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Sustainable Flood Management and Risk Reduction Action

Flash Flood Risk Assessment Data and Tools for Somalia

Final Report

28 March 2022

Prepared for the Ministry of Energy and Water Resources of Somalia and the United Nations Environment Programme

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Prepared for:	Ministry of Energy and Water Resources of Somalia and the United Nations Environment Programme
Prepared by:	UNEP-DHI

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Executive Summary

The Ministry of Energy and Water Resources (MOEWR) in collaboration with the United Nations Environment Programme (UNEP) is carrying out the project “Sustainable Flood Management and Risk Reduction Action”, ongoing from August 2021 to March 2022. The project is funded by the Foreign, Commonwealth & Development Office (FCDO).

The Somalia National Water Resource Strategy (NWRS) 2021- 2025, launched by MOEWR, identified, as one of the main challenges for development, the need for “strengthening the water sector governance frameworks and developing a cooperative government approach that progressively improves the Federal Government of Somalia (FGS) and Federal Member States (FMS) ministries’ approach to water resource management and development” (MOEWR, 2021). Alongside the establishment of cooperative partnerships with ministries at FGS and FMS levels, the creation of task forces and clusters, and the strengthening of governance and policy, NWRS also focuses on building the capacity of institutions.

UNEP activities within the project are aimed at supporting MOEWR and National Flood and Drought Task Force members, including members from Hirshabelle, Jubaland and South West states, by providing:

1. data, information and tools to carry out flash flood risk assessment
2. research on applicability of Nature-based Solutions (NbS) for flood and drought mitigation
3. workshops for sharing of findings, collection of feedback and capacity-building.

This report documents the work pertaining to the first objective focusing on flash flood risk. The data outputs of the project are available via the project online resource www.jubashabelle-tmo.org This portal was used to disseminate findings during the workshop programme chaired by MOEWR. It has served as a key interface between stakeholders and the project team.

Key outputs and recommendations

The aim was to provide the National Task Force members with data, information and tools to carry out a flash flood risk assessment. For this purpose, flash flood hazard potential approaches were investigated, and vulnerability indicators calculated for the areas of study based on a surveyed household sample. The workflow in the Risk Assessment application of the portal allows determining exposure and identifying areas at higher risk.

Many locations in Somalia are prone to flash floods caused mainly by *Gu* rainfall events occurring between March and June, but also in some years in the *Deyr* season from October to December. This type of flood is generated by heavy rainfall over a few hours, typically resulting in a sudden increase in river flow followed by a quick recession.

For the assessment of flash flood risk, the focus areas were selected based on the availability of information with regards to flash flood occurrence: Beledweyne and Qhardo.

Flood risk can be defined as a function of the magnitude of the flood hazard, the degree of exposure of the impacted area, and the vulnerability of communities to flood damage. Hence, in this study:

a) approaches to determine flash flood hazard were investigated,

b) vulnerability to flooding of communities in the study areas was estimated,

c) datasets were generated and included in the Risk Assessment application of the portal

The hazard and vulnerability datasets, in combination with the functionality and workflows available in the Risk Assessment app, allow the stakeholders to determine exposure and identify and locate areas in the country at higher risk.

Approaches to determine flash flood hazard

Approaches to assess wadi flash flood potential were investigated by the project team, selected based on a literature review conducted to investigate the existence of indicators that are best suited to the geomorphology and climatic conditions of Somalia, and on the project teams' experience with well-known flood-related indicators and widely applied data sources. Four different approaches to assess and map the potential for flash floods in Somalia were selected: the Flash Flood Potential Index (FFPI), the Height Above Nearest Drainage point (HAND), the use of Global Precipitation Measurement (GPM) 30-minute GPM-Early data product by NASA, and the morphometric approach. The research consisted of assessing the performance of each approach by verifying if the few flash flood events known had been properly captured.

The FFPI quantitatively describes a given sub-basin's risk of flash flooding based on its inherent, static characteristics such as slope, land cover, land use and soil type/texture. The HAND does not refer to the risk or likelihood of an area being hit by a flood, instead it is a static approach for mapping the potential extent of inundation. The investigation found that the FFPI does not perform well and that HAND shows some promise as it is easy to use and read, however, it does not directly afford a measure of hazard.

The applicability of data product 30-minute GPM-Early was tested for a known event in 2019. The timing of heavy rainfall corresponds well with ground measurements although these are not directly comparable. In terms of freely available data for use by the MOEWR and National Task Force, this product has been found to be the best available.

The morphometric approach was found to have been applied to parts of the world with similar terrain and climatic conditions and to our knowledge had not been applied yet to Somalia. This method has the advantage of being simple to apply and requires relatively little data, being based on three parameters calculated and combined to assess the hazard potential of flash floods: drainage density, stream frequency and bifurcation ratio. These parameters are then plotted against each other and compared to empirical relationships to determine the flood hazard degree for a catchment or sub-basin. The catchments are then classified as follows: (A) high potential for flash flooding and low possibility for groundwater recharge; (B) moderate potential for flash floods, and moderate possibility for groundwater recharge; and (C) low potential for flash floods and high possibility for groundwater recharge. For the study areas considered, it was found that there is no basin showing a high potential for flash floods. However, in Qardho and Garoowe one basin is classified as medium-to-high potential for flash flooding.

It was not possible to draw conclusions about their applicability due to a lack of data describing the occurrence of flash flood events that could be used for validation – most noticeably, exact location, day and time.

It is recommended that further detailed information on the occurrence and severity of flash flood events in the country is collected and compared with these indices to assess their applicability and the potential for practical application of the most promising method(s). It is also recommended that the potential for flash flood forecasting is assessed. This would require:

- identification and ranking of vulnerable sites where flash floods occur and where potential losses are high.
- assessment of the lead-time from heavy rainfall to flooding at these locations. This will require detailed information on the timing of the rainfall, e.g., using GPM-Early data, and the timing of the flood, collected at the site. As measurements of river water levels are rarely available, this would typically be based on interviews with the local population.
- assessment of the applicability of available sources of real-time rainfall data to enable early warning. If none of these are suitable, the potential of possible future sources, such as weather radars or automatically reporting rain gauges in the catchment area, should be assessed.

- Finally, the path towards an operational early warning system for (some of) the identified vulnerable locations should be outlined, describing the required activities and investments.

Vulnerability to flooding of communities in the study areas

Regarding the estimation of vulnerability to flooding, a collection of indicators and a workflow to calculate physical, social and economic components of vulnerability, as well as total vulnerability, is available via the Risk Assessment application of the portal www.jubashabelle-tmo.org.

The indicators are available to the National Flood and Drought Task Force and MOEWR for exposed communities within our study areas, namely the cities of Beledweyne, Jalalaqsi, Bulo Burde, Mahaday Weyne, Jowhar in Hirshabelle State; and the city of Qardho in Puntland. The process undertaken to determine vulnerability contained the following steps:

1. Household mapping and land cover classification of communities in the study areas.
2. Selection and calculation of indicators to estimate social, economic and physical vulnerability, considering constraints imposed by the existence of publicly available data.
3. Populating the Risk Assessment application of the portal with indicator layers.
4. Application of a Multi-Criteria Analysis (MCA) approach for estimation of overall vulnerability, by using available tools in the portal.

The outputs of a parallel project activity, a Knowledge Attitudes Practices (KAP) study, supported by project partner FAO, were used in the calculation of the indicators derived from responses to a household questionnaire of 1,272 sampled households across the study area. The indicators presented in Appendix A have been calculated based on publicly available data and the responses. An approach for extrapolation of values from the sample to the overall household population in the six urban centres is proposed. However, due to lack of data, this has been done only for demonstration purposes and it is emphasized that the extrapolated values should not be considered valid until a quality assurance procedure is carried out by the National Flood and Drought Task Force.

Overall physical, social and economic vulnerability components are a product of the combination of their respective indicators. Our team has carried out a classification exercise for the purpose of illustrating the methodology and approach. This classification must be carried out by stakeholders using their expert knowledge and, when needed, further data and supporting studies. This will be especially important for non-numerical indicators that are not susceptible to direct classification using statistical methods such as quantiles, for example.

Available datasets and Risk Assessment workflow

The Risk Assessment application provides a tool for reclassification of vulnerability indicators and calculation of total vulnerability following the methodology described in this report. All data produced by this research study is available to be inspected and/or downloaded by National Flood and Drought Task Force members and state-level task force members.

Spatially distributed riverine flood hazard data, that is public freely available, such as river flood hazard maps by the Global Assessment Report [1]on Disaster Risk Reduction (GAR) by UNEP and UNISDR were obtained for Somalia and uploaded so that it is available from within the app. Having additional hazard datasets means that the risk assessment workflow demonstrated in this project, and the fact that vulnerability indicators remain applicable, means that the task force is provided the capability of conducting risk assessment focused on flash floods but also riverine floods within the study areas.

[1] The GAR 15 global flood hazard assessment uses a probabilistic approach for modelling riverine floods for major river basins around the globe. For access to the source visit: https://preview.grid.unep.ch/index.php?preview=data&events=floods&evcat=1&lang=eng

Finally, it is recommended that for sustainable application of this project's outcomes, the next step in the collaboration between MOEWR and UNEP is aimed at strengthening the capacity of the federal and state-level authorities. Via the project's workshop programme, requests by MOEWR and task force members have been put forward and relevant areas for development identified.

