Use of Geo-Information Tools to Investigate Flood Risk

A Case Study of Kwale County

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Abstract

Five years since the adoption of the Sendai Framework for Disaster Risk Reduction 2015-2030, the concept of building resilience amongst communities to flooding is still a major concern in developing countries. This is evident from the ever-increasing flood events across Kenya and the inability of communities affected by floods to act appropriately prior to a flood event. Kwale County, in Kenya, the example of this study typifies this situation. Kenya Red Cross Society implemented a project whose goal was to strengthen institutional and community capacity in anticipatory flood risk management. The project employed the early warning services (EWS) model in understanding knowledge of flood risks. To investigate flood risk in Kwale County, openly available geo-information tools were used in systematic collection of information to understand areas exposed to floods, the communities affected and impacts they experience. These tools included; the Height Above Nearest Drainage (HAND) that identified flood prone areas and dwellings at risk of flooding from satellite imagery analysis. Open Street Map Automated Navigation Directions (OsmAnd) mobile navigation system that geo-located dwellings at risk of flooding and Kobo that collected geo-tagged data to validate inhabited buildings as to whether they are at risk of flooding. The results showed that, HAND technique identified dwellings at risk of flooding with 89% accuracy. Geo-location using OsmAnd showed that most houses identified to be at risk of flooding were falling within a circle with a radius of 5 meters. The results also show that the majority of the study area is characterized by moderate to very high flood hazard risks; 16% characterized by very high flood hazard risk, while 26% are at medium risk of flooding. This study demonstrates that HAND is a reliable tool for identification of houses at risk of flooding. The county government of Kwale and other acting institutions should endeavour in the use of these geo-information tools in investigating flood risk. Information obtained from these tools will enable such institutions to understand flood prone areas and communities at high risk of floods for better prioritization of early warning system needs and in guiding flood preparedness and early response activities.

Keywords: Early warning service, geo-information tools, flood hazard, flood map.

1. Introduction

Floods are amongst the biggest humanitarian crises globally. Impacts of floods have been increasing exponentially ranging from economic losses and deaths of people. The experience of floods in developing countries is a major concern that needs more research to come up with mitigation action items (Domeneghetti et al., 2015). In Kenya, floods usually occur during the March-April-May (MAM) and October-November-December (OND) rainfall seasons (FEWS NET, 2019). Flooding often occurs along river basins when the banks break leading to loss of lives, disruption of people's livelihoods, infrastructure destruction and interruption of economic activities.

Kwale County, is among the counties severely affected by floods, it is situated in the Southern Coastal part of Kenya. The main cause of flooding is rainfall received in the Athi basin as well as Usambara highlands in Tanzania. In 2019, more than 1500 families were displaced and 9 people lost their lives during the March- April-May (MAM) season (Relief Web, 2017) This is just one instance of flood impacts experienced in Kwale during the MAM season. Despite the availability of weather and climate forecasts, communities always act after a flood occurs. Yet there exists a window of opportunity between when a forecast is issued and when the flood event occurs, where early actions could have been taken by the flood prone communities to cushion them from the impacts of a flood. The impacts of these flood events can be mitigated if climate/weather forecasts are well communicated, interpreted and used by flood prone communities to implement early actions in order to mitigate the impacts of floods.

1.1 Flood early warning system

Early warning systems (EWS) form a major part of global disaster risk reduction efforts. EWS is an integrated system of hazard monitoring, forecasting and prediction, disaster risk assessment, communication and preparedness activities systems and processes that enable individuals, communities, governments, businesses, and others to take timely action to reduce disaster risks in advance of hazardous event (UNISDR, 2017). The main purpose of an FEWS is to issue warnings when a flood is imminent or already occurring (UNEP-DTU, 2017).

A people centred end to end EWS is a combination of four components(Paripurno & Nugroho, 2018); (a) knowledge of risk; (b) follow-up and warning service; (c) dissemination and communication; (d) response capability that gives timely information to the communities on imminent disasters (Figure 1). Knowledge of the risks entails establishing a system to collect and share data on flood risks and vulnerability in the area. Monitoring and warning service entails establishing sensors that measure water levels at relevant sites. Dissemination and communication entails communicating the information about risks. Response capacity looks at building community response capabilities (UNEP-DTU, 2017). This study focuses on knowledge of risk.

