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Flood Forecasting in Malawi's Shire River Basin

[1]Daniel Nakapu Hussein, [2]Mwakio Tole and [2]Maarifa Mwakumanya

[1]Department of Geographical Sciences, Faculty of Environmental Sciences, Mzuzu University, Private Bag 201, Luwinga, Mzuzu 2, Malawi
[2]Department of Environmental Sciences, School of Environmental and Earth Sciences, Pwani University, Post Office Box 195-80108, Kilifi, Kenya

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Corresponding Author:
Daniel Nakapu Hussein
Department of Geographical Sciences, Faculty of Environmental Sciences, Mzuzu University, Private Bag 201, Luwinga, Mzuzu 2, Malawi
Email: husseindaniel@yahoo.com

Abstract: The paper describes a study conducted in 2021-2022 in the Shire River Basin (SRB) of Chikwawa District, Malawi to evaluate how flood forecasting is currently performed and to provide recommendations for improvement. Flooding often occurs in the basin, endangering people's lives and property. A case in point is the 2015 flood and 2019 Tropical Cyclone Idai, which were so devastating that Malawi required international assistance. This showed that the Flood Forecasting System (FFS) in the basin has not been as robust as needed to adequately warn and prepare communities before the flood occurrence. For this purpose, a study was conducted in four Traditional Authorities (T/As) of Chikwawa District, namely Mlilima, Kasisi, Makhuwira and Lundu. Individual and group interviews were conducted with 114 residents and government officials, and a survey of 270 households was conducted by 5 research assistants. Several types of research methods were used: (1) Case study (2019 flood), (2) Phenomenological (live experiences of local people), and (3) Quantitative analysis (by users of the FFS). The results showed that a sophisticated Indigenous Flood Forecasting System (IFFS) exists in the SRB to improve both flood detection and early warning systems, however, it is not used by the Malawian government officials tasked with Flood Forecasting (FF). Based on these findings, we recommend the development and implementation of a new "Integrated Flood Forecasting System" in the Shire River Basin, which combines both scientific and indigenous FFS to combat flood impacts.

Keywords: Chikwawa, Indigenous Knowledge, Scientific Technologies, Shire River Basin, Tropical Cyclone Idai

Introduction

The Shire River Basin (SRB) in Malawi is prone to severe and frequent flooding. Floods pose a significant threat to communities worldwide. Flood damage is one of the most important examples of climate-related disaster risks, causing huge financial losses, killing or displacing people, and affecting infrastructure and agricultural production (Perera *et al*., 2019).

Therefore, strengthening the Flood Forecasting Systems (FFSs) is necessary to predict water-related disasters to reduce human loss and property, and environmental damage (Bezak *et al*., 2021; Prada, 2016). Effective flood forecasting systems also encourage communities to proactively develop infrastructure and emergency response systems to mitigate damage and deaths from flooding. The Malawian government established a Department of Disaster Management Affairs (DoDMA) in all 11 districts of the basin to help victims of natural disasters.

Today, two systems for flood forecasting exist in the world namely; the Scientific Flood Forecasting System (SFFS) and Indigenous Flood Forecasting System (IFFS) (Hiwasaki *et al*., 2014; Tran *et al*., 2009). Both are sciences, that is, systems of knowledge concerned with the physical world and its phenomena. Both are also observational in nature. However, they differ with respect to the ways in which the observation is done and, to some extent, what is being observed.

The SFFS is primarily quantitative. This system is applied anywhere as it is not tied to any one particular geographical region. It utilizes various mechanical tools designed to measure certain aspects of the environment, such as water levels in rivers, temperature, rainfall, geographical mapping, wind direction, and strength

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(Kamin *et al*., 2017; Tran *et al*., 2009). The combination of the above aspects helps to develop a flood hazard map that shows flood-prone areas to alert communities on where to build their infrastructure to reduce disasters (Rimba *et al*., 2017).

The IFFS, on the other hand, is primarily qualitative and based on personal observations by community members living in a given area (Kalanda-Joshua *et al*., 2011). It is specific to a particular region and is mostly empirical, drawing on centuries of accumulated experiences and interpretations of environmental changes by the people living in that area. In addition, it is a strategy that is workable, practical, local, inexpensive, feasible, and easy to implement (Turi *et al*., 2019). Indigenous Knowledge (IK) and local practices of community members are neither taught nor documented in the classroom.

The IK of disaster monitoring, forecasting, and early warning is based on the observation of temperature, cloud cover, wind and animal and plant behaviour (Abdulrashid, 2020). In addition, IFFS assesses many of the environmental factors important for research using SFFS indicators such as meteorological parameters, but also indicators not used in SFFS such as the behaviour of animals and plants (Raj, 2013). This knowledge exists for two reasons: First, it has a strong and dynamic mode of transmission from generation to generation through practice and oral tradition, and second, it has a functional utility in the communities involved.

However, there are some limitations observed when using these two FFSs (Kalanda-Joshua *et al*., 2011). For example, IK has been getting eroded due to rapid changes in socio-economic and environmental contexts, affecting their vulnerability to natural hazard risks and the way they respond to flood disasters (Dan and Kapoi, 2018). Furthermore, the use of IK in flood forecasting is currently facing a challenge as either community elders were passing on due to old age or relocating to higher places because they could not withstand the floods (Chawawa, 2018). Likewise, the SFFS has its weaknesses such as the low flood forecasting accuracy of 75% (Kalanda-Joshua *et al*., 2011), which is not good enough for flood disaster management. Other limitations of SFFS include the inaccessibility of weather station locations, the difficulty of interpreting the collected data, and the cost of purchasing and installing the instruments (Balehegn *et al*., 2019).