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List of Acronyms

CCCM	Camp Coordination and Camp Management
Dd	Drainage density
EO	Earth Observation
ESA CCI	The European Space Agency Climate Change Initiative
FAO	Food and Agriculture Organization of the United Nations
FCDO	Foreign, Commonwealth & Development Office
FFPI	Flash Flood Potential Index
FGS	Federal Government of Somalia
FMS	Federal Member State
Fs	stream Frequency
GPM	Global Precipitation Measurement mission
HAND	Height Above Nearest Drainage point
HDX	The Humanitarian Data Exchange. International Organization for Migration (IOM), Displacement Tracking Matrix (DTM)
IDP	Internally Displaced People
JAXA	Japan Aerospace Exploration Agency
KAP	Knowledge Attitudes Practices
MCA	Multi Criteria Analysis
MOA	Ministry of Agriculture and Irrigation
MOEWR	Ministry of Energy and Water Resources
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NbS	Nature-based Solutions
NDVI	Normalized Difference Vegetation Index
NWRS	National Water Resource Strategy
NWS	National Weather Service
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
PET	Potential Evapotranspiration
Rb	Bifurcation ratio
SRTM	Shuttle Radar Topography Mission
SWALIM	Somalia Water and Land Information Management System
SWI	Soil Water Index
TMO	Transboundary Monitoring Observatory
UNEP	United Nations Environment Programme
UNFPA	United Nations Population Fund
UNICEF	United Nations International Children's Emergency Fund
UNOCHA	United Nations Office for the Coordination of Humanitarian Affairs
UNSOS	United Nations Support Office in Somalia
USGS	United States Geological Survey
WRM	Water Resources Management

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1 Background

The Ministry of Energy and Water Resources (MOEWR) in collaboration with the United Nations Environment Programme (UNEP) is carrying out the project "Sustainable Flood Management and Risk Reduction Action", ongoing from August 2021 to March 2022. The project is funded by the Foreign, Commonwealth & Development Office (FCDO) of the Government of the United Kingdom via its International Climate Financing Water Resources Management (WRM) programme, which also included a component of implementing flood mitigation interventions carried out by the Food and Agriculture Organization of the United Nations (FAO).

The direct beneficiaries are the National Flood and Drought Task Force, the existing State Flood Task Force members from Hirshabelle, Jubaland and South West States, decision-makers and planners regarding flood and drought mitigation/disaster management and, at a broader scale, Somali technical experts and stakeholders on flood and drought issues at federal and state level.

The project's study areas are the Shabelle River Basin; the Shabelle River stretch in Hirshabelle State flowing through key urban centres from Beledweyne, Jalalaqsi, Bulo Burde, Mahaday, to Jowhar; and Qardho, in Puntland State.

1.1 Objectives

In this context, UNEP – via its collaborating centre UNEP-DHI[2] - is supporting MOEWR with the following project objectives:

1. Support government stakeholders with data, information and tools to carry out flash flood risk assessment
2. Research on applicability of Nature-based Solutions (NbS) for flood and drought mitigation
3. Workshops for sharing of findings, collection of feedback and capacity-building.

The data outputs of the project will be delivered to MOEWR and available via the project online resource www.jubashabelle-tmo.org. This portal was used to disseminate findings and in the workshop programme MOEWR and UNEP delivered. It served as a key interface between the stakeholders and the project team.

1.2 Research to inform Policy Guidance

The Somalia National Water Resource Strategy (NWRS) 2021-2025, launched by MOEWR in April 2021, is the key national policy instrument driving holistic water sector reform, as well as defining priority projects to address the identified main challenges to growth and development.

One of the challenges the NWRS aims to address is the need for "strengthening the water sector governance frameworks and developing a cooperative government approach that progressively improves the FGS and FMS ministries' approach to water resource management and development" (MOEWR, 2021).

Governance frameworks and corresponding policy, legal and regulatory instruments will, among other issues, be produced to address Disaster Risk Reduction (DRR), including flood and drought risk management. The NWRS recognizes the importance that task forces and clusters have had as coordination and facilitation platforms in general, and for monitoring and reporting on flood and

[2] UNEP-DHI Centre on Water and Environment is a UNEP centre of expertise, dedicated to improving the management, development and use of freshwater resources from local to global level, in operation since 1996. https://www.unepdhi.org/

drought response, including humanitarian support resources. Furthermore, the NWRS highlights the establishment of the National Flood and Drought Task Force as a key element for coordinating inter-ministerial responses. This is done under Sub-strategy 10 - Plan and responds to climate variability and its impacts on water resources management and development (adaptation, mitigation and recovery); Strategic Objective SO10b - Flood and drought risk management strategies and plans developed; and Action A49 - Establish Permanent Flood Task Force/Committee to coordinate governmental action.

Alongside cooperative partnerships with ministries at FGS and FMS levels, the creation of task forces and clusters, and strengthening governance and policy, the NWRS also focuses on building the capacity of institutions. Namely, under Sub-strategy 7: Undertake capacity-building & knowledge exchange interventions.

UNEP's scope of work under this project includes activities designed to support the implementation of the NWRS in the afore-mentioned aspects and the objectives laid out by the FCDO. This will be achieved by producing research data and information and corresponding consultative and capacity-building workshops to support the FGS and the National Flood and Drought Task Force's mandate. These activities will also benefit a broader range of stakeholders within the flood and drought management institutional framework in Somalia.

1.3 Purpose of this Report

This report consists of the final written deliverable of the project focusing on flash flood risk assessment. It presents the objective, methodology, results and conclusions of this project component, describing the data and tools available to the National Flood and Drought Task force and recommendations for bridging the identified gaps and future studies.

2 Introduction to Flash Floods

In addition to the riverine floods regularly occurring along the Shabelle and other rivers in Somalia, heavy rainfall events are causing flash floods in many parts of the country. These generally occur in wadies (ephemeral rivers) and are characterised by a sudden increase in the flow followed by a quick recession, see the example in Figure 2.1.

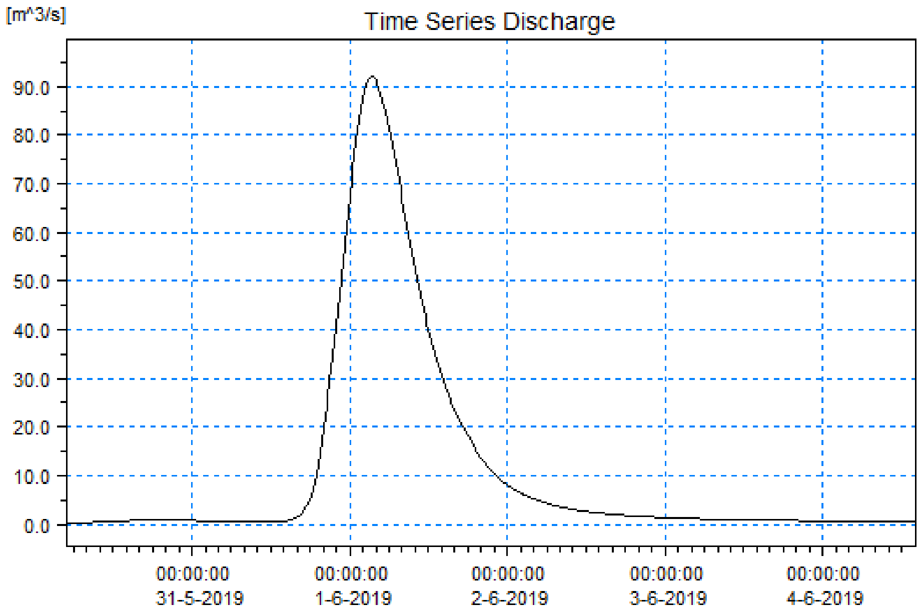

Figure 2.1 Flash floods are characterised by a sudden increase in the flow followed by a quick recession.

These flood events are difficult to predict. Meteorological services may indicate an increased risk of heavy rainfall in an area but are only capable of predicting when and where the heavy showers will hit at very short notice, if at all.

Real-time monitoring of river water level has been implemented in some mountainous areas around the world to automatically activate a siren to warn the population in flood prone settlements further down the river.

The use of weather radars may enable short-term warning by monitoring intense, convective rainfall events and extrapolating their path. Satellite measurements of rainfall may, in principle, be applied for this also, but most satellite-based rainfall data is only available several hours after measurement and therefore unsuited to provide early warning of flash floods.

The main options for flash flood mitigation are:

- Flash flood hazard mapping, indicating the risk of flash flood based on catchment and river characteristics and current conditions, such as the soil moisture. The mapping can be used to prioritize other mitigation actions and strengthen preparedness.
- Flood water retention structures like for example certain types of Nature-based Solutions, may be constructed along the rivers, where flash floods occur, to retain water when high run-off occurs while allowing low flow to pass undisturbed. This may be a small dam across the river with a culvert through.
- Flood water diversion to reduce the risk of flooding at vulnerable locations; downstream structures may be set up to automatically divert excess water to areas where flooding will

cause limited damage, see Figure 2.2. This could be fields along the river located near a town. It may be required to create polders in the selected fields to control and limit the flooding.