1.2 Knowledge of Flood Risk and Flood Early Warning System

Risk knowledge is an essential prerequisite for an early warning service, this entails vulnerability assessment of whom and what is most exposed and vulnerable to the impacts of flooding. Site-specific information identifies communities at risk of disasters, prioritization of EWS needs and guides preparedness and early response activities (ISDR, 2006). Risk knowledge involves collecting data and conducting risk assessments to assist relevant stakeholders including communities at risk to enhance knowledge about hazards, vulnerabilities and capacities in order to design early warning systems, prepare for preventive actions and guide effective response.

The indicators that inform risk knowledge include:

1. **Local risk assessment:** this looks at the interaction of vulnerability and hazard scenarios for determining the risk to the exposed elements with a detailed resolution. This is key in connecting top-down and bottom-up approaches.
2. **Hazard mapping:** this looks at developing hazard maps for different scenarios in order to identify exposure to different hazard magnitudes.
3. **Vulnerability mapping:** this looks at mapping and documenting vulnerable elements and critical infrastructure, which are periodically updated.

In general, risk is composed of three main elements: Hazards, exposure and, vulnerability (the susceptibility of communities to hazards) and lack of coping capacity (lack of adaptive mechanisms that can alleviate the impact) (De Groeve et al., 2015). Vulnerability considers the strength of the individuals to cope with the hazards while lack of adaptive capacity

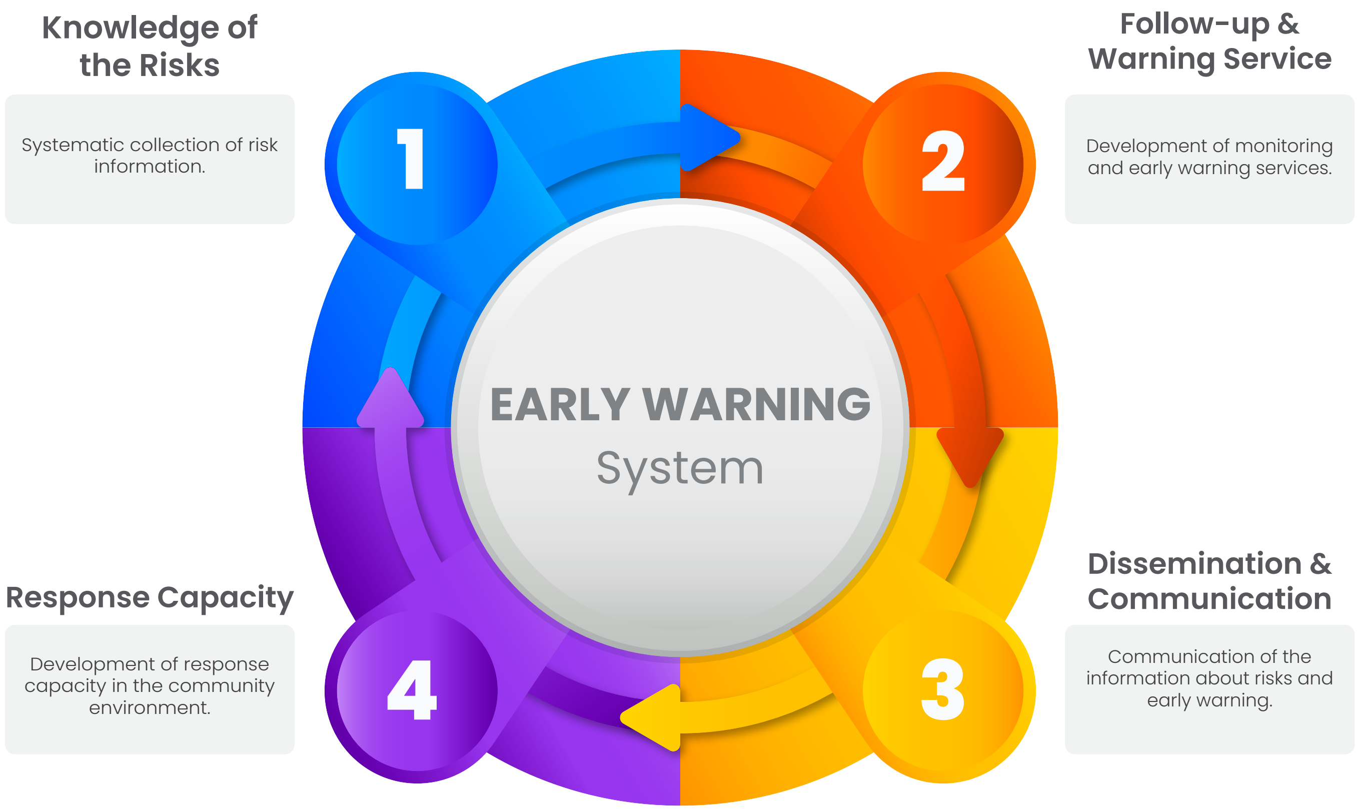

Figure 1: Early warning System

considers institutional capacity such as communicating early warning information to the communities at risk. Drawing from the above literature, this study specifies risk using a multiplicative equation where each component is treated equally:

