AN EARLY WARNING SYSTEM MODEL FOR THE RESILIENCE OF RURAL KENYA TO FLASH FLOODS

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ABSTRACT

Over the years, climate change has led to unpredictive patterns that are associated with extreme weather events. Consequently, in Kenya, increased precipitation has resulted in serious flash flood events. Tana River County, a rural coastal county in Kenya, is one of the high-risk areas that are greatly vulnerable. This is because short-term early warnings are not prevalent. This study therefore aims to develop a flash flood early warning system model that will improve data collection, data analysis and dissemination strategies by integrating intelligent systems. Moreover, Vision 2030 Kenya's development foot-print, has categorically addressed the need to improve ICT to reduce the level of vulnerability in Kenya's rural counties. In this study, the World Meteorological Organization Flash Flood Forecasting (WMO-FFI) benchmark criterion will be modelled into a rating tool using an open modelling toolkit. Using questionnaires, the researcher will collect data on the existing flash flood early warning system. The results of this will be evaluated using the rating tool. Secondary data from climate databases online will be used to predict the next flood scenario (design reference point) in Tana River County through regression analysis. The researcher will then develop a model, integrating intelligent systems, and will define short-term early warnings for this scenario. Using the same rating tool modelled from the benchmark criterion (WMO-FFI), the researcher will seek to validate the intelligent flash flood early warning system model developed. Validation data will also be collected through the distribution of questionnaires, the results of which will further be evaluated using the rating tool.

Keywords: Flash floods, intelligent systems, short-term early warnings, world meteorological organization flash flood initiative

Introduction

The need for resilience is well espoused in the UN 2030 agenda for sustainable development. In it, the UN recognizes the importance for early warnings through the sustainable development goal (SDG) 13 (UNISDR, 2015). The gap in knowledge, the lack of application of intelligent flash flood early warning systems in Kenya, is well presented by Hoedjes et al., (2014). They report that there are no weather radars in Kenya, meaning that there are currently no short-term early warnings. The problem being studied is the lack of short-term early warnings in rural coastal counties for flash floods, which leads to displacement of people and damage to property (Keoduangsine, & Goodwin, 2012). This is due to poor ICT access, caused by delayed ICT infrastructure development in rural counties of Kenya. These make flood forecasts in Tana River County unreliable because forecasting and disseminating warnings depends on connectivity.

The current hydrological models used in Kenya are also inadequate (Shilenje & Ogwang, 2015) and as Liu, Hu, He, Wai Chan, & Lai (2015) explain, this is because they process a lot of data and variables. This has led to intelligent systems being applied as a solution. Shilenje & Ogwang (2015) further justify the proposed model by Hoedjes et al., (2014), stating that the existing observational networks are inadequate and affect the quality of early warnings.

This study is in line with Kenya's development footprint as it addresses one of the priority action points of the plan (Vision2030, 2017). The Tana River Delta is one of the vision 2030 flagship projects under water and sanitation. The LAPSSET (Lamu Port-South Sudan-Ethiopia-Transport) corridor project, another under Vision 2030, is an infrastructure project that will improve the transport linkage and economic growth of the county. These projects will depend on accurate forecasting to survive extreme weather events that frequent the coast.

CLIMATE RESILIENCE THEORY

In the 1970's, Crawford Stanley Holling's research in ecology gave rise to the concept of resilience. He defines resilience as a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (C. S, 1973). Another definition, is that it is the capacity of communities to withstand disaster (Agoes Pratikto, 2015). The latter definition is adopted for its simplicity and focus on the community.

Since coastal areas are occupied by millions of global citizens, it is important to increase their adaptive capacity as these areas are prone to disasters like flash floods (Keoduangsine, & Goodwin, 2012; Pratikto & Suntoyo, 2015). Vulnerability as defined by Tyler & Moench (2012) is the lack of resilience. The challenge is that significant numbers of rural people, are oftentimes excluded from adaptation research and making them vulnerable.