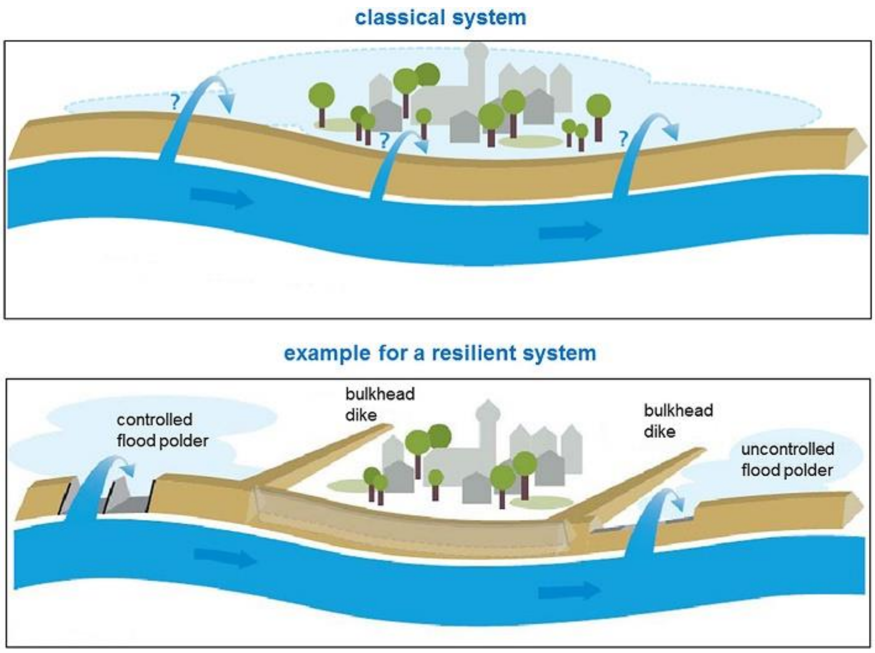

Figure 2.2 Flood damage at key locations may be limited by deliberate flooding of less vulnerable areas (Jupner, 2013).

Options for flash flood risk assessment are discussed below while possible flash flood mitigation measures are described in the report *Applicability of nature-based solutions for flood and drought in Somalia, UNEP-DHI, March 2022.*

3 Flash Flood Risk Assessment

A flood risk assessment can be undertaken over a large area or for a particular site to:

- identify whether and the degree to which flood risk is an issue
- identify flood-prone zones
- inform decisions in relation to zoning and planning applications; and
- develop appropriate flood risk mitigation and management measures for development sites in flood-risk areas.

The information generated in this research study – in combination with tools in the project's online resource, the www.jubashabelle-tmo.org portal and its applications – aims to support the National Flood and Drought Task Force with carrying out risk assessment for the study areas.

A flood disaster occurs when the magnitude of a flood event exceeds the capacity of the impacted area to cope with the event, resulting in loss of life, livelihoods and damage to infrastructure. Flood risk can, therefore, be defined as a function of the magnitude of the flood hazard, the degree of exposure of the impacted area, and the vulnerability of communities to flood damage.

The research carried out to study each component associated with the determination of risk is discussed individually in more detail in the following sections.

3.1 Hazard Potential

A flood hazard analysis of the Shabelle River is being carried out within the scope of a parallel project by FAO for the Ministry of Agriculture and Irrigation (MOAI) of Somalia, the Hirshabelle Resilient Riverine Agricultural Project. This type of analysis of flood hazard will involve determining the flood flow volume, depth of flood water, speed or velocity of flood water and the duration of the flood event.

To avoid duplication, the focus of this project's research supported by UNEP turned to the less studied and understood flood hazard phenomena occurring in Beledweyne, Hirshabelle State and Qhardo, Puntland State: flash floods in ephemeral rivers (wadis) following heavy rainfall events as presented in section 2 of this report.

Overviews of flash flood hazard can be useful to plan mitigation measures and emergency action. These may include some of the globally available information which has been included in the "Data Monitor" application portal www.jubashabelle-tmo.org, such as the Flash Flood Potential Index (FFPI) and the Height Above Nearest Drainage point (HAND). These are described below along with other possible data sources and methods to assess flood hazard.

3.1.1 Flash Flood Potential Index (FFPI)

The FFPI is a method of ranking watersheds by their relative run-off potential. FFPI was originally developed at the National Weather Service (NWS) Colorado Basin River Forecast Center in 2003 (Smith, 2003).

The goal of the FFPI is to quantitatively describe a given sub-basin's risk of flash flooding based on its inherent, static characteristics such as slope, land cover, land use and soil type/texture. The FFPI is calculated as a weighted average of slope, soil moisture, and the Normalized Difference Vegetation Index (NDVI), where:

- Slope is calculated from a 90-metre DEM and assigned a weight of 0.35

- The Soil Water Index (SWI) quantifies the moisture condition at various depths in the soil. It is provided by Copernicus Global Land Service at global scale based on H SAF Metop-ASCAT satellite soil moisture observations and can be seen in the portal. It is available every 10 days and is assigned a weight of 0.35
- The Normalized Difference Vegetation Index (NDVI) is the average MODIS[3] vegetation index produced on 16-day intervals and at multiple spatial resolutions. This is weighted by 0.3.

The applicability of the FFPI for Somalia has been assessed by comparing values at times when widespread flash flooding occurred with values seen under normal conditions. The differences were few and insignificant, however, indicating that the FFPI may not be very useful for Somalia. The reason is probably that the occurrence of flash floods in Somalia is poorly correlated with the variation of soil moisture and the state of vegetation, as these indices also display little variation during the floods.

3.1.2 Height Above Nearest Drainage

The Height Above Nearest Drainage point (HAND (Nobre, 2015)) data was used to make a first assessment of flood-prone areas. This dataset is available in the portal. The HAND values can be interpreted as the flood level required for a specific area to be flooded. The map is derived from a 90-m DEM, see Figure 3.1.

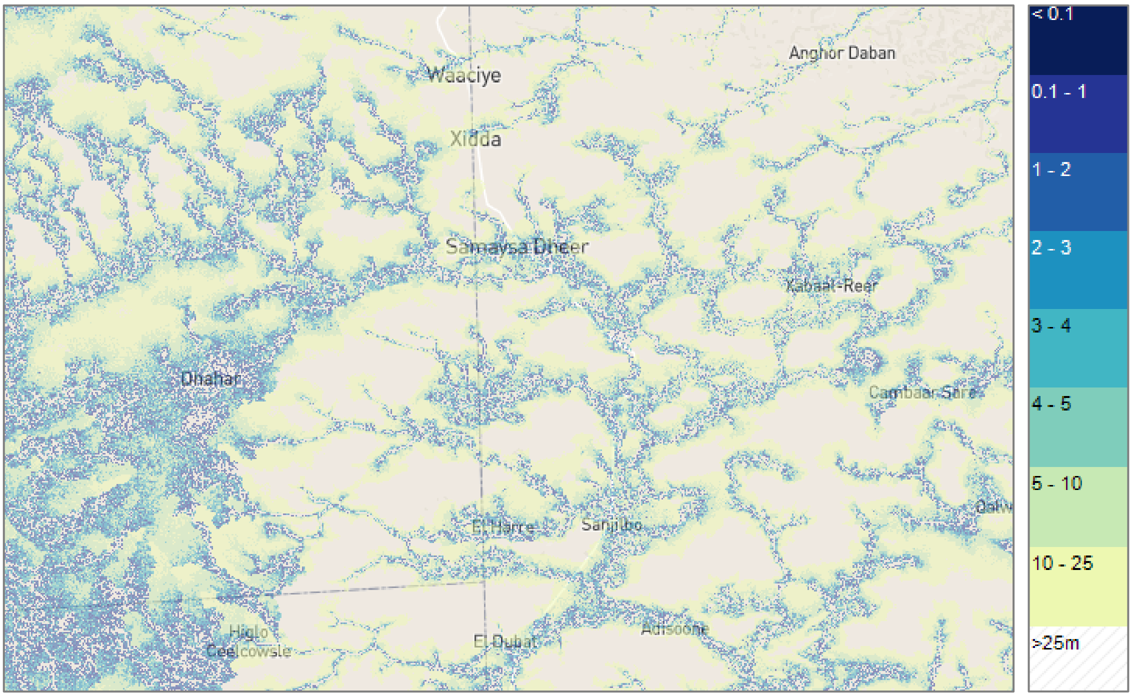

Figure 3.1 The Height Above Nearest Drainage point (HAND) provides an indication of the potential extent of inundation.

The HAND map does not refer to the risk or likelihood of an area being hit by a flood. It is a simple static approach for mapping the potential extent of inundation. It does not depend on flood observations and extends beyond methods for mapping low-lying areas. While relying on the contour concept, the method utilizes drainage-normalized topography and flow paths to delineate

[3] The central sensor on board NASAs Terra Satellite Platform is the Moderate Resolution Imaging Spectroradiometer (MODIS) http://modis-land.gsfc.nasa.gov/vi.html

the relative vertical distances (drop) to the nearest river. The HAND-delineated relative drop is an effective distributed predictor of flood potential, which is directly related to the river stage-height.

HAND values in Qardho are shown in Figure 3.2.