The challenges of the two FFSs require improved disaster management strategies through their integration for better utilization at all community levels (Rai and Khawas, 2019; Dube and Munsaka, 2018; Mazzoleni *et al*., 2017; Raj, 2013). There is currently a call for practitioners responsible for flood forecasting to recognize IK and integrate it with scientific knowledge to increase forecasting accuracy and mitigate the disaster (Turi *et al*., 2019). Therefore, this study evaluated the IK of local people and the scientific technologies used by meteorologists to forecast flooding in order to suggest ways to improve the forecasting system in the Shire River Basin of Chikwawa District.

To fully understand the Shire River Basin floods in general, and the 2019 flood in particular, the following FFSs usage questions were explored through individual interviews and group discussions:

1. What FFSs were used to predict the floods in the basin?
2. If an IFFS was used, what was assessed?
3. If an SFFS was used, what was assessed?
4. Do you think IFFS and SFFS indicators could be integrated into one system? If so, how would this be done?

Materials and Methods

Study Site

Geographical Location

The study was conducted in the Shire River Basin of Chikwawa District. Chikwawa is part of the 10 districts in Malawi's Shire River Basin severely affected by the 2019 Tropical Cyclone Idai. Chikwawa District is bordered by other districts such as Mwanza to the north, Thyolo to the east, Blantyre to the northeast and Nsanje to the south and the country of Mozambique to the west (Jury, 2014; Palamuleni *et al*., 2011). It has an area of 4,755 km^2 (Palamuleni *et al*., 2010). It is enclosed within the Thyolo-Chikwawa escarpment and bounded by latitudes 15°2'0" to 16°3'0" South and longitudes 34°01'3" to 36°05'3" East (Fig. 1).

Climate

Chikwawa's climate is characterized by two clearly defined seasons; the hot and dry season from May to October and the warm and wet season from November to April. It generally receives unreliable and variable rainfall, ranging from a minimum of about 170 mm to a maximum of about 967.6 mm per year, with rainfall intensity influenced by the incidences of strong cyclones from the Mozambique and Tanzania channels (Jury, 2014). Temperatures are generally high with an average minimum of approximately 27.6°C in July and maximum of about 44.0°C usually experienced in November every year whilst the mean monthly temperatures are usually above 20.0°C (Palamuleni *et al*., 2010).