In light with the projected increase of risks in many regions from the effects of climate change, augmented exposure and population growth in risk prone areas (Mechler & Bouwer, 2015) improved knowledge and understanding of the fundamental causes of disasters, identification of the main risk drivers and analysis of their spatiotemporal changes are key for effective disaster risk management (Burton, 2010). Thus, disaster risk management should be based on an understanding of risk in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment.

1.3 Use of geospatial tools in understanding communities at risk of disasters

There has been a rapid adoption of geospatial technologies by the humanitarian community attributed to an urgent need for updated information in crises and conflict situations involving large-scale human displacement (Lang et al., 2019). At the same time, there has been an increase of novel and cutting-edge information and communication technologies for the collection, analysis and dissemination of data, re-inventing the way in which risk management is carried out throughout its cycle (risk identification and reduction, preparedness, disaster relief and recovery). The applications of these geospatial technologies are expected to enable better mitigation of, and adaptation to, the disastrous impact of natural hazards. The description of risks may particularly benefit from the integrated use of new algorithms and monitoring techniques. The ability of new tools to carry out intensive analyses over huge datasets makes it possible to perform future risk assessments, keeping abreast of temporal and spatial changes in hazard, exposure, and vulnerability (Albano et al., 2018).

Geospatial tools are essential in systematic collection and analysis of disaster risk information on hazard, vulnerability and adaptive capacity. These tools assist in mapping out the spatial distribution of a hazard, identification of communities exposed and identification of vulnerabilities and adaptive capacities of these communities to the hazard. The main product of a geo-information system (GIS) in the EWS is the flood hazard map; a map showing areas likely to experience flooding. GIS tools such as use of earth observation satellites, mobile navigation systems and GIS data collection tools form an integral part in deriving flood hazard maps.

In the investigation of adaptive capacities of communities to hazards, GIS tools can be used in addressing early warning gaps of a flood early warning service by obtaining geo-referenced community feedback on the awareness of flood early warning information in specific locations as it was alluded by (Ahmed et al., 2020). Furthermore, geo-referenced information is critical to the success of a people-centred EWS as it identifies the capacities of different members of the community, aids dissemination of information and their involvement in community-based disaster risk management initiatives (Marchezini et al., 2018). The main objective of this paper is to showcase the use of openly available geo-information tools in investigating flood risk in Kwale County; where flood risk is a component of hazard and exposure.

Equation:

Flood Risk *= Hazard & Exposure + Vulnerability + Lack of coping capacity*

Flood Risk Equation

2. Materials and Methods

Kwale is one of six counties located in south coastal region of Kenya. It is located in arid and semi-arid land (ASAL) zone characterized by two major rain seasons; March-April-May (MAM) and October-November-December (OND). The county topography is generally low-lying and falls within the altitude range of 0 to 174 meters (m) above sea level, with the central part of the county receiving around 500–750 mm of rainfall annually (Figure 2). These areas are in close proximity to rivers, within river catchments and near the Indian Ocean.

This study utilized openly available geospatial datasets which were used to delineate inhabited buildings at risk of flooding. To supplement the geospatial data questionnaire forms were administered to households at risk of flooding. Table 1 below provides a summary of the datasets.

2.1 Use of earth observation satellites in generating flood hazard and exposure

In order to determine communities living in flood prone areas in Kwale, the study utilized advanced land observation satellite (ALOS) at 12.5-meter spatial resolution to derive a digital elevation model (DEM), watershed catchments and stream segments. A DEM is a digital representation of the land surface elevation with respect to any reference datum (Balasubramanian, 2017). The DEM and stream segments were then used to derive height above nearest drainage (HAND). HAND technique is a low-complex, terrain-based approach for flood inundation mapping that uses elevation data, discharge-height relationships and stream flow inputs(Nobre et al., 2011) .