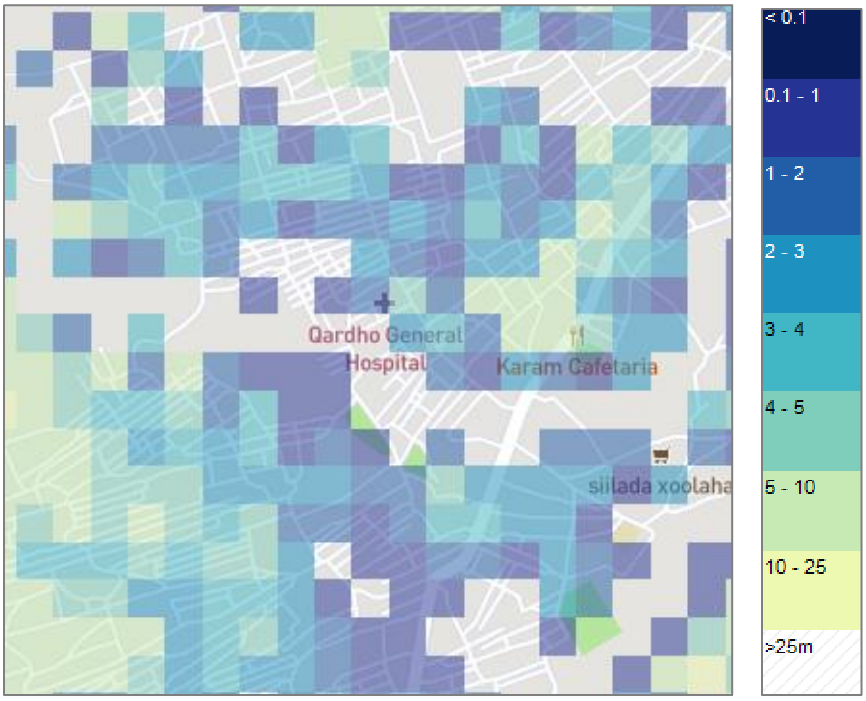

Figure 3.2 HAND values in Qardho

3.1.3 Global Precipitation Measurement

Satellite-based rainfall data of the Global Precipitation Measurement (GPM)[4] mission is automatically made available as daily, processed data in the portal, typically a few days after observation. It is available in the versions Early, Late, and Final with increasing accuracy and latency. To enable assessment of its applicability for flash flood mitigation, time series of the 30-minute GPM-Early data at the time of the 2019 flood has been downloaded and included in the portal. The timing of heavy rainfall corresponds well with ground measurements although these are not directly comparable. The GPM Early data is usually available for download from NASA 4-6 hours after measurement. Further information on the time between the heavy rainfall events and the occurrence of flash floods at vulnerable locations in Somalia is required to assess whether data of this type could be useful to mitigate flash floods here.

The data can be visualized on the map, showing the distribution and intensity of rainfall (Figure 3.3) and as time series covering the country or selected districts (Figure 3.4). The user can thereby see the spatial distribution of rainfall at a given time and the timely variation of rainfall for a selected area.

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[4] Building upon the success of TRMM, the GPM concept centres on the deployment of a "Core" satellite carrying an advanced radar/radiometer system to measure precipitation from space and serve as a reference standard to unify precipitation measurements from a constellation of research and operational satellites. Source: https://pmm.nasa.gov/GPM

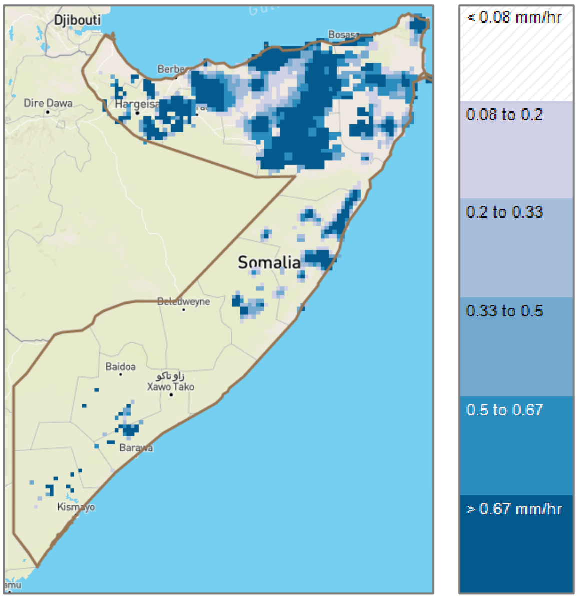

Figure 3.3 30-minute GPM rainfall data on 1 June 2019 at 11 am.

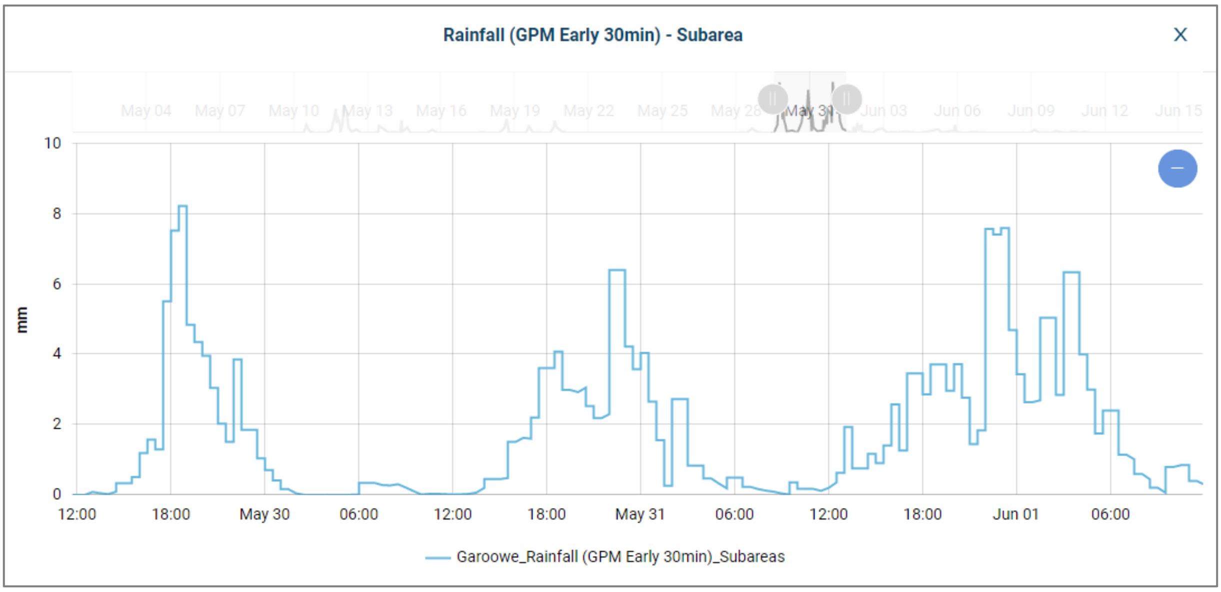

Figure 3.4 The 30-minute GPM rainfall data averaged over Garoowe district during the 2019 flood.

3.1.4 The Morphometric Approach

To assess wadi flash flood potential, a literature review has been conducted to investigate the existence of indicators that are best suited to the geomorphology and climatic conditions of Somalia. The morphometric approach,[5] described in the following section, was found to have been applied to parts of the world with similar terrain and climatic conditions as Somalia. This method has the advantage of being simple to apply and requires relatively little data.

[5] El-Shamy, I. (1992) Recent Recharge and Flash Flooding Opportunities in the Eastern Desert, Egypt. Annals of Geological Survey of Egypt, 18, 323-334.

Methodology

Consistent data on the (ephemeral) river network is required and a digital model of terrain.

Data Sources

HydroRIVERS[6] by World Wildlife Fund (WWF) is a database of all global rivers that have a catchment area of at least 10 km^2 or an average river flow of 0.1 m^3/s, or both. This database was used to source the river network delineation for the assessment. It contains rivers covering the whole country of Somalia and including river orders 1 to 12 from the Strahler stream order system.

The Digital Elevation Model used is the Global Shuttle Radar Topography Mission (STRM) at 30 m resolution.

Study Areas

Flash floods are known to have occurred in Puntland, e.g., around 1 June 2019, at Qardho and Garoowe, and to occasionally occur near Beledweyne. The method has therefore been tested for these areas.

Description of the Morphometric Approach

The morphometric method is based on three parameters calculated and combined to assess the hazard potential of flash floods for different sub-basins. These parameters are presented in Table 3.1.

Table 3.1 Description of the morphometric approach parameters

Parameters	Abbreviation	Units	Description / equation
Drainage density	D_d	km^{-1}	Total streams length / A
Stream frequency	F_s	km^{-2}	Total number of streams / A
(Weighted mean) Bifurcation ratio	WMR_b	-	$\sum \frac{\left\{\left(\frac{N_u}{N_{u+1}}\right) \cdot (N_u + N_{u+1})\right\}}{\sum N}$ $N_u = number\ of\ streams\ of\ order\ u$

The morphometric parameters are then plotted against each other and compared to empirical relationships to determine the flood hazard degree for a catchment or sub-basin:

- Bifurcation ratio (Rb) versus drainage density (Dd),
- Bifurcation ratio versus stream frequency (Fs).