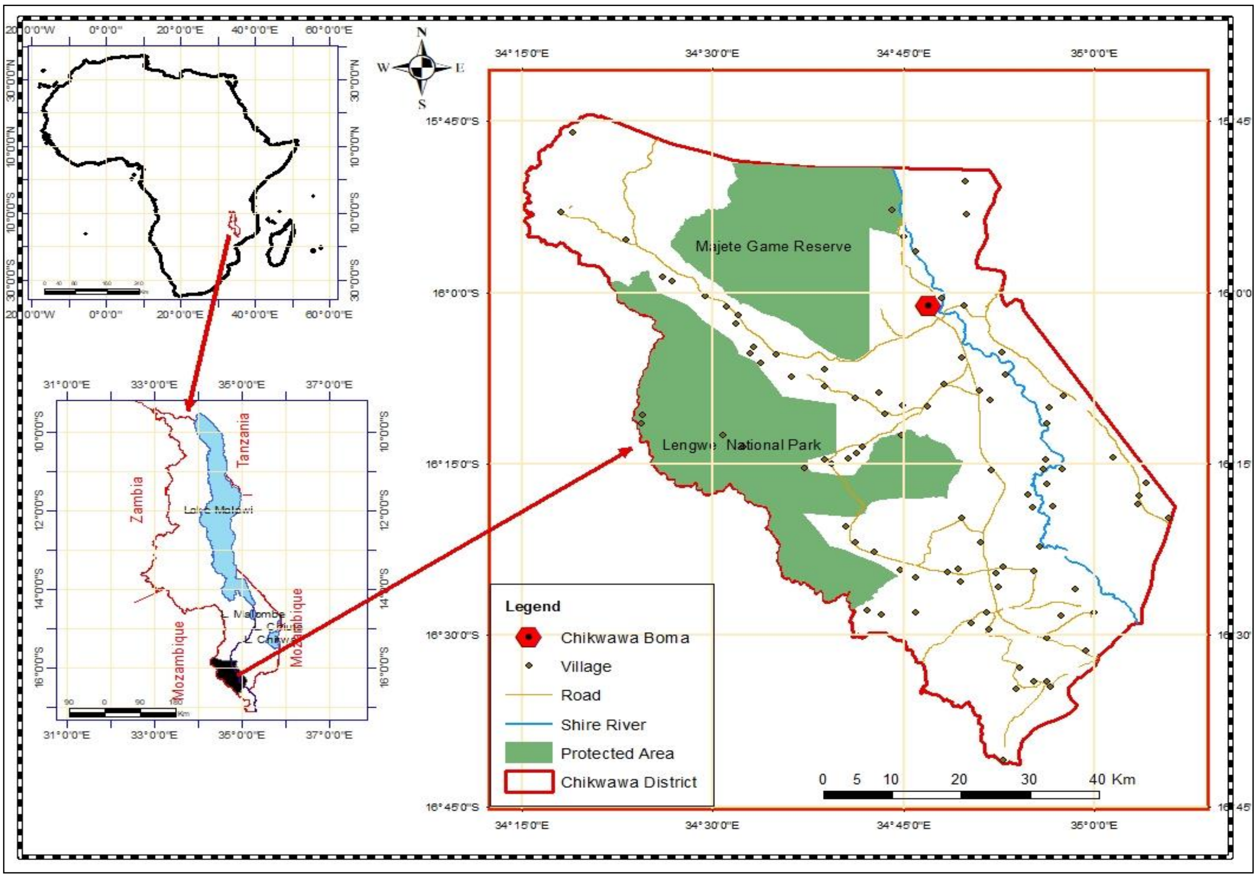

Fig. 1: Geographical location of the Shire River Basin in Chikwawa District

Vegetation

Chikwawa is one of the districts in Malawi that has both terrestrial and aquatic vegetation types. The district's terrestrial ecosystem is Acacia thicket savannah, predominantly found in Lengwe National Park (LNP), and open/closed mixed woodland found in low lying areas, while aquatic vegetation includes marsh grasslands and reed grass, which are prevalent in wetlands. The type of vegetation includes tree species as well as open/closed mixed forests that include tree species (Palamuleni *et al*., 2011). However, over the past decades, the SRB has experienced significant changes in its forest structure, composition, and land cover due to rapid population growth and climate change (Jury, 2014). The removal of vegetation in the study area poses a threat because it promotes runoff that causes flooding.

Sample Size Calculation

Fisher's formula was used to determine the sample size. The formula was appropriate because it factors in the issues of heterogeneity of the population to be sampled, the feasibility of the study, human accessibility and vulnerability, and financial and ethical constraints in accessing a population of interest in the study area. The formula was used in line with the suggestion of Ayaa (2013), who recommended it for a population greater than 10,000 inhabitants as was the case in the four T/As in Chikwawa District. The target sample size was calculated as follows:

$$n = \frac{Z^2 pq}{d^2} \tag{1}$$

where:

n = Sample size
z^2 = 95% at a standard value of 1.96
p = Population proportion assumed at 50% (0.5)
q = The desired level of precision 1 -0.5 (0.5)
d^2 = Statistical significance set at 5% (0.05)

Thus, a detailed calculation of the formula was:

$$n = \frac{z^2 \times p(q)}{d^2}$$
$$n = \frac{1.96^2 \times 0.5(0.5)}{0.05^2} \tag{2}$$
$$n = 384.16$$

Table 1: Distribution of respondents

Population	Sample size	Sampling methods	Data collection
Household survey	270	Random sampling	Survey
Group participants	96	Purposive sampling	FGD
Community elders	8	Purposive sampling	KII
Malawian Government Representatives (MGRs)	6	Purposive sampling	KII
Non-Governmental Organisation (NGO) officials	4	Purposive sampling	KII
Total	384		

Of the calculated study population, 270 participated in the household survey, and 96 formed gender-disaggregated focus group discussions. In addition, 8 community elders and 10 representatives of the Malawian government and "Non-Governmental Organisations" (NGOs) were the main informants interviewed. Table 1 shows the distribution of respondents per T/As.

Table 1 shows that a total of 374 participants, i.e., those who participated in the household survey, focus group discussions, and community elders were residents of Chikwawa District. In addition, 6 Malawi government officials were recruited from the following: (1) Departments of Disaster, Forestry and Climate Change and Meteorological Services (CC&MS); (2) Ministries of Water, Agriculture, and Lands. The Malawi Red Cross Society (MRCS), Welthungerhilfe (WHH), World Vision Malawi (WVM), and the Evangelical Association of Malawi (EAM) were identified as participants from the non-governmental organizations.

Data Collection

Multiple types of data were collected for this study between September 2021 and January 2022 using different research designs that included the following; (1) Case Study: People's forecasting strategies for the 2019 Shire River Basin flood triggered by Tropical Cyclone Idai were examined. This flood was selected because it was the most destructive in recent history in the region (Šakić Trogrlić *et al*., 2019; Zuzani *et al*., 2019); (2) Phenomenological: Lived experiences of community members regarding their use of FFSs in their daily lives were elicited through the use of open-ended questions; (3) Quantitative: Certain aspects of FFSs and their community history and infrastructure were observed and documented; and (4) Baseline survey of Terrestrial Ecology: This included identifying, studying and naming plants and animals that were used to forecast floods. The floods were studied in three different settings: Focus Group Discussions (FGDs) with the people of Chikwawa District, and key informant interviews (KIIs) with government and non-government representatives, and Community Elders' Interviews (CEIs). Indigenous flood forecasting strategies were identified during the Household Survey (HS).