The climate resilience framework discussed in this study is one developed for the Asian Cities Climate Change Resilience Network (ACCCRN). The framework facilitates planning for adaptation by integrating resilience elements. Within their resilience elements they discuss infrastructure systems in which the following are priority interventions in resilience strategies: flood monitoring and early warning systems; flood resistant housing; hydrological modelling studies to guide flood prevention; flood shelters; and rainwater harvesting (Tyler & Moench, 2012).

Table 1: Climate resilience elements in the ACCCRN

Resilience elements	Priority interventions proposed in city resilience strategies
Infrastructure systems	• Flood monitoring and early warning systems • Storm and flood resistant housing • Hydrological and hydraulic modelling studies to guide flood prevention investments • Flood shelters • Rainwater harvesting
Ecosystems	• Mangrove restoration and protection • Watershed planning and forest protection • Groundwater recharge • Biological riverbank stabilization
Agent capacities	• Build awareness of climate risks • Engage communities in resilience planning • Build climate change issues into school curriculum • Train community groups and local government in disaster risk management and response • Improve public health surveillance • Alternative livelihoods to increase choice for peri-urban poor
Institutions	• Water demand management • Limit development rights in floodplains • New local government coordination and technical support organizations • Improve public information on flood hazard and evacuation • Improve climate forecasting and warning services • Engage communities in climate resilience planning

(Source: Tyler & Moench, 2012**)**

SHORT-TERM EARLY WARNINGS

Short-term early warnings are defined by the community's needs with regards to preparations. These heavily depend on the flash flood early warning systems available. Lead time requirements are described as the minimum time required for preparatory measures to be executed effectively (Shilenje & Ogwang, 2015). This paper will discuss the following factors that affect early warnings; observational networks, data analysis and dissemination strategies.

In Kenya, there are 72 automatic weather stations which collect weather data through sensors that can be remotely accessed to retrieve and analyze the data (Shilenje & Ogwang, 2015). Others include, 39 manned 24-hour synoptic stations, 14 agro-meteorological stations, 3 Airport Weather Observation Systems at Nairobi, 17 Hydro-meteorological Airport Weather Systems for flood forecasting and about 1000 rainfall stations. In Tana River County, as in other rural counties in Kenya, observational networks are barely in existence.

Secondly, the Kenya Meteorological Department lacks modern facilities and ensembles for data analysis. Shilenje & Ogwang (2015) assert that there is need for improvement of weather models used in order to enhance capacity in weather prediction. They give PRECIS (Providing Regional Climates for Impacts Studies) as an example of a regional climate model. This was developed with the intention of supporting developing countries make more accurate predictions.

Finally, the dissemination strategies used by the Kenya Meteorological Department include print and electronic mass media, provincial directors of meteorology, radio internet and internet as recorded in the Climate and Development Knowledge Network (2012). In these regions, traditional institutions such as chiefs, are critical for warning delivery (Shilenje & Ogwang, 2015).

‘Nyumba kumi’ (meaning ten homes) is an initiative by the Kenyan government for community policing to reduce insecurity in the country (Law Enforcement Agency, 2015). It encourages interactive partnerships and collaboration within a community in matters related to security. As a platform, it encourages the transmission of information, educating the community and creating awareness on various issues that affect the community and would therefore be an asset in the delivery of early warnings.

WORLD METEOROLOGICAL ORGANISATION FLASH FLOOD INITIATIVE (WMO-FFI)

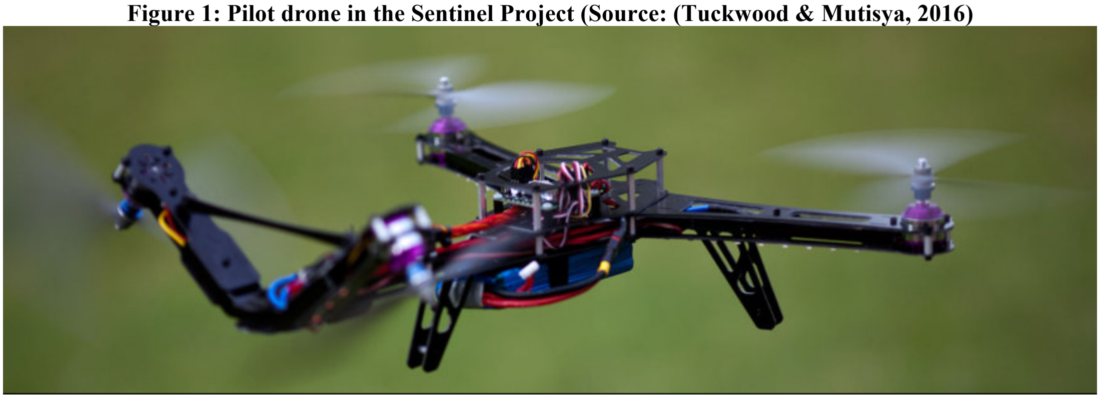
The role of the flood forecasting initiative (WMO-FFI) is to ensure that national flood forecasting services are well suited to deliver accurate and timely forecasting products and services. This is to aid with preparedness and response in case of weather events. WMO adapted a benchmark criterion which was compiled from requirements and priorities for flash flood early warning systems.