The empirical diagrams shown below divide the resulting plot into three zones. The first zone (A) is characterized by high potential for flash flooding and low possibility for groundwater recharge. The second zone (B) is characterized by moderate potential for flash floods, and moderate possibility for groundwater recharge. The third zone (C) is characterized by low potential for flash floods and high possibility for groundwater recharge. The diagrams shown in Figure 3.5 are from a study of the flash flood hazard from 4th-order catchments.[7] The smaller catchments selected in Somalia are all of 3rd-order and thus the method is applied here on 3rd-order catchments instead of 4th-order catchments.

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[6] For more information, please visit https://www.hydrosheds.org/page/hydrorivers.
[7] Farhan, Y. and A. Ayed (2017): Assessment of Flash-flood hazard in arid watersheds of Jordan. Journal of Geographic Information Systems, 9, 717-751

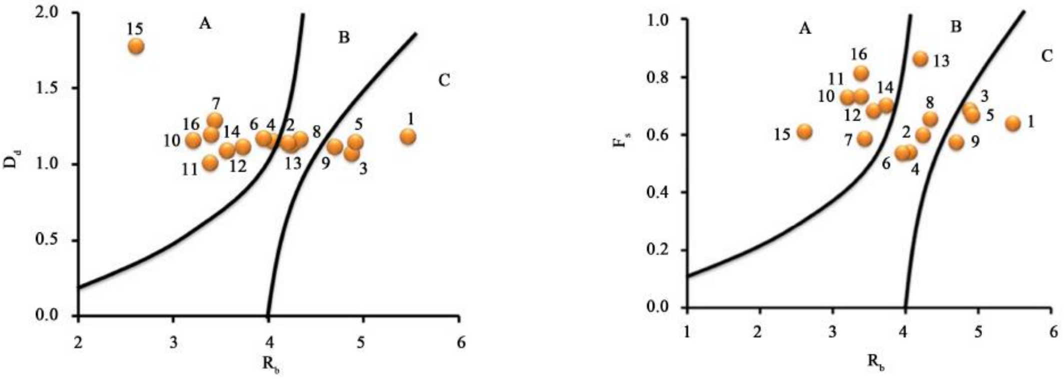

Figure 3.5 **The flash flood potential is determined using empirical diagrams as in this example (Farhan, 2017).**

To aggregate the results of both relationships and illustrate the overall hazard, the following scoring scale has been used on each diagram:

- If the basin is in zone A, the score is 2
- If the basin is in zone B, the score is 1
- If the basin is in zone C, the score is 0

For each basin, the scores obtained through each diagram are added to each other, giving the final score which can range between 0 (lowest potential) and 4 (highest potential):

Score	Potential hazard
0	Low
1	Low to medium
2	Medium
3	Medium to high
4	High

Results and Discussion

The results obtained for the bifurcation ratio and the drainage density are similar to those of Farhan Y. and Ayed A. (2017). However, the stream frequency values were consistently one order of magnitude below those of Farhan Y. and Ayed A. (2017) and did not fit the available diagrams' divisions. Based on different articles where this method has been used, the diagrams appear to be scaled to the data as the zones' division do not consistently follow the same pattern. There are uncertainties linked to the method i.e., the diagrams' definition as described above, the resolution of the river network (influencing the number and the length of rivers within a basin), and the basins definition especially in flat areas. The use of 3rd-order basins instead of 4th-order ones could also be a source of divergence. To get a comparable set of points, the stream frequency values have been multiplied by a factor 10 in the analysis below.

Figure 3.6 shows the selected sub-basins positioned on the empirical diagrams. The green dots represent the analysed basins, the grey dots represent the original stream frequency values.

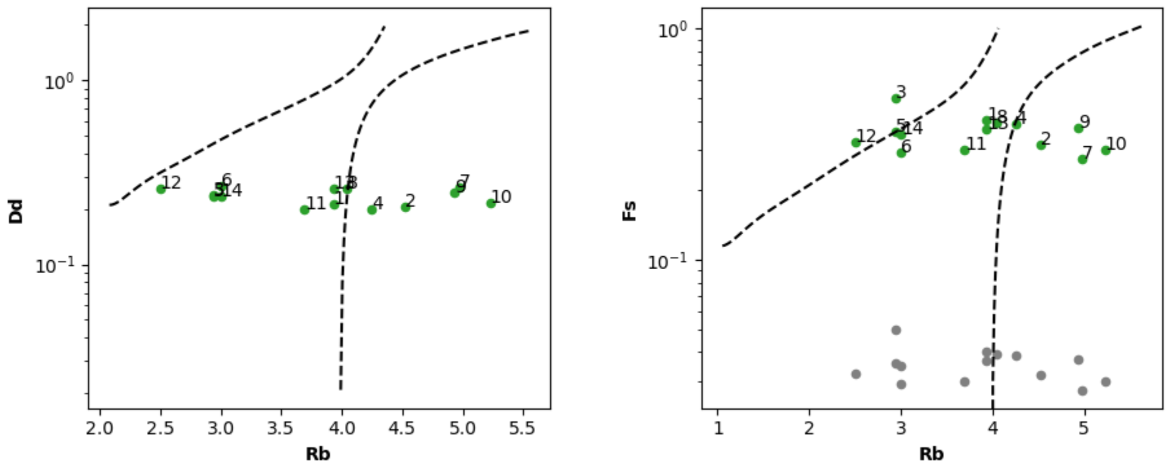

Figure 3.6 Morphometric diagrams with the position of the 3rd order basins of the study area

The results for the studied areas are shown in colour-code from Figure 3.7 to Figure 3.9 below. There is no basin showing a high potential for flash floods. However, in Qardho and Garoowe one basin is classified as medium-to-high potential for flash flooding.

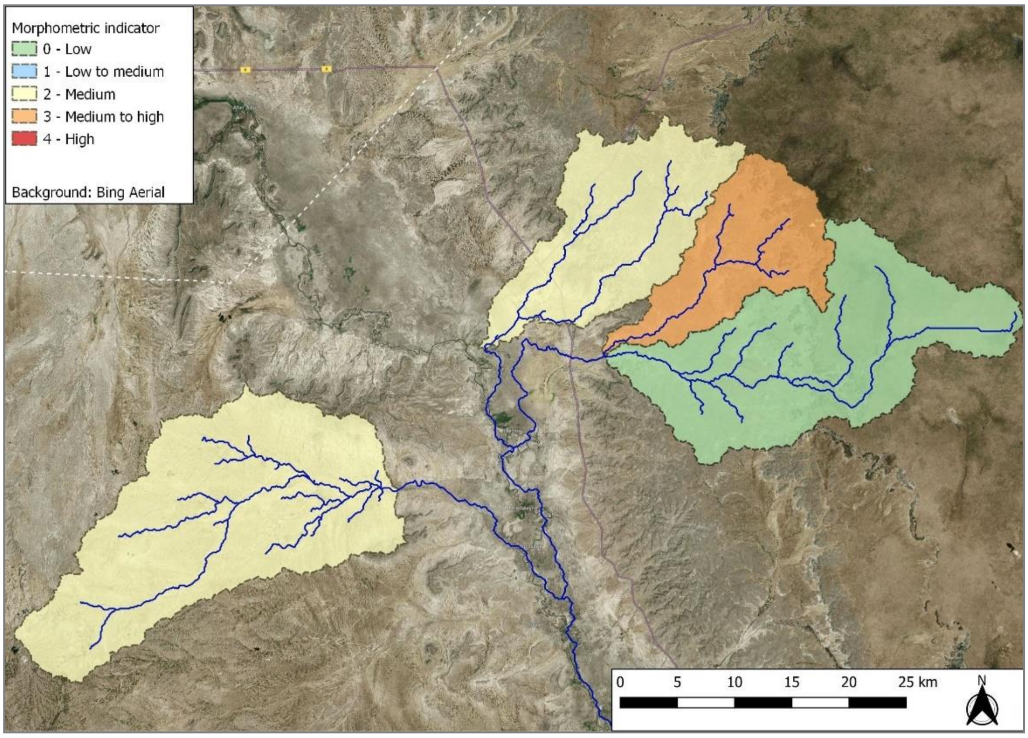

Figure 3.7 Results of the morphometric approach on some basins in the Beledweyne region, flash flood hazard potential is colour coded from 0 – low to 4 – high