Because of their accessibility and vulnerability, people from the following Traditional Authorities (T/As) of Mlilima, Kasisi, Makhuwira and Lundu participated in the study. FGDs were conducted by one researcher who met separately with groups of twelve people of the same gender. Eight FGDs were conducted on a total of 96 participants. For KIIs, the same researcher met with individuals. For CEIs, pairs of elders over the age of 60, one male and one female, were interviewed from the T/As. Conversations were recorded in Chichewa using a voice recorder, and transcribed in Chichewa. They were subsequently translated into English. To collect live experiential data regarding FFS usage, five research assistants asked a series of open-ended questions in a survey to 270 heads of Households (HSs) as identified by the residents of each household. HSs were conducted in Chichewa and the results translated into English. Semi-structured questionnaires with open-ended and closed-ended questions were used to gather information on the available indicators used to predict the occurrence of the flood in each village (Ngwese *et al*., 2018). Fieldwork included extensive visits to the study sites to physically identify local plant and animal communities that were used as indicators for flood forecasting.

Data Analysis

Subsequent to data collection, all qualitative data were organized into different thematic areas. Content analysis approach was adopted to improve the reliability of the study and the emic approach was applied to analyze the data to reflect the actual response of respondents. Initially, some discussions that included formal and structured interviews were conducted with the population surveyed during pilot study. It helped to identify the main issues to be investigated in detail during the actual data collection (Turi *et al*., 2019). The local names of plants and animals were written into a microsoft excel version 13 spreadsheet, saved to disk and then used in writing the report. Tables were created to summarize this information. Furthermore, quantitative data from household surveys, mainly their biodata, were analyzed into percentages using a Statistical Package for Social Scientists (SPSS), version 25.1.

Results and Discussion

Socio-Economic Characteristics of Respondents

The questionnaires were administered to women (62.6%) and men (37.4%). This implies that more women took part in the household survey than men. This was because most of the men worked in their fields to prepare for the onset of the rainy season. In the study area, more men were involved in farming and fishing activities while women spent most of their time on household chores and small businesses. Due to the rapid population growth in the study area, agriculture was practiced in marginal areas such as along river banks and in mountainous areas, resulting in runoff that favoured flooding.

In addition, the majority of respondents (80.4%) were married, 14.5% were either widows or widowers, 3.3% were divorced, and 1.9% were single. Because there were more married families, it was easier for the majority of participants to move to higher ground for safety reasons during floods. This was because the men managed to build makeshift structures for their families while they waited for the waters to subside in the lowland areas.

In terms of age, the results showed that 33% of the target group was aged between 40 and 49, followed by those aged 50-59 who made up 23%. The 60-69-year-olds made up 16%, the 70-79-year-olds made up 20%, and the fewest of the participants were those over the age of 80 who made up 8% of the participants. Such a young community had the opportunity to flee to safer places in the event of a flood. In addition, a larger number of the young people indicated that the majority of residents were still economically active and had the means to buy food during a disaster without necessarily relying on handouts (Ringo *et al*., 2016).

Finally, on the level of education, more than half of the participants (56.7%) completed 8 years of primary school, 14.4% achieved secondary education and 0.4% had no formal education. This indicated a low level of literacy in the study area. A high level of education was essential especially on issues which required a thorough understanding of flood forecasting and a critical analysis of flood impacts. A high level of education was also critical to efforts to eradicate poverty, as communities were more easily able to use their level of education to support themselves during and after a flood compared to people with low levels of education (Ringo *et al*., 2016).

Indigenous Flood Forecasting System Used in 2019

Table 2 shows the indigenous knowledge indicators communities in the study area used to predict the 2019 Tropical Cyclone Idai flood. During the FGDs, participants stated that they already knew about the upcoming 2019-flood event using local indicators that included climatic elements, celestial bodies and biological aspects (plants and animals). Participants elucidated how they monitored the environmental conditions around them and made early predictions about the flood event. The majority of them had to evacuate to higher places to avoid being affected by the disaster.

This means there are several indicators that local people in the Shire River Basin of Chikwawa District use to protect themselves from flooding. As argued by Turi *et al.* (2019), different methods and techniques have been used to predict and estimate flooding in the area. The findings are consistent events in Kenya, where local people used indicators such as frog croaking, fruit overproduction, presence of ants in villages, tree leaf shedding, and wind patterns to predict floods (Mukuna, 2015).

The Malawi Scientific Flood Forecasting System Used in 2019

Table 3 shows the SFFS used to forecast the 2019 flooding in Malawi's Shire River Basin. The Malawian flood forecasting system consisted of a network of both manned and automated instruments found at weather stations in the Chikwawa District. Meteorological data was the only data considered by this system. Weather stations at Chikwawa Boma Offices (CBO) and Nchalo Sugar Irrigation Scheme (NSIS) used both manned and automated instruments to measure various weather indicators ahead of the 2019 floods. The scientific tools used were mainly rain gauges, thermometers and other instruments.

The SRB SFFS also has an Operation Decision Support System (ODSS) that measures the water levels to forecast flooding. The ODSS has sensors that record real-time series of River Shire (RS) flow and are therefore essential for forecasting floods.

There are also operational gauges along the RS at Kamuzu bridge and in Thedzi village to monitor discharge. However, the Thedzi river gauge (Fig. 2) was vandalized and therefore, could not be used to forecast the flood in 2019.