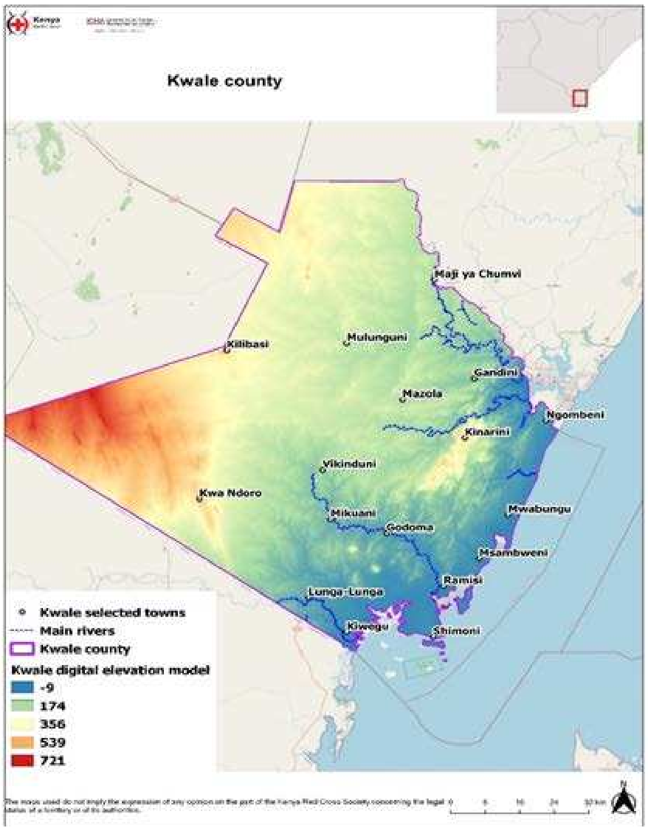

Figure 2: Kwale County

Table 1: Datasets used to delineate inhabited buildings at risk of flooding

Data products	Source	Resolution/frequency	Format	Access link
Digtal elevation model from the Advanced land observation satellite (ALOS)	Japan Aerospace Exploration Agency's (JAXA)	12.5 meters	Raster	https://www.eorc.jaxa.jp/ALOS/en/sitemap.htm
High resolution Settlement, 2015; a high resolution population dataset obtained from satellite imagery (Tiecke et al., 2017)	Centre for International Earth Science Information Network (CIESIN) at Columbia University	30 meters	Raster	https://www.ciesin.columbia.edu/data/hrsl/#data
Questionnaires	Field data collection using KoboCollect		Data frame	
Admin files	Kenya National Bureau of Statistics	County levels	Vector	www.knbs.or.ke

The High-Resolution Settlement Layer (HRSL) from the Centre for International earth Science Information Network (CIESIN) at Colombia university (de Sherbinin et al., 2017) was used to determine inhabited settlements exposed to floods. The HRSL at a resolution of 1 arc-second (approximately 30 meters) provides detailed delineation of settlements which are useful for disaster preparedness and humanitarian planning. HRSL is based on recent census data and high spatial resolution (0.5 meters) satellite imagery from the DigitalGlobe.

Collaboration with technology companies such as Facebook and civil society groups on prevention of online hatred and radicalization and use its local knowledge to inform their policies and digital products.

2.2 Geo-locating communities at risk of flooding using mobile navigation tools - OsmAnd

Geo-coordinates of sampled buildings within the vertical distance to channel network from 0 to 1 meter in Kwale were preloaded in the Open Street Map Automated Navigation Directions (OsmAnd) mobile navigation tool. OsmAnd is an open source offline mobile-based map and navigation application from open street map that enables one to track and geo-locate predefined coordinates. This tool has been largely used in studies by (Adewara, 2015) and (Eilbracht, 2016). OsmAnd was used to geo-locate predefined settlements at risk of flooding thus guiding on areas to conduct quantitative surveys (Figure 3). The questionnaires were administered in each of the buildings tracked to be at risk of flooding.

An extensive field-validation survey was undertaken to obtain detailed information of the houses delineated to be at risk of flooding from the HAND tool. It was also conducted to assess the accuracy of the HAND model in generating the flood risk maps. This entailed geo-locating sampled buildings at risk using OsmAnd. Validation was done through observing if a house was near a river or if it was within a stream segment that leads into a river. The other form of validation was through observation of water marks on wall buildings. The validation exercise also paved way to interview respondents residing inside the geo-located buildings at risk of flooding by getting a response if in the near past, they indeed experienced flooding. This was done using the KoboCollect tool; an open-source offline mobile-based data collection application that enables one to administer surveys.