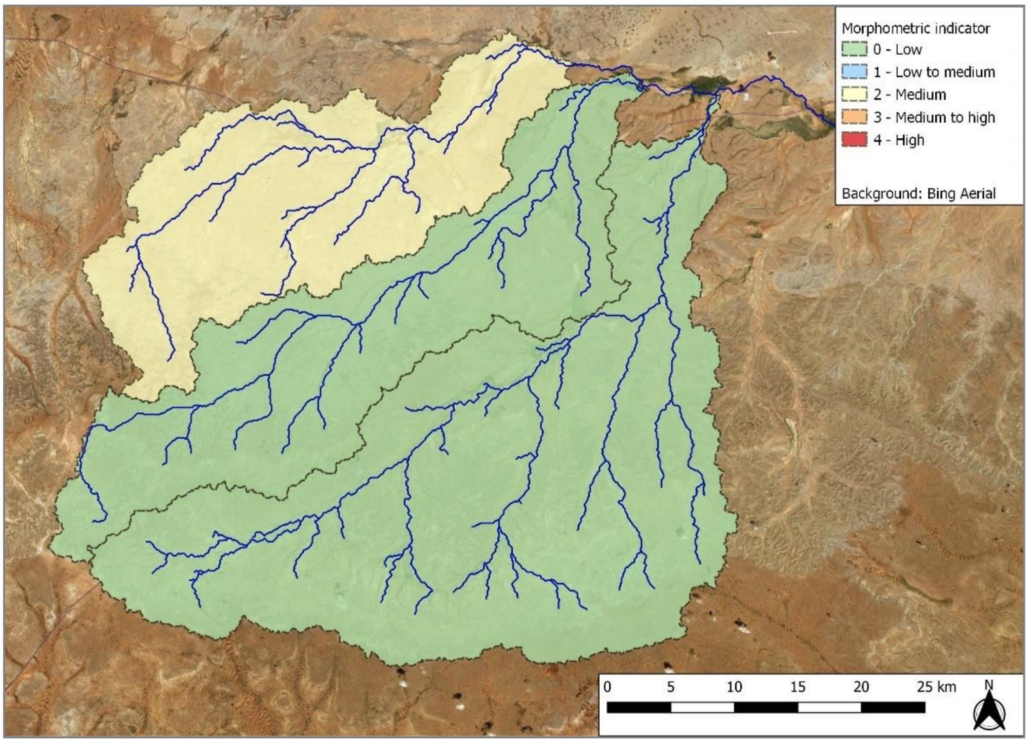

Figure 3.8 Results of the morphometric approach on some basins in the Garoowe region, flash flood hazard potential is colour coded from 0 – low to 4 – high

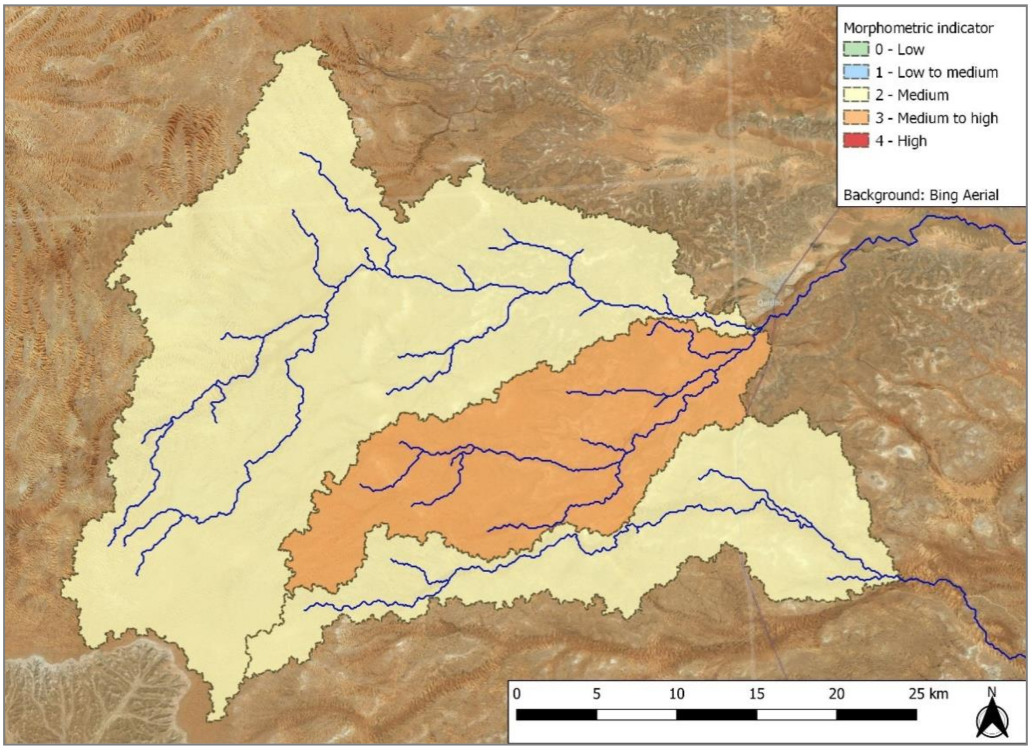

Figure 3.9 Results of the morphometric approach on some basins in the Qardho region, flash flood hazard potential is colour coded from 0 – low to 4 – high

Provided that the necessary data is gathered and analysed, the classification obtained with this approach could be upscaled to cover all of Somalia. It is recommended, however, that the initial results shown here are validated against local information on the occurrence of flash floods along the selected wadis before the method is applied to a larger extent.

3.2 Vulnerability

Vulnerability can be defined as the resilience of a community to withstand the potential impacts of a specific hazard. Vulnerability is complex and multi-faceted as it is the product of the combination of environmental, economic, social, institutional, technical and physical aspects. The quantification of vulnerability thus requires measurement and assessment into a large matrix of interacting elements within an area.

In the case of this assessment, we are assessing vulnerability to flooding in general within our study areas, the cities of Beledweyne, Jalalaqsi, Bulo Burde, Mahaday Weyne, Jowhar in Hirshabelle State; and the city of Qardho in Puntland.

Vulnerability thus requires the collection of information that enables a combined assessment of the physical, economic and social components into a single framework which can determine the vulnerability of an area to flood threats. Each element of vulnerability thus needs to be assessed independently initially and then these elements need to be combined into a specific scoring. It is therefore necessary to map out the various components associated with vulnerability. The key components to map are as follows:

- Physical vulnerability is a function of a structure or a person's ability to withstand the flood; structural elements are a key component in determining physical vulnerability (e.g., a shack construction is less likely to withstand the impact of a flood versus a solid brick or concrete construction).
- Social vulnerability is a function of many factors, but the main component is essentially poverty. Generally, the poorer the community the least socially organized it is. Recovery mechanisms are not in place (e.g. insurance), people are generally in a worse physical condition (sick or undernourished), etc. Other factors that influence social vulnerability include access to medical care and disaster response centres.
- Economic vulnerability is a function of economic exposure in specific areas. Expensive real estate, industry, and commercial buildings are more prone to economic impacts than poorer areas.

These elements combined can determine overall vulnerability to flooding of exposed communities in our study areas.

The process undertaken to determine vulnerability was carried out by applying GIS modelling and tools contained in the following steps:

1. Household mapping of communities in the study areas
2. Selection indicators to estimate social, economic and physical vulnerability, bearing in mind the constraints imposed by the lack of publicly available data
3. Calculation of the selected indicators for each household, based on a sample of surveyed households during a community field survey carried out within the study area between January and February 2022
4. Populating the Risk Assessment application of the portal with indicator layers and applying the Multi-Criteria Analysis (MCA) approach available in the Risk Assessment app for estimation of overall vulnerability.

For the calculation of the selected indicators, the outputs of a parallel project activity supported by project partner FAO, a Knowledge Attitudes Practices (KAP) study, were used. The KAP study focused on riverbank breakages along the Shabelle River, and its purpose is to understand the dynamics of the behaviour of farmers when faced with the breaking and/or failure of river embankments.

This FAO-supported activity involved the implementation of a household questionnaire to survey communities in our study area on different aspects related to riverbank breakages. A vulnerability module was added to the household questionnaire which served as a data collection effort for the flood vulnerability estimation component of the UNEP research activities. The generation of the questions for the household vulnerability questionnaire was hence a joint effort between both teams, where local experts of the subconsultant hired by FAO, Savana Consultancy and Research Services Ltd, provided crucial advice for the final selection of the questions as well as household classification into clusters.

The data from the questionnaire was used to populate indicators used in the estimation particularly of social and economic vulnerability for the sample households interviewed during the survey.

At the time of submission of this report, the Technical Implementation Note on Knowledge, Attitudes and Practices Study on Riverbank Breakages along the Shabelle River, by Savana Consultancy and Research Services Ltd (February 2022), had been published detailing the survey methodology and outputs.

3.2.1 Household Mapping

A land cover layer obtained from The European Space Agency Climate Change Initiative (ESA CCI) with a resolution of 1 km has been used as the base land cover layer. To be able to store more detailed information, it has been resampled to a resolution of a 10-metre grid for the entire Somalia. Additional classes from other sources, like OpenStreetMap (OSM, 2020), has then been used to update the 10-metre land cover map, such as: railway, airport, road, bridge, shopping complex, army, hospital, police, church, mosque, school, university and industrial. This land cover map was used as a departure point to assess the types of land classes within our six urban areas.

A polygon layer containing the buildings (30 December 2021) for these cities was sourced from OpenStreetMap through the Humanitarian Data Exchange (HDX) data portal. The building polygon layer was converted into a point layer – one point for each building. In Jowhar, additional points were added to match the latest urban development. Google Earth (2022) was used to verify the latest urban development. The total number of residential buildings was estimated to be 37,927. For the purpose of this study this was assumed to be the number of households.

The households surveyed by the KAP team correspond to a total of 1,272 sample points which were mapped using the coordinates for the household collected by the enumerators. The smaple households were selected by the Savana team who picked settlements spread out along the Shabelle River from Beledweyne to Jowhar based on different assumed clusters:

- Population density: high, medium and low
- Types of settlements: formal and informal
- Household types: migrant/displaced and traditional inhabitant
- Livelihoods: urban, agro-pastoral, pastoral, and, riverine

A household layer was created by merging the points from both sources to create a base layer for the next steps of the vulnerability estimation.