The benchmark criterion includes grading that is used to score flash flood early warning systems (WMO, 2013). It covers 4 main topics; institutional issues; infrastructural issues; economic issues; and sustainability of services. It uses the rasch model for scoring i.e., ‘0’ to ‘3’ represent various degrees of scoring.

A CASE OF EARLY WARNINGS IN KENYA

A case of prediction is presented by the Sentinel Project in Kenya’s Tana River County. ‘Una Uhakika?’ Swahili for ‘are you sure?’, is a mobile phone-based project that aims at monitoring the probability of violence in the county. This is done through the monitoring of rumors and countering their spread, after which drones are deployed for surveillance. Tuckwood & Mutisya, (2016) report that in the past, violence has begun with the transmission of rumors spread through mobile phones which increase the probability of miscommunication.

Figure 1: Pilot drone in the Sentinel Project (Source: (Tuckwood & Mutisya, 2016)

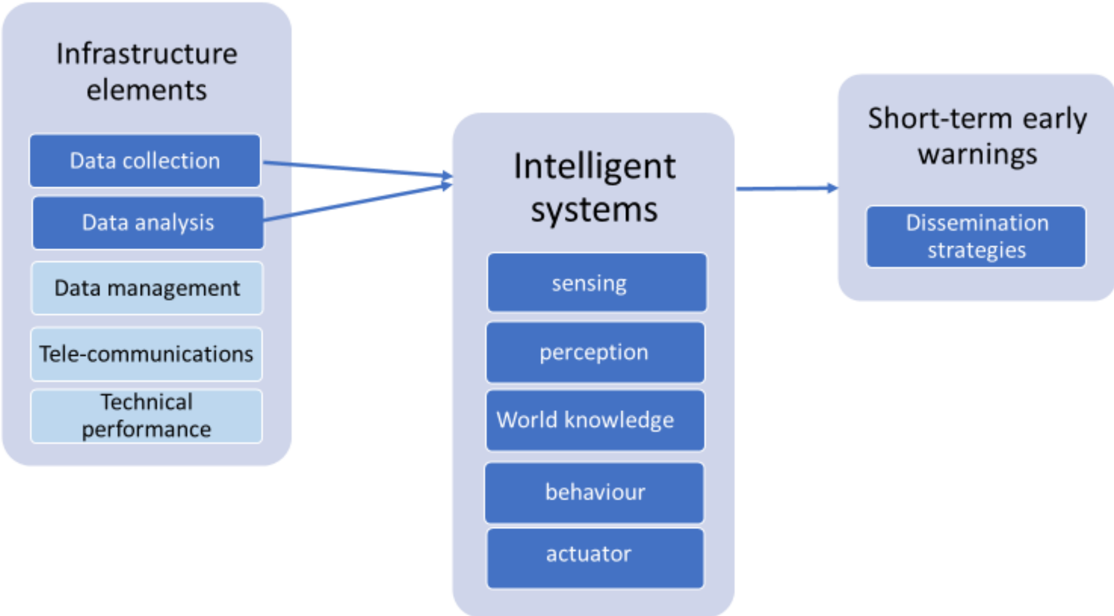


Drones as employed here, are unmanned aerial vehicles that utilize sensors to give information with spatial resolution. Chang, Wang, Chang, Liang, & Lin, (2016) add that their numerous advantages have led to their adoption in weather observation and flood early warning operations. For example, they can fly without spatial restrictions, they can be deployed in a short amount of time and they can also fly to dangerous zones (Smídl & Hofman, 2013).