Figure 3: Red cross action team member geo-locating settlements affected by floods

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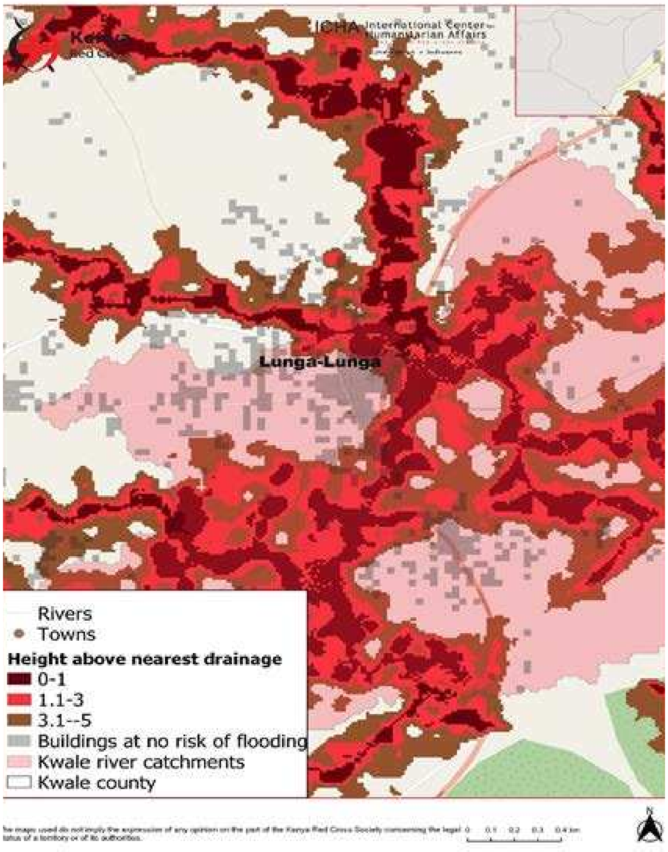

Figure 4: Vertical distances to channel networks (0 - 1 = high risk, 1.1 - 3 = medium risk, 3.1 - 5 = low risk)