3.2.2 Selection of Indicators

Based on available data, a selection of indicators used in community flood vulnerability assessments was carried out by the research team. Table 3.2 describes a selected few for each of the three components of vulnerability. A full list of the vulnerability indicators generated is presented in Appendix A.

Table 3.2 Example of some of the physical, social and economic vulnerability indicators selected by the project team

Physical vulnerability	Social vulnerability	Economic vulnerability
Distance to hospital - The distance from hospitals determines how long an affected community can receive assistance.	**Employment status -** Determines sustainability of the household needs being met, and response to the impacts of a hazard.	**Property value –** The higher the property value, the more expensive it would be to rebuild if affected by hazard. .
Distance to police - The distance from police stations determines how long an affected community can receive assistance.	**Health access -** Determines if individuals affected by hazard can recover with the aid of the public health system	**Dwelling ownership -** Individuals who own property are likely to insure their property.
Distance to road - The distance from roads determines how long an affected community can receive assistance.	**Literacy -** Indication of which social stratum the household falls in, and determines how well information can be perceived and transmitted	**Income -** Indication of which social stratum the household falls in.
Population density - Higher population density can lead to the increased impact of a hazard, and more people would be affected	**Education -** Indication of which social stratum the household falls in and determines how well information can be perceived and transmitted.	**Credit access -** Access to credit allows households to be able to recover more easily and rapidly after suffering the impacts of a flood event.

All indicators were added as attributes to the base household point layer produced, in addition to the three clusters categorizing the KAP survey points.

3.2.3 Estimation of Indicators

The indicators were estimated based on two types of sources: publicly available databases or the data produced by the household questionnaire carried out by the KAP study team (Savana Consultancy and Research Services Ltd).

The 1,272 households' clusters and indicators were estimated in their entirety (full list in Appendix A) based on the information contained in the responses to the flood vulnerability questionnaire.

In the case of the remaining 37,927 households, clusters "Population density" and "Household types" as well as physical vulnerability indicators "Distance to road", "Distance to police" and "Distance to hospital" were estimated directly based on publicly available information as described in the following sections.

Population density, household types and livelihoods

The first step in estimating indicators for the 37,927 households was to populate the clusters "Population density" and "Household types".

To estimate population density for each point, data from Camp Coordination and Camp Management (CCCM) covering all Internally Displaced People (IDP) in Somalia were downloaded (Midnimo, 2019). The individual location of IDP camps were mapped and added as reference point to the Household data. This allowed classification of cluster “Household types” as “migrant/displaced”. All others were classified as “traditional inhabitant”.

According to the Somalia National Bureau of Statistics, the average household size is approximately 6.5 members. The average number of 6.5 was added to each household to be able to calculate the population density in the urban areas.

The added IDP camp location indicates an area where several families live. Since these areas were only represented by a single location, the estimated number of families was used as the population instead of the actual number of individuals.

Figure 3.10 shows an example for the city of Beledweyne of households mapped together with IDP sites (small green points among the household black points) to the left, and calculated population density to the right. This allowed classification of cluster “Population density”.

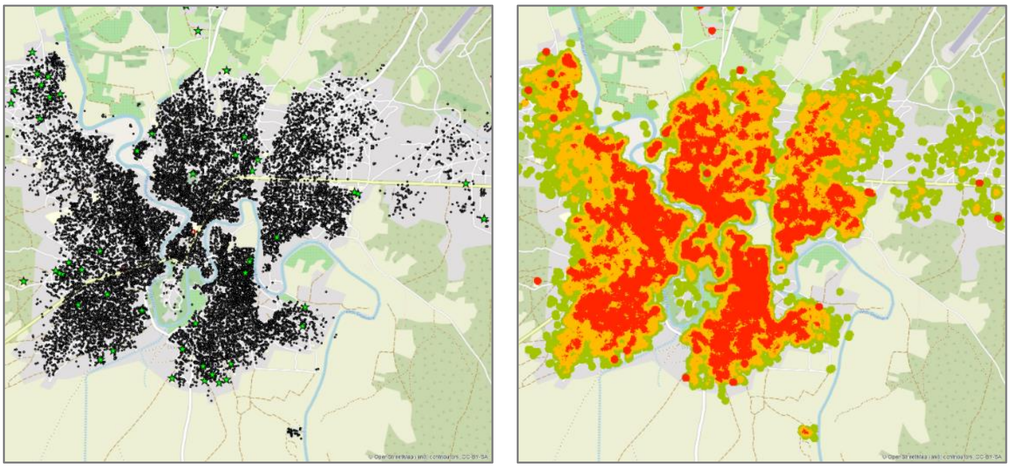

Figure 3.10 Households and IDP sites used to calculate the population density in Beledweyne

In turn, the classification for cluster “Livelihoods” was based on population density, if the latter is classified as “High” or “Medium”, then this cluster was set as “urban”.

“Distance to road”, “Distance to police” and “Distance to hospital”

Next, indicators “Distance to road”, “Distance to police” and “Distance to hospital” were estimated. For each of the six urban centres the roads were mapped, together with the known local hospitals and police stations identified, as described in section 3.2.1. Using a GIS model, these distance-focused indicators were calculated for each of the household points.

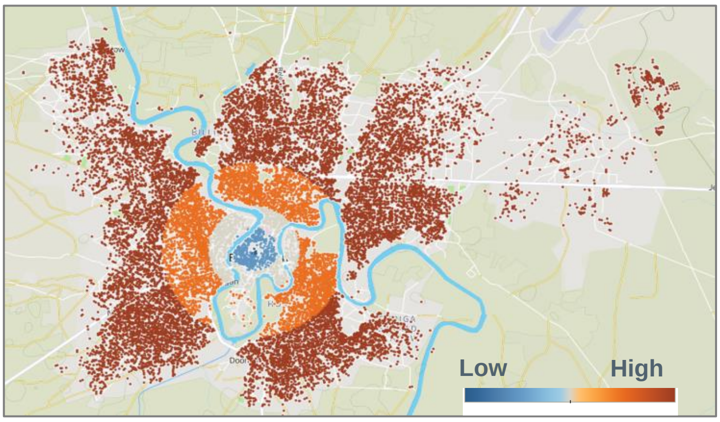

Figure 3.11 The point layer showing indicator "Distance to police station" for the Beledweyne study area where blue indicates low, and red high, distance

The estimated indicator layers have been uploaded to the Risk Assessment application of the portal and mapped, making it available to National Flood and Drought Task Force members and members of state-level task forces as well as a broader range of stakeholders.

Possible Approach for Extrapolation

Most of the assumed household points were not surveyed and hence do not have indicator values for most of the list in Appendix A. In addition, the three indicators which were possible to estimate at the appropriate level of granularity all fall within the physical vulnerability component. Not having indicators of the social and economic type curtails the estimation of total vulnerability for these households.

A possible approach for extrapolation using the KAP surveyed households as a sample, is to assume the same indicator values based on the cluster categorization. Following this proposed approach, the outstanding indicator values for the households in the study area would be assigned by extrapolation of the KAP surveyed households' indicator values based on common clusters "Population density" and "Household types". Five different combinations were used in the assignment of the indicator values, corresponding to the three "Population density" classes of "high", "medium" and "low", in conjugation with the two classes for "Household types", "migrant/displaced" and "traditional resident".

This procedure was carried out by the team and a household layer was produced, where household points have both measured and extrapolated indicator values, see examples in Figure 3.12.

Validation and Quality Assurance Required

The proposed extrapolation approach would greatly benefit from amassing information regarding the third cluster "Types of settlements", according to which households are categorized into "formal" and "informal". Though it would have been possible to infer, it was decided, due to lack of geographically distributed data on the legal status of buildings at the level of resolution required, to leave this cluster as non-available (N/A) for the non-surveyed households. If this data is made available, the extrapolation could now be supported on combining all classes pertaining to all three clusters which would have resulted in 12 conditional relations between sampled points and the population. Three examples are presented in Figure 3.12.

The extrapolation was carried out to illustrate the remaining application of the vulnerability estimation methodology, but it requires validation. Through further data collection at the local level, the National Flood and Drought Task Force would be able to interrogate the vulnerability classification of each city and quality assure extrapolated values. **It is emphasized that the indicator-extrapolated values cannot be used for any purpose without this required validation procedure.**