Fig. 2: Dysfunctional gauge at Thedzi Village along the Shire River

Table 2: Indigenous knowledge indicators used in 2019

No	Indicator	Description	Period
1	Plants	Excess leaf growth	August 2018 to March 2019
2	Fruit	Overproduction of mangoes	June 2018 to March 2019
3	Rainfall	Heavy and prolonged rainfall	November 2018 to March 2019
4	Temperature	High heat caused people to wear less clothing	September 2018 to March 2019
5	Atesi frogs	Atesi frogs *(Guttular toad)* cried continuously for several days	October 2018 to March 2019
6	African Pythons	African Pythons *(Python sebae)* made the squeaking sounds that signal their feeling threatened	September 2018 to March 2019
7	Moon	Halo rings around the moon warned them of an impending flood	September 2018 to March 2019
8	Wind	Destruction of houses and trees from heavy winds	November 2018 to March 2019

Source: Hussein *et al*. (2022)

Table 3: Scientific technology indicators used in 2019

Indicator	Instrument	Flood danger values
Rainfall	Rain gauges at CBO and NSIS	Rainfall intensity about 160 mm in 24 h
Temperature	Thermometers at CBO and NSIS	Above 28°C
Wind speed	Cup anemometer located at CBO and NSIS	170 km per h
River height	River gauges located at the Kamuzu Bridge	Above 1.5 m

Finally, there is an alarm system at the Kapichira Falls, located on the lower Shire River in between the Chikwawa District town and Majete game reserve. When there is a lot of water upstream in the Chikwawa District, an alarm goes off to warn people downstream of the river's rising water level in the RS. People would therefore abandon the banks of the RS and move to higher ground. This shows that the SRB has advanced tools to detect a flood days before it occurs.

However, local communities also used other scientific tools to forecast the 2019 flood. Household respondents reported using phones, radios and televisions to receive weather updates from the Malawian SFFS as issued by the Department of CC&MS. In addition, some household participants said they often observed water swelling in the Shire River using rain gauges installed by NGOs in their communities. Any changes in the flow would be reported to Village Civil Protection Committee (VCPC) members, who would move with whistles to warn people to evacuate.

Interviews with government officials revealed that they do not consider indigenous knowledge indicators as acceptable Flood Forecasting (FF) tools. They were therefore, not used to predict the 2019 flood.

External SFFS Data Used in 2019

Data was also collected from outside of Malawi to augment weather products such as storm mapping. As some of the excess water and rainfall in Malawi came from the neighbouring countries of Tanzania and Mozambique, the DCC&MS found it necessary to collect information from these countries. Storm tracking weather data was also collected from international sources such as Accu Weather (USA), Cables News Network (CNN) and the British Broadcasting Corporation (BBC).

Live Experiences with Indigenous Flood Forecasting Systems (IFFS)

Chikwawa District residents described a variety of FFS indicators used in the SRB IFFS. Some of these, such as wind, rainfall, cloud quantity (amount) and temperature, were similar to those used in the SRB SFFS. However, they were assessed differently. Unique indicators of the IFFS were the behaviour of animals and plants. For example, one of the key informants interviewed said:

> "*These crocodiles emerge on the floodplains in quest of fish when the Shire River overflows its banks due to high discharge. Fish move to areas with plenty of water, and crocodiles follow them since they are their meal. As the river's streamflow levels rise, the water in the floodplain pushes the crocodiles closer to human settlements, indicating a massive build-up of water from the Shire River. We evacuate to higher grounds for safety when we see these indicators. These crocodiles are also dangerous to humans". [Makhuwira CEI, September 24, 2021]*

Some of the changes identified by the IFFS occurred long before the SFFS registered signs indicating imminent flooding. For example, one participant noted the following:

> *"An increase in the presence of butterflies in villages in June 2018, when they multiplied*

> *very much, indicated that flooding was imminent that year. This comes as a result of the availability of caterpillars and army worms eating the large chunk of previous season's crops like maize. It indicates that even during the winter season, many months after the rains had stopped, there was still a lot of water underground causing maize stalks to be still fresh, hence caterpillars could use that as food* [Makhuwira Men FGD, September 24, 2021]

Tables 4-7 give examples of the different general indicators and their changes in relation to impending flood.

Meteorological Elements

Table 4 shows meteorological elements communities in the study area used to forecast flooding. The majority of FGD participants reported that the most common meteorological elements used to predict flooding in the study area were rainfall, temperature, wind and clouds. As reported by Ngwese *et al*. (2018), the use of meteorological indicators to predict flooding was crucial since very high temperatures over a prolonged period indicated that flooding was likely that year as it was a processes of evaporation and transpiration which influenced cloud formation through condensation.