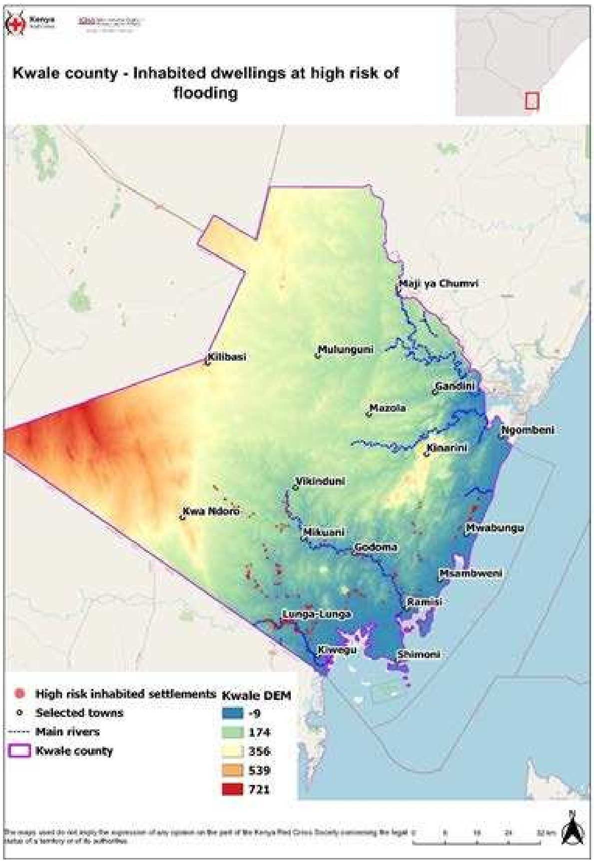

Figure 5: Inhabited settlements at high risk of flooding in Kwale County

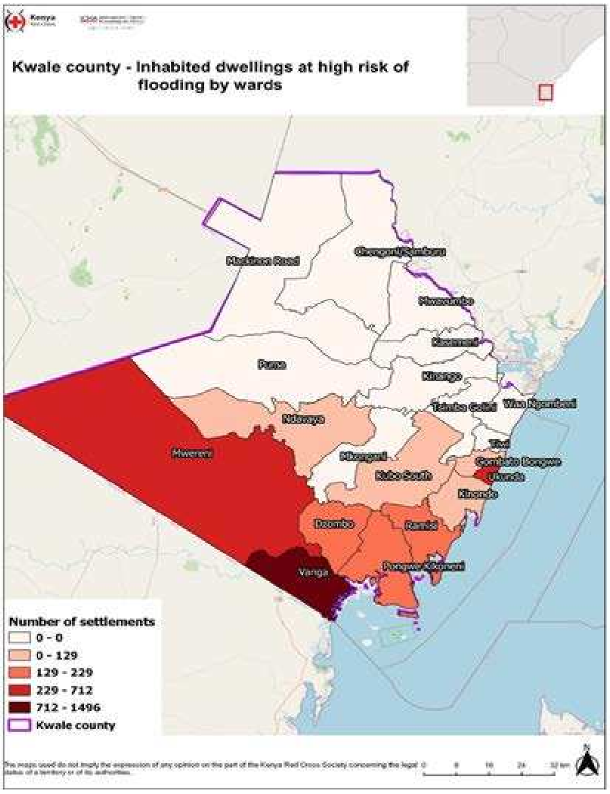

Figure 6: Inhabited dwellings at high risk of flooding aggregated by Wards

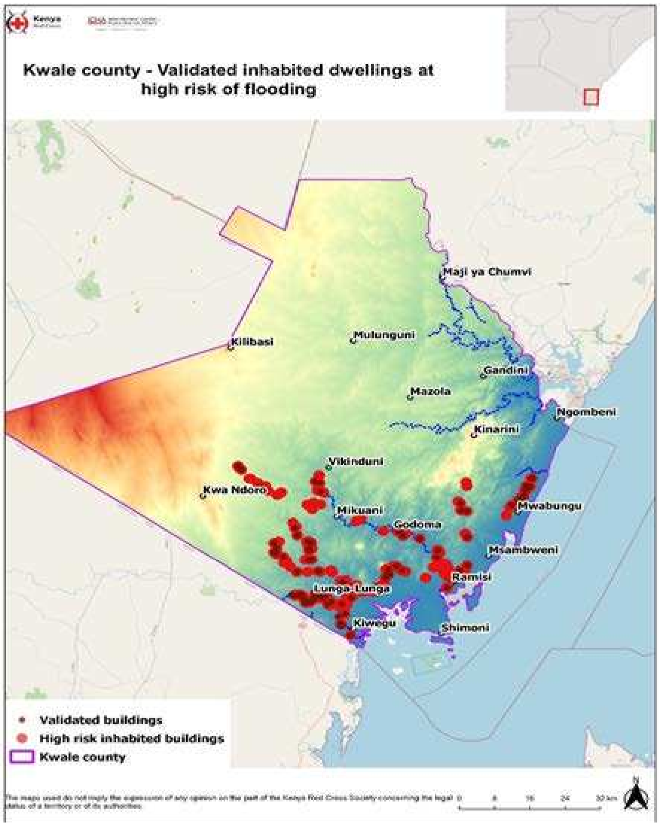

Figure 7: OsmAnd geo-located and validated settlements

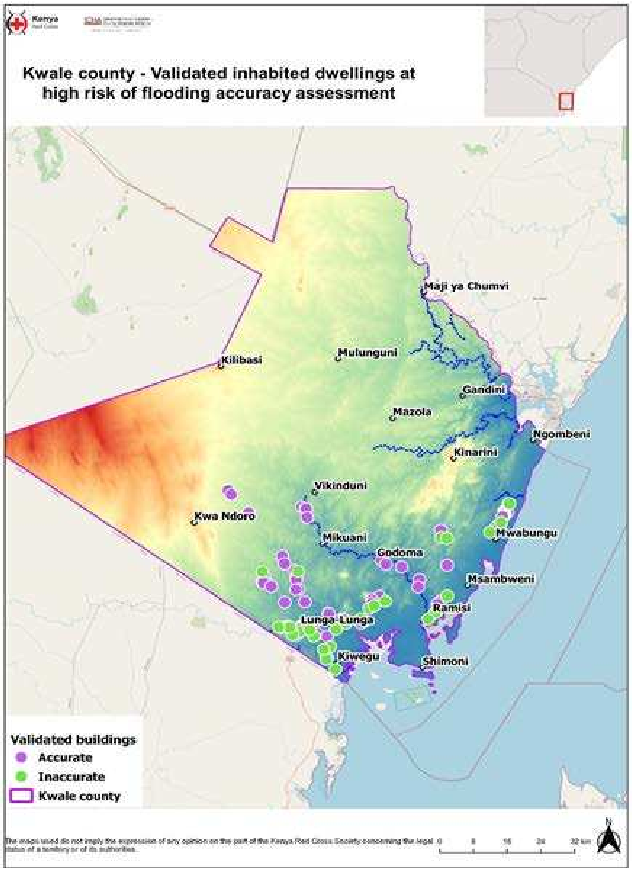

Figure 9: Accuracy assessment of inhabited buildings at high risk of flooding

3. Results

Using HAND, vertical distances to channel networks within watershed catchments in Kwale were generated. The vertical distances to channel networks were then classified into three flood hazard dimensions where distances between 0 - 1 = high risk, 1.1 - 3 = medium risk and 3.1 - 5 = low risk.

Inhabited settlements that intersected with the third flood hazard dimensions (houses that are within a vertical distance to channel network of between 3.1 to 5 meters) from HAND were mapped out in order to determine the spatial distribution of inhabited dwellings exposed to floods. These are houses that are within a vertical distance to channel network from 0 to 1 meter, illustrated in Figure 5.

A total number of 22,191 inhabited settlements were delineated to be at risk of flooding. This is attributed to their close proximity to rivers, river catchments and stream flows. The results indicate that 16.24% of inhabited settlements are at high risk of flooding while 25.89% are at medium risk, with 57.89% at low risk of flooding. This implies that in extreme flooding scenarios 3,603 inhabited settlements are highly likely to be affected by floods. These settlements are in Vanga, Mwereni, Ukunda, Pongwe Kikononi, Dzombo, Ramisi,Gombato Bongwe, Kinondo, Kubo South and Ndavaya Wards. Most of the houses at high risk are in Vanga and Mwereni Wards.

The spatial distribution of homes and other inhabited dwellings at risk of floods is illustrated in Figure 6 and 7 below.

During the field validation exercise, 89.47% of the geo-located buildings were marked to be at risk of flooding based on expert ground observation and confirmation of respondents residing inside the buildings that they indeed had experienced flooding in the near past while 10.53 % of geo-located were inaccurately marked to be a risk of flooding (Figure 9). The confidence level of HAND methodology was therefore at 89.47.

Results of field-validation exercise, indicate that 89% of the household respondents confirmed that their houses were at risk of flooding (Figure 8).

