisions that mitigate their vulnerability to climate-related risks. The application transformed complex climate data into user-friendly visualizations that are accessible to local stakeholders hence serving as a vital tool for enhancing risk communication and hence a significant contribution to DRR. Furthermore, this addresses a significant gap in current climate risk management, where technical data often remains inaccessible to those who need it most.

The identification of high-risk zones and recurring vulnerability patterns supports data-driven decision-making. Local authorities can utilize these insights to allocate resources effectively, prioritize intervention areas, and plan climate adaptation strategies leading to more resilient communities in the face of climate change. Lastly, the study underscores the need for inclusive policies that integrate GIS-based early warning systems into national and regional disaster management frameworks, addressing the socio-economic vulnerabilities faced by marginalized communities.

Acknowledgements

This research was funded by USAID through the Climate Adaptation Research Program (CARP) under the Periperi U consortium. We sincerely thank the Department of Geospatial Sciences and Technology at Ardhi University for hosting the project, and gratefully acknowledge the collaborative support received from the University of Arizona and Stellenbosch University, whose guidance and technical input significantly contributed to the success of this work. We thank all the organizations and stakeholders for sharing their ideas and data with us. We are grateful to the people from Tandale, Msasani, Hananasif and Chamwino for allowing us to enter their communities and helping us to conduct the much-needed fieldworks and arrange community workshops. We appreciate two anonymous reviewers for their valuable comments and suggestions in improving the quality of the manuscript.

References

Ajibade, F. O., Ajibade, T. F., Idowu, T. E., Nwogwu, N. A., Adelodun, B., Lasisi, K. H., Opafola, O. T., Ajala, O. A., Fadugba, O. G., & Adewumi, J. R. (2021). Flood-prone area mapping using GIS-based analytical hierarchy frameworks for Ibadan city, Nigeria. *Journal of Multi-Criteria Decision Analysis*, *28*(5–6), 283–295. https://doi.org/10.1002/mcda.1759

Al-Sabhan, W., Mulligan, M., & Blackburn, G. A. (2023). *A real-time hydrological model for flood prediction using GIS and the WWW*. www.elsevier.com/locate/compenvurbsys

Blöschl, G. (2022). Three hypotheses on changing river flood hazards. In *Hydrology and Earth System Sciences* (Vol. 26, Issue 19, pp. 5015–5033). Copernicus Publications. https://doi.org/10.5194/hess-26-5015-2022

Cruz-Bello, G. M., & Alfie-Cohen, M. (2022). Capturing flood community perceptions for social vulnerability reduction and risk management planning. *Environmental Science and Policy*, *132*, 190–197. https://doi.org/10.1016/j.envsci.2022.02.029

Dewan, A. M. (2013). Floods in a megacity: Geospatial techniques in assessing hazards, risk and vulnerability. In *Floods in a Megacity: Geospatial Techniques in Assessing Hazards, Risk and Vulnerability*. Springer Netherlands. https://doi.org/10.1007/978-94-007-5875-9

Erman, A., Tariverdi, M., Xiaomeng, M. O., Rose, C., Vincent, C., Malgioglio, S., Rentschler, J., Hallegatte, S., & Yoshida, N. (2019). *Wading Out the Storm The Role of Poverty in Exposure, Vulnerability and Resilience to Floods in Dar Es Salaam*. http://www.worldbank.org/prwp.

Garcia-Aristizabal, A., Capuano, P., Russo, R., & Gasparini, P. (2017). Multi-hazard risk pathway scenarios associated with unconventional gas development: Identification and challenges for their assessment. *Energy Procedia*, *125*,116–125. https://doi.org/10.1016/j.egypro.2017.08.087

Grimaldi, S., Li, Y., Pauwels, V. R. N., & Walker, J. P. (2016). Remote Sensing-Derived Water Extent and Level to Constrain Hydraulic Flood Forecasting Models: Opportunities and Challenges. In *Surveys in Geophysics* (Vol. 37, Issue 5, pp. 977–1034). Springer Netherlands. https://doi.org/10.1007/s10712-016-9378-y

Gosset, M., Dibi-Anoh, P. A., Schumann, G., Hostache, R., Paris, A., Zahiri, E. P., Kacou, M., & Gal, L. (2023). Hydrometeorological Extreme Events in Africa: The Role of Satellite Observations for Monitoring Pluvial and Fluvial Flood Risk. In *Surveys in Geophysics* (Vol. 44, Issue 1, pp. 197–223). Springer Science and Business Media B.V. https://doi.org/10.1007/s10712-022-09749-6

Hoque, M. A. A., Pradhan, B., & Ahmed, N. (2020). Assessing drought vulnerability using geospatial techniques in northwestern part of Bangladesh. *Science of the Total Environment*, *705*. https://doi.org/10.1016/j.scitotenv.2019.135957.