Table 4: Meteorological changes

Indicator	Description	Implication	Period
Clouds	Clouds increased in number	More rain that year likely to cause floods	September 2018 and March 2019
	Dark clouds appeared at lower height	About to rain heavily	December 2018 and March 2019
Rainfall	Heavy rainfall lasts for several days	Floods likely to occur soon	December 2018 and March 2019
Wind	Destroyed property and knocked over big branches of trees	Abnormal rain was to be experienced that rain season	October 2018 and March 2019
Temperature	People wore less clothes and perspired more	heavy rains likely to cause floods	September 2018 and December 2019

Table 5: Celestial body changes

Indicator	Description	Implication	Period
Moon	Rings formed around it like a rainbow	Signs of heavy rains	September 2018 and March 2019
Stars	Appeared in the early morning to the east	Heavy rains to cause floods	September 2018 and March 2019
Sun	Red and very hot	Heavy rains	September 2018 and March 2019

Table 6: Animal behaviour

Indicator	Description	Implication	Period
Millipedes (Bongololo) *Diplopoda*	Abundance in villages	Prolonged rainfall causing floods	December 2018 and March 2019
Pouched mouse (Dugu) *Saccostomus capensis*	Abundance in villages	Water table raised	January 2019 and March 2019
Birds (Tsekwe)	Sudden death in large numbers	Abnormal heat leading to heavy rain	October 2018 and March 2019
Red Ants (Lithumbu) *Solenopsis invicta*	Moved into villages in large groups	Smelt water moisture in soil	December 2018 and March 2019

Table 7: Plant growth

Indicator	Description	Implication	Period
Mango trees (Mango) *Mangifera indica*	Overproduced fruits	Water table was raised high	June 2018 and March 2019
Neem trees (Nimu) *Azadirachta indica*	Grew many leaves	Too much water underground	August 2018 and March 2019
Pawpaw trees (Mpapaya) *Carica papaya*	Dried and died in large numbers	Too much heat causing rains	September 2018 and March 2019
Grass (Tsekela) *Hyparrhenia rufa*	Remained green during both winter and summer seasons	Raised water table indicating Too much water underground	June 2018 and March 2019
Pumpkins (Maungu) *Cucurbita maxima*	Overproduction	A lot of water underground	December 2018 and March 2019

The results showed that by mid-October, the Shire River Basin in Chikwawa District would be so hot that most residents were sleeping outside their houses. In addition, the male participants stated that the majority of them spent most of the afternoon hours with little clothing.

Cloud cover was also a reliable indicator for flood forecasting among meteorological indicators. A male FGD participant from T/A Kasisi associated flooding with dark clouds forming in the sky, indicative of a disaster.

In addition, cyclones, which occurred very frequently from December to March, also indicated the threat of flooding. Due to climate change, cyclone-induced flooding is becoming more frequent in Chikwawa District's Shire River Basin.

Celestial Bodies

Table 5 shows the heavenly bodies used by the local people to forecast floods. In comparison with other groups of indicators, celestial bodies constituted the smallest group. During the FGDs, participants acknowledged the significance of heavenly bodies in predicting floods. It was learnt during data collection that the fewest celestial bodies that included the moon, stars, and sun predicted floods almost four months before the onset of the rainy season. As one participant said, *"Halos that surround the moon at night are always visible starting from the month of September until the rains start in December, indicating that floods will occur that year"*, [Lundu Women FGD, October 5, 2021].

Animal Behaviour

Table 6 shows the animal indicators used to forecast flooding in the Chikwawa District of the Shire River Basin. FGD participants managed to explicitly describe how animals of different sizes were used to forecast flooding in the study area. The most frequently mentioned animals were ants and frogs. Red ants (*Lithumbu) Solenopsis invicta* were the most common indicators of heavy rains as they moved around houses at night and disrupted sleep. According to Šakić Trogrlić *et al*. (2019), their appearance in the villages was found to predict flooding as they fled underground moisture. In this regard, their presence on the ground was an indication that the water table was high and any amount of rain that would be absorbed in the area would result in flooding. On the other hand, frogs in wetlands cried continuously signaling that there was more water in their hiding places, so heavy rains could cause flooding in the area.

In addition, the results of the study also revealed that community elders to predict flooding when large animals such as lions (mkango) *Panthera leo* and spotted hyenas (fisi) *crocuta crocuta*, which always live in the forest, were seen near villages. For example, one FGD participant commented that, "When these animals, lions (mkango), elephants (njovu) and spotted hyenas (fisi), show themselves to the villagers, it means that there will be flooding this year, because that is a sign of them moving to safer places", [Kasisi Women FGD, September 22, 2021].

Plant Behaviour

Table 7 shows the plant indicators that communities in Chikwawa District have been using to forecast floods. Plant IK indicators ranged from grass, shrubs to trees. Plants have played an important role in forecasting floods due to their ability to change their phenology in response to changes in the environment. In most cases, indicators of plant flooding were observed by their changes in the amount and type of leaf growth, as well as fruit production. Furthermore, many FGD participants identified shrubs as the most commonly used plant indicators for forecasting floods. In this regard, as narrated by one of the FGD participants:

> *"Before the flood, a shrub called mkotamo (Combresum massembicense) which was leafless in other years, grew many leaves, an indication of significant heavy rains that would cause flooding", [Mlilima Men FGD, September 23, 2021]*

As Šakić Trogrlić *et al*. (2019) noted, plants also have a long lead time, so communities observed some strange changes that would predict flooding as early as July.

Future IFFS and SFFS Integration

Based on their experiences with IFFS and SFFS indicators, respondents made several suggestions on the possible integration of the two systems in the Malawian Shire River Basin of Chikwawa District. Comments from government officials on the potential integration of IFFS and SFFS in the Shire River Basin included the following:

1. "Since the use of indigenous knowledge is not yet well organised, as there is no Government institution driving this, what is required is to strengthen the utilisation of scientific knowledge, provided by the Department of Climate Change and Meteorological Services (DCC&MS), with well trained and skilled officers" [Director of DCC&MS]

2. "We have to do data collection by triangulation per area, that is collect indigenous knowledge data from different people and compare the results with science and then document the results". [Department of Disaster Management Affairs]
3. A representative of an NGO suggested that the integration of the two systems could take place six months before the start of the rainy season, but did not indicate how this could be done

The community elders and FGD participants suggested that better communication between residents and government officials is needed as scientists do not accept their IFFS indicators in most cases. They proposed meetings to educate government officials on the importance of the IFFS indicators.