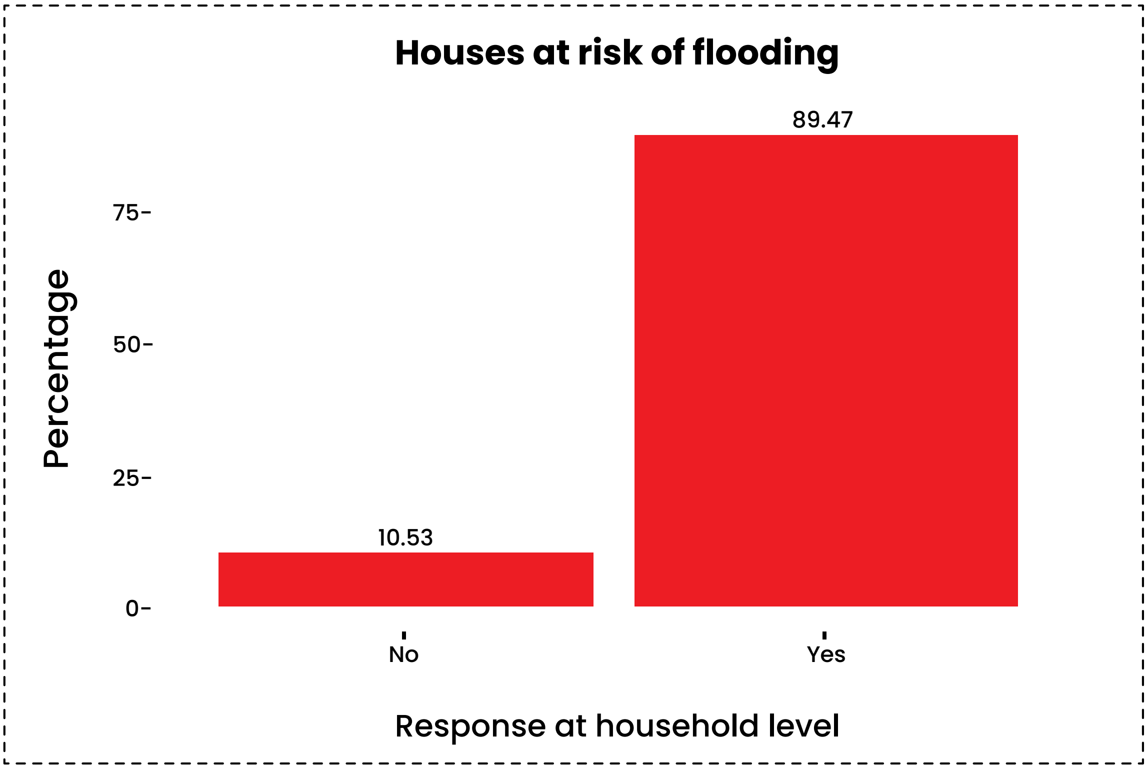

Figure 8: Validated settlements

4. Discussion

This study has demonstrated the capability of using of geo-information tools specifically HAND, OsmAnd and KoboCollect to identify houses at risk of flooding. The HAND technique used elevation data derived from the advanced land observation satellite (ALOS) in order to generate discharge-height relationships and stream flow inputs. These were used to generate vertical distances to channel networks which were then classified into three flood hazard dimensions namely high, medium and low risk. High resolution inhabited settlements that intersected with the third flood hazard dimensions were mapped out in order to determine the spatial distribution of flood exposed dwellings in Kwale County.

Results on flood exposure analysis indicates that in extreme flooding scenarios about 3,603 inhabited settlements in Kwale are highly likely to be affected by floods. These settlements are located in Vanga, Mwereni, Ukunda, Pongwe Kikononi, Dzombo, Ramisi, Gombato Bongwe, Kinondo, Kubo South and Ndavaya Wards. Consequently, this technique can be utilized to approximate the number of inhabited settlements at risk during a flood. Such information can be utilized by humanitarian actors such as the Kenya Red Cross and other County stakeholders to improve emergency response efforts.

The OsmAnd mobile navigation system also proved to be an important tool in validation of houses at risk of flooding. OsmAnd enabled geo-tracking of inhabited settlements at high risk of flooding from HAND. Once the inhabited settlements were geo-located using OsmAnd, ground observations were made to ascertain if a house was near a river or within a stream segment that leads into a river. The other form of validation was through observation of water marks on wall buildings. The validated settlement coordinates felt within circles with a radius of 5 meters. Validation results from this study show that HAND methodology identified dwellings at risk of flooding with 89% accuracy with most of the houses at high risk located in Vanga and Mwereni Wards. The majority of the study area is characterized by moderate to very high flood hazard risks; 16% of Kwale is characterized by very high flood hazard risk, while 26% are at medium risk of flooding. Therefore, the derived flood exposure maps can be used for flood-risk management.

5. Conclusion and Recommendations

Geo-information tools are important in deriving flood exposure hazard, geo-locating and validating inhabited dwellings likely to be affected by floods. The county government of Kwale and other acting institutions should endeavour in the use of such geo-information tools in investigating flood risk. Information obtained from these tools will enable such institutions to understand flood prone areas and communities at high risk of floods in guiding flood preparedness and early response activities.

HAND as a method of generating flood hazard and consequently exposure maps, could be used as a tool within the flood EWS to generate evidence with regard to knowledge of flood risk. Knowledge of risk as a prerequisite for a successful EWS, entails understanding which communities are exposed to flooding and their specific location. Awareness of where communities at risk of floods are located can help the Kwale County government in prioritization of EWS needs, and guide preparations for preparedness and early response activities. The county government could preposition flood early warning services in Wards at with the most inhabited settlements at high risk of flooding. Early warning services such as community flood warning messaging could inform communities residing in close proximity to rivers or in low lying areas to move to higher ground based on a credible rainfall flood forecast. The county government could also use the generated flood exposure maps from HAND to initiate long term flood risk management programs such as reconstruction of safe shelters far away from flood prone areas. This will safeguard communities from the effects of floods.

Using the flood hazard from HAND, the study proposes further exposure analysis of other flood impacts besides settlements such population, roads, schools, hospitals, market centres and croplands likely to be impacted by floods. This will thus inform the county government of Kwale on taking flood early actions that are linked to these impacts. The study proposes the use of more robust geo-information scientific methods to generate flood hazard and exposure maps from hydro-meteorological models such as the Global Flood Awareness System (GloFAS) and high spatial resolution digital elevation models extracted from Lidar or drone imagery to generate accurate flood hazard maps.

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