Jiang, J., Chen, C., Zhou, Y., Berretti, S., Liu, L., Pei, Q., Zhou, J., & Wan, S. (2024). Heterogeneous Dynamic Graph Convolutional Networks for Enhanced Spatiotemporal Flood Forecasting by Remote Sensing. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *17*, 3108–3122. https://doi.org/10.1109/JSTARS.2023.3349162

Kebede, A. S., & Nicholls, R. J. (2012). Exposure and vulnerability to climate extremes: Population and asset exposure to coastal flooding in Dar es Salaam, Tanzania. *Regional Environmental Change*, *12*(1), 81–94. https://doi.org/10.1007/s10113-011-0239-4

Khan, N. (2013). *Flood Prediction and Disaster Risk Analysis using GIS based wireless sensor Networks,A Review*. https://www.researchgate.net/publication/257356474

Li, F., Li, H., Lu, W., Zhang, G., & Kim, J. C. (2019). Meteorological drought monitoring in Northeastern China using multiple indices. *Water (Switzerland)*, *11*(1). https://doi.org/10.3390/w11010072

Li, J., Chen, Y., Zhu, Y., & Liu, J. (2023). Study of Flood Simulation in Small and Medium-Sized Basins Based on the Liuxihe Model. *Sustainability (Switzerland)*, *15*(14). https://doi.org/10.3390/su151411225

Mckee, T. B., Doesken, N. J., & Kleist, J. (1993). The relationship of Drought frequency and duration to time scales. In *Eighth Conference on Applied Climatology*. https://www.droughtmanagement.info/literature/AMS_Relationship_Drought_Frequency_Duration_Time_Scales_1993.pdf

Mioc, D., Nickerson, B. G., Anton, F., Fraser, D., MacGillivray, E., Morton, A., Tang, P., Arp, J. P., & Liang, G. (2008). Web-GIS application for flood prediction and monitoring. *WIT Transactions on Ecology and the Environment*, *118*, 145–154. https://doi.org/10.2495/FRIAR080151

Motta, M., de Castro Neto, M., & Sarmento, P. (2021). A mixed approach for urban flood prediction using Machine Learning and GIS. *International Journal of Disaster Risk Reduction*, *56*. https://doi.org/10.1016/j.ijdrr.2021.102154

Olanrewaju, C. C., & Reddy, M. (2022). Assessment and prediction of flood hazards using standardized precipitation index—A case study of eThekwini metropolitan area. *Journal of Flood Risk Management*, *15*(2). https://doi.org/10.1111/jfr3.12788

Olorunfemi, F. B. (2011). *Paper presented at NISER Research Seminar Series*.

Pei, Z., Fang, S., Wang, L., & Yang, W. (2020). Comparative analysis of drought indicated by the SPI and SPEI at various timescales in inner Mongolia, China. *Water (Switzerland)*, *12*(7). https://doi.org/10.3390/w12071925

Rentschler, J., Salhab, M., & Jafino, B. A. (2022). Flood exposure and poverty in 188 countries. *Nature Communications*, *13*(1). https://doi.org/10.1038/s41467-022-30727-4

Thomas, V. (2017). Climate Change and Natural Disasters: Transforming Economies and Policies for a Sustainable Future. In *Climate Change and Natural Disasters: Transforming Economies and Policies for a Sustainable Future*. Taylor and Francis. https://doi.org/10.4324/9781315081045

Worldbank Group. (2022). *Climate and Development: An Agenda for Action 2 Climate and Development: An Agenda for Action*. www.worldbank.org

Zhao, Y., Chen, Y., Zhu, Y., & Xu, S. (2023). Evaluating the Feasibility of the Liuxihe Model for Forecasting Inflow Flood to the Fengshuba Reservoir. *Water (Switzerland)*, *15*(6). https://doi.org/10.3390/w15061048