CONCEPTUAL FRAMEWORK

The conceptual framework presented below is deduced from the World Meteorological Organization Flash Flood Initiative (WMO-FFI) benchmark criterion.

Figure 2: Conceptual Framework



For practicality of this research, the study focuses on 3 areas; observation networks, data analysis and dissemination strategies. This is because other researchers have done the same which makes it easier to compare methodologies adopted. The developed model will be an extension of the existing model, meaning less resources required for its installation.

DEVELOPING THE RATING TOOL

The World Meteorological Organization Flash Flood Initiative (WMO-FFI) benchmark criterion will be adopted as a data collection tool for this research. The benchmark criterion will also be used to develop a rating tool for flash flood early warning systems. It will be based on the rasch model for scoring. This will be executed through the ADOxx toolkit, of the Open Model Initiative Laboratory (OMiLAB) open models (Karagiannis & Andrei Buchmann, 2016). These are well suited for structuring the information into a conceptual model; they are also easy to use.

DEFINING THE EXISTING MODEL

Information gathered through the WMO-FFI benchmark criterion will be used to define the existing model, as the model to be developed in this study will hinge on the existing model functions. The results will be in the form of scores that will rate the existing flash flood early warning system model that exists in Kenya.

Out of the pool of stakeholders involved in weather forecasting in Kenya, an expert sample pool is obtained from the following institutions: Kenya Meteorological Department (KMD); IGAD Climate Prediction and Application Centre (ICPAC); and Department of Meteorology (Climate and Development Knowledge Network, 2012). These are selected because they are invested in research and have resources actively engaged in meteorology. The Kenya Meteorological Society (professional body of meteorologists in Kenya) currently has a recorded 117 members. The questionnaires will be administered to an average of 110 respondents who will be selected through simple random sampling. The minimum targeted for this research is 40 responses. These respondents will, preferably, be on contract employment with the above-mentioned institutions, ensuring a relevant level of experience. This will ensure internal validity.

The tool employed to analyze primary data gathered will be SPSS because it allows easy data manipulation. Data will be coded and entered into SPSS. Missing values analyses will be performed for all the items in the questionnaire followed by reliability analyses. Internal consistency will be evaluated by determining the Cronbach alpha of at least .7 while correlation between variables will be conducted using Pearson's test (Bryman & Bell, 2015). R^2 value (between 0 and 1) will be used to check whether there is a moderation effect, that is, whether intelligent systems moderate the relationship between infrastructure elements and short-term early warnings (Bryman & Bell, 2015).

FLASH FLOOD SCENARIO

Secondary data will be obtained from online weather databases (weather underground website), for both Tana River County and the central highlands of Kenya. This is because, Tana River County is very dry and receives scanty rainfall. The source of flash floods in this county is rainfall from the central highlands of Kenya. The secondary data will undergo statistical analysis (regression) for the forecast of a flash flood scenario. The use of regression is in-keeping with the existing methods used for weather forecasting in Kenya. This will act as a reference point while developing the model in this study.

IFFEWS- PROVISIONAL SHORT-TERM EARLY WARNINGS

The purpose of the model developed in this study is to address the shortcomings of the existing system (Hoedjes et al., 2014; Shilenje & Ogwang, 2015). In the Hoedjes et al., (2014) model, the researchers discuss the Meteosat Second Generation (MSG) satellite option for weather observation to supplement Safaricom's microwave links for Kenya's remote areas. Tana River County is inadequately covered by the telecommunications provider, meaning meteosats would be the only source of data for the county. These, however, are said to have bad resolution on imagery affecting accuracy of forecasts.