Conclusion

Communities in flood-prone areas develop useful knowledge that is used to improve flood forecasting system techniques. When the two types of flood forecasting systems are integrated, they provide residents with more relevant information than an IFFS or SFFS alone could provide. A flood forecasting system that integrates SFFS and IFFS is particularly effective in long-term disaster management strategies and promotes better response at national, regional and local levels.

IFFS is able to give people timely warning of impending flooding, although it does not know exactly which days flooding will occur. In this context, SFFS can then be activated to predict the timing of the upcoming flood.

From Tables 4-7, which provide examples of the different general IK indicators and their changes in the context of a flood threat, it is easy to see that the SRB IFFS is far more sophisticated than the SFFS flood prediction in terms of the types of indicators used. While the SFFS only measures meteorological information, the IFFS also evaluates data from three other sources in addition to meteorology. The IFFS also observes changes in celestial bodies, and the behaviour of plants and animals.

In Malawi, during floods like Tropical Cyclone Idai in 2019, flood disaster management failed to prevent property damage, displacement and deaths with only the SFFS deployed. Therefore, this study demonstrated that community members have the necessary skills and information to effectively contribute to the development of an Integrated Flood Forecasting System used in 2019.

This new FFS would be more sensitive to flood forecasts than the current SFFS and IFFS due to its ability to detect and interpret subtle environmental changes, some of which, such as overproduction of plant leaves and fruits, begin well before the SFFS sensors, which register an impending flood. Perhaps more importantly, the inclusion of IFFS indicators and the involvement of the people who use them to participate in the design and delivery of an integrated FFS would improve the system's credibility with local residents. We believe this would be a more effective community response to flood warnings.

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Author's Contributions

Daniel Hussein: Data collection, development and writing of the first drafted.

Mwakio Tole: Reviewed the article critically and edited it.

Maarifa Mwakumanya: Designed the research plan and organized the study.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues are involved.

References

Abdulrashid, L. (2020). The use of indigenous knowledge in flood disaster forecasting for flood disaster risk reduction in northern Katsina state. *Fudma Journal of Sciences*, *4*(4), 469-476. https://doi.org/10.33003/fjs-2020-0404-504

Ayaa, D. D. (2013). Effects of changes in indigenous knowledge environmental knowledge on the bio-physical and community livelihoods in Teso District, Kenya. *Kenyatta University*, *Nairobi*, *1*(1), 201. http://www.secheresse.info/spip.php?article34550

Balehegn, M., Balehey, S., Fu, C., & Liang, W. (2019). Indigenous weather and climate forecasting knowledge among Afar pastoralists of north eastern Ethiopia: Role in adaptation to weather and climate variability. *Pastoralism*, *9*(1), 8. https://doi.org/10.1186/s13570-019-0143-y

Bezak, N., Petan, S., Kobold, M., Brilly, M., Bálint, Z., Balabanova, S., Cazac, V., Csík, A., Godina, R., Janál, P., Klemar, Ž., Kopáčiková, E., Liedl, P., Matreata, M., Korniienko, V., Vladiković, D., & Šraj, M. (2021). A catalogue of the flood forecasting practices in the Danube River Basin. *River Research and Applications*, *37*(7), 909–918. https://doi.org/10.1002/rra.3826

Chawawa, N. E. (2018). Why do smallholder farmers insist on living in flood-prone areas? Understanding self-perceived vulnerability and dynamics of local adaptation in Malawi. *The University of Edinburgh, Edinburgh*, *1*(1), 279.

Dube, E., & Munsaka, E. (2018). The contribution of indigenous knowledge to disaster risk reduction activities in Zimbabwe: A big call to practitioners. *Jàmbá: Journal of Disaster Risk Studies*, *10*(1). https://doi.org/10.4102/jamba.v10i1.493

Dan, A. D., & Kapoi, K. J. (2018). Effects of Changes in Use of Indigenous Knowledge Systems on Land Cover in Teso Busia County, Kenya. *African Journal of Environmental Science and Technology*, *12*(10), 384-396. https://doi.org/10.5897/AJEST2017.2332

Hiwasaki, L., Luna, E., Syamsidik, & Shaw, R. (2014). Process for integrating local and indigenous knowledge with science for hydro-meteorological disaster risk reduction and climate change adaptation in coastal and small island communities. *International Journal of Disaster Risk Reduction*, *10*, 15-27. https://doi.org/10.1016/j.ijdrr.2014.07.007

Hussein, S., Norren, A., Yousan, T., Khan, I., Aziz, H., Rehman, E., Saleem, A., Imam, M., F., Saeed. A. (2022). Cropping pattern to cope with climate change scenario in Pakistan. *Bioscience Research*. *19*(2): 957-963. ISSN: 2218-3973