The use of drones is considered in this study. Like in the Hoedjes et al., (2014) concept, where they make use of already existing telecommunications infrastructure, this research will hinge on the already existing Sentinel project set up in Tana River County. Their drones could lend much needed flash flood monitoring functions for IFFEWS model minimizing financial implications.
The drones will be adorned with disposable wireless sensors, made of printed circuits on paper, that provide measurements once dropped into the Tana river. As the river flows, it takes the sensors along. The drones, deployed upstream, can track the sensors through a signal that the sensors emit. In this way, with their location being monitored, the flood water flow can be modelled (Hodson, 2013). The drones can further provide field images to support the data being provided by the sensors. A disadvantage of using drones is that at night there are operation limitations and sensors that can counter these challenges are thus costlier (Chang, Wang, Chang, Liang, & Lin, 2016). However, in this study, the disposable sensors would still provide adequate information required even in the absence of imagery.

Challenge & Ogwang, (2015) highlight that the Kenya Meteorological Department lacks adequate facilities for data analysis. To this end, analytics will be inserted into the model to support analysis of real time data collected from the disposable sensors.

In the Hoedjes et al., (2014) model, the researchers discuss dissemination strategies; sending out Safaricom alerts to mapped out risk areas. This also does not favor Tana River County. For dissemination strategies, this research will use the existing infrastructure with specific endorsements for radio, as it is most effective in rural areas. However, to enhance information penetration, this research explores opportunities that the 'Nyumba Kumi' (which means ten homes) Initiative could bring (Law Enforcement Agency, 2015). This platform would increase the comprehensiveness of warnings by ensuring risks are well understood and enabling the dissemination of information. The structure also offers support in case of response activities and planning that might be required.

VALIDATION OF THE IFFEWS MODEL

The intelligent flash flood early warning system model developed will be sent out to experts in meteorology for validation. For this reason, 30 Malaysian meteorologists will be contacted through email and face-to-face where necessary, for their expert opinion on the draft model (Bryman & Bell, 2015). A close-ended questionnaire will be used for both email and structured interviews. The components and functions of the developed model will be attached to these questionnaires. Noteworthy is that Malaysia has immensely invested in intelligent systems for flood early warnings making it a good source for samples ("Drones to Monitor Floods in Malaysia - FloodList", 2015). The WMO-FFI benchmark criterion will also be used in the validation process.

FINAL IFFEWS MODEL

With the expert feedback, due amendments will be made to the draft model. The final draft will thus be proposed as the Intelligent Flash Flood Early Warning System (IFFEWS) model. Furthermore, the experts ought to confirm that the model developed for this study improves: observational networks; data analysis; and dissemination strategies. Consequently, that it can deliver short-term early warnings with appropriate lead time.

CONCLUSIONS

The main contribution of this research is to the climate resilience theory, improving resilience of Tana River County through application of intelligent systems. This will address the inadequacies of the current system. This study is also in line with Kenya's development footprint as it addresses one of the priority action points of the plan (Vision2030, 2016). The Tana River Delta is one of the vision 2030 flagship project, Kenya's development blueprint. The LAPSSET (Lamu Port-South Sudan-Ethiopia-Transport) corridor project, another under Vision 2030, is an infrastructure project that will improve the transport linkage and economic growth in Tana River County. These projects will depend on accurate forecasting to survive extreme weather events that frequent the coast.

The purpose of knowledge gained from this research is to improve infrastructure of short-term warning delivery. This information will benefit the county government and the Kenya Meteorological Department as they execute their mandate to provide accurate forecasts and reliable warnings to the public.

The expected outcome is that an intelligent flash flood early warning system model will be developed that provides reliable alerts in Tana River County. This would improve services and product offerings by the Kenya Meteorological Department and other relevant stakeholders. Over and above that, that the research advances understanding of the knowledge gap, offering solutions for rural coastal counties. The results of the same will be published in order to disseminate knowledge derived from this study.

Limitations in this study include economic constraints in Tana River County affect the adoption of technology and the required skill-sets in this area are thus limited. These pose a threat to the implementation of the model developed in this study. Furthermore, data collection may prove a challenge due to the long distance between Kenya and Malaysia. Therefore, time constraints are expected when maintaining correspondence with test subjects.

The findings of the paper can provide the meteorological industry in Malaysia with areas to explore regarding the resilience of rural coastal areas towards flash floods. This is because, Malaysia having a vast coastline on both of its peninsulas means that its coastal areas are exposed to extreme weather events.

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