Jury, M. R. (2014). Malawi’s shire river fluctuations and climate. *Journal of Hydrometeorology*, *15*(5), 2039-2049. https://doi.org/10.1175/JHM-D-13-0195.1

Kalanda-Joshua, M., Ngongondo, C., Chipeta, L., & Mpembeka, F. (2011). Integrating indigenous knowledge with conventional science: Enhancing localised climate and weather forecasts in Nessa, Mulanje, Malawi. *Physics and Chemistry of the Earth, Parts A/B/C*, *36*(14–15), 996-1003. https://doi.org/10.1016/j.pce.2011.08.001

Kamin, M., Ahmad, N. F. A., Razali, S. N. M., Hilaham, M. M., Rahman, M. A., Ngadiman, N., & Sahat, S. (2017). *Geographical Information System (GIS) application for flood prediction at Sungai Sembrong*. 020071. https://doi.org/10.1063/1.5005404

Mazzoleni, M., Verlaan, M., Alfonso, L., Monego, M., Norbiato, D., Ferri, M., & Solomatine, D. P. (2017). Can assimilation of crowdsourced data in hydrological modelling improve flood prediction?. *Hydrology and Earth System Sciences*, *21*(2), 839-861. https://doi.org/10.5194/hess-21-839-2017

Mukuna, T. E. (2015). Integration of Indigenous and Scientific Technology in Disaster Risk Reduction Education in Kenya; A Framework for Sustainable Development. *The International Journal of Humanities & Social Studies*, *3*(2). https://doi.org/internationaljournalcorner.com/index.php/theijhss/article/view/131972

Ngwese, N., M, Saito, O, Sato, A., Agyeman Boafo, Y., & Jasaw, G. (2018). Traditional and Local Knowledge Practices for Disaster Risk Reduction in Northern Ghana. *Sustainability*, *10*(3), 825. https://doi.org/10.3390/su10030825

Palamuleni, L. G., Ndomba, P. M., & Annegarn, H. J. (2011). Evaluating land cover change and its impact on hydrological regime in Upper Shire river catchment, Malawi. *Regional Environmental Change*, *11*, 845-855. https://doi.org/10.1007/s10113-011-0220-2

Palamuleni, L. G., Annegarn, H. J., & Landmann, T. (2010). Land cover mapping in the Upper Shire River catchment in Malawi using Landsat satellite data. *Geocarto International*, *25*(7), 503-523. https://doi.org/10.1080/10106049.2010.490601

Perera, D., Seidou, O., Agnihotri, J., Rasmy, M., Smakhtin, V., Coulibaly, P., & Mehmood, H. (2019). Flood early warning systems: A review of benefits, challenges and prospects. *UNU-INWEH, Hamilton*. https://doi.org/10.53328/MJFQ3791

Prada, R, M, C. (2016). *Operational Flood Forecasting, Warning and Response for Multi-Scale Flood Risks in Developing Cities* (1st ed.). CRC Press. https://doi.org/10.1201/9780138745011

Rai, P., & Khawas, V. (2019). Traditional knowledge system in disaster risk reduction: Exploration, acknowledgement and proposition. *Jàmbá Journal of Disaster Risk Studies*, *11*(1). https://doi.org/10.4102/jamba.v11i1.484

Raj, R. (2013). Harmonizing traditional and scientific knowledge systems in rainfall prediction and utilization. *Bridging Scales and Knowledge Systems. Washington DC, Island Press*, 225-39. ISBN-10: 1597268402, Rimba, A. B., Setiawati, M. D., Sambah, A. B., & Miura, F. (2017). Physical flood vulnerability mapping applying geospatial techniques in Okazaki City, Aichi Prefecture, Japan. *Urban Science*, *1*(1), 7. https://doi.org/10.3390/urbansci1010007

Ringo, J., Luvinga, K., Morsardi, L., Omary, I., Mayengo, G., & Kawonga, S. (2016). Indigenous knowledge in flood management and control in Kilosa District, Tanzania. *Int. J. Mar. Atmos. & Earth Sci*, *4*(1), 1-15.

Šakić Trogrlić, R., Wright, G. B., Duncan, M. J., van den Homberg, M. J., Adeloye, A. J., Mwale, F. D., & Mwafulirwa, J. (2019). Characterising local knowledge across the flood risk management cycle: A case study of Southern Malawi. *Sustainability*, *11*(6), 1681. https://doi.org/10.3390/su11061681

Tran, P., Shaw, R., Chantry, G., & Norton, J. (2009). GIS and local knowledge in disaster management: A case study of flood risk mapping in Viet Nam. *Disasters*, *33*(1), 152–169. https://doi.org/10.1111/j.1467-7717.2008.01067.x

Turi, J., A, Ahmad, M, Haloul, M, I., K, Manand, A and Arif, M., I, M. (2019). Role of indigenous knowledge in managing floods projects. *Advances in Social Sciences Research Journal*, *6*(9), 87-96. https://doi.org/10.14738/assrj.69.7074

Zuzani, P. N., Ngongondo, C. S., Mwale, F. D., & Willems, P. (2019). Examining trends of hydro-meteorological extremes in the Shire River Basin in Malawi. *Physics and Chemistry of the Earth, Parts A/B/C*, *112*, 91-102. https://doi.org/10.1016/j.pce.2019.02.007