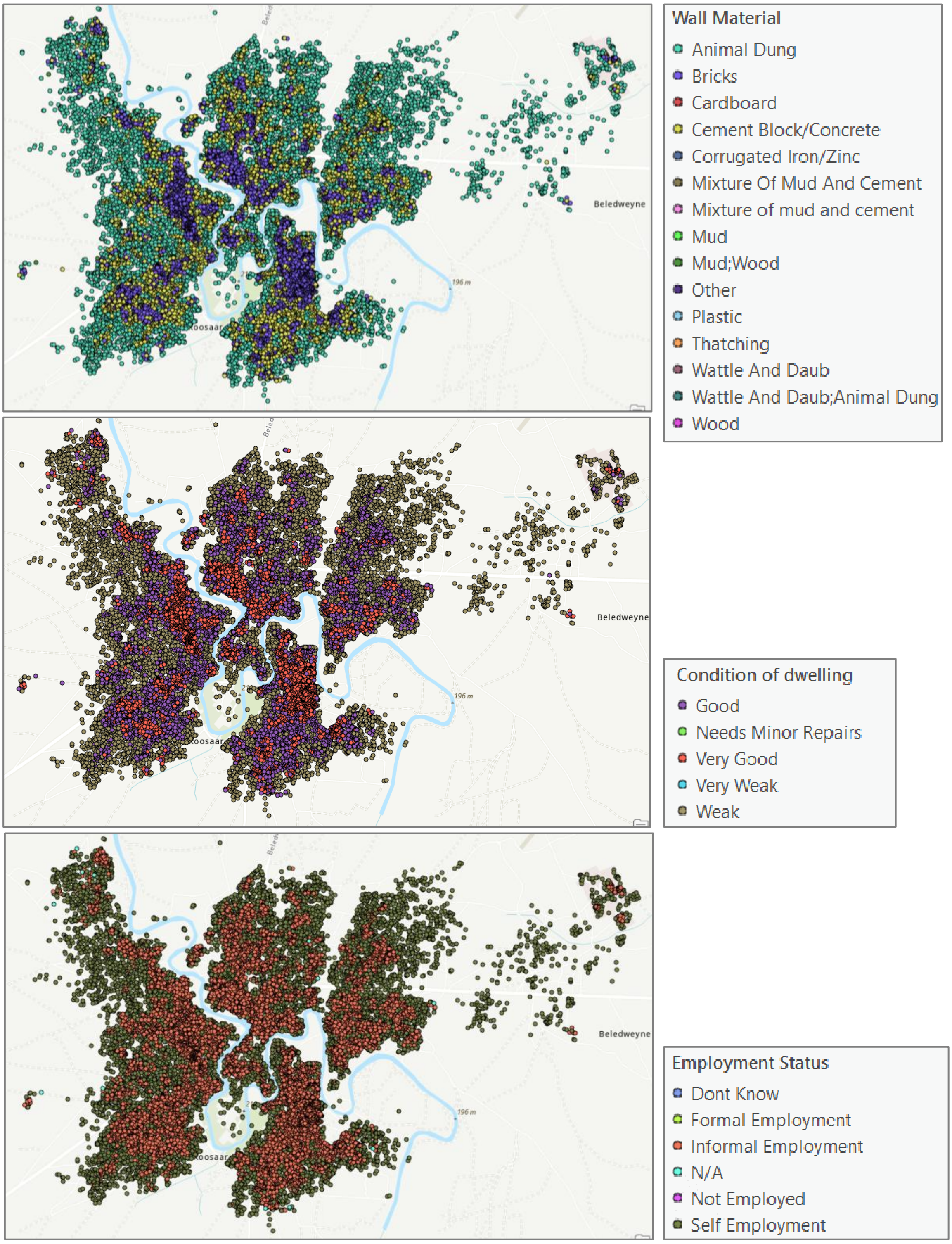

Figure 3.12 Indicators "Condition of dwelling", "Wall material" and "Employment status" for the town of Beledweyne, containing values that have been extrapolated from the KAP survey sample households

3.2.4 Multi-Criteria Analysis

Having measured and extrapolated indicator values for all households, it is possible to estimate total vulnerability to flooding in the study areas. Prior to estimating total vulnerability, it is first necessary to calculate the physical, social and economic components. Multi-Criteria Analysis was the selected approach for this purpose.

Following this approach, indicators for each of the three components is assigned a weight reflecting its relative importance (or influence) in the estimation. This procedure is repeated to arrive at a total vulnerability, where in turn a weight is assigned to the three components themselves. To this end, a tool is available within the Risk Assessment application via the “Assessment” button, see Figure 3.13.

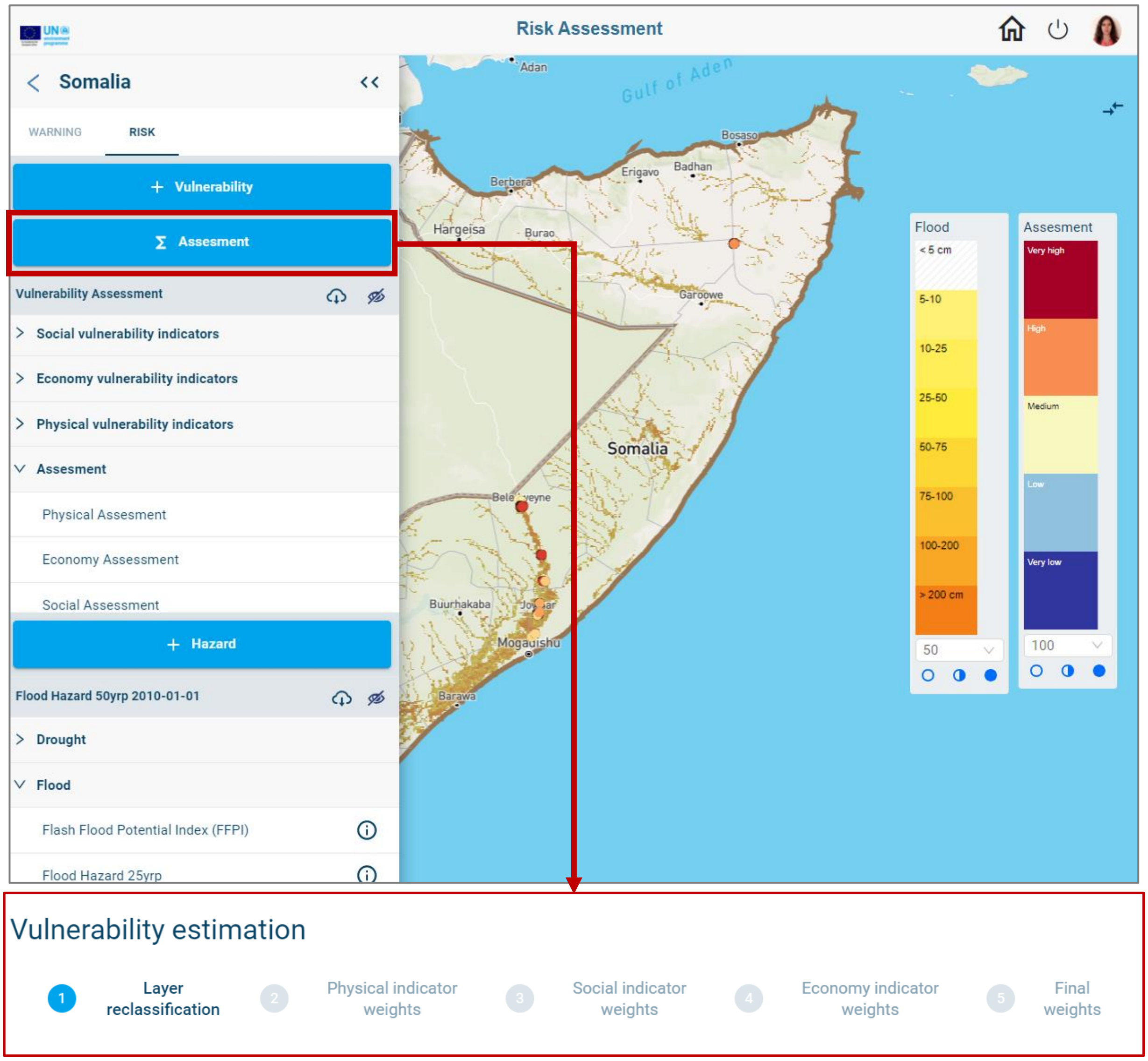

Figure 3.13 Snapshot of the Risk Assessment app showing the vulnerability estimation workflow based on an MCA approach

By using this tool, it is possible to start a simple and user-friendly workflow that allows the estimation of physical, social, economic and total vulnerability using an MCA methodology on user-selected indicators. The workflow contains the following five steps:

1. Layer reclassification
2. Physical indicator weights
3. Social indicator weights
4. Economic indicator weights
5. Final weights

As mentioned, physical, social and economic components of vulnerability are a product of the combination of their respective indicators, these being of different types (numerical, qualitative) and of varying scale ranges. As step 1 of the workflow, the user selects which of the available indicators are to be included in the vulnerability assessment and sets a common numerical scale – for e.g., 1 “low vulnerability” to 5 “high vulnerability” – for each indicator. The tool reclassifies all indicators to the selected common scale.

Table 3.3 showcases an example of such a classification exercise with the purpose of illustrating the methodology and approach. However, this classification must be carried out by the stakeholders using their expert knowledge and, when needed, further data and supporting studies. This will be especially important for non-numerical indicators that are not susceptible to a direct classification using statistical methods such as quantiles, for example. Appendix B presents some of the reclassifications proposed by the team.

Table 3.3 Physical vulnerability indicators classification

Indicator Name	Original Classification	New Classification
Disability	1 = Yes 2 = No	1 5
Emergency safe place	1 = Yes 2 = No	1 5
Emergency transport	1 = On foot 2 = Public transport 3 = Own transport	5 3 1
Condition of dwelling	1 = Very weak (appear neglected, at very high risk of collapsing) 2 = Weak 3 = Needs minor repairs 4 = Good 5 = Very good (appear regularly maintained, no risk of collapsing whatsoever)	5 4 3 2 1
Distance to hospital	0 – 50 metre 50 – 250 metre 250 – 500 metre 500 – 1000 metre >1000 metre	1 2 3 4 5
Distance to police	0 – 50 metre 50 – 250 metre 250 – 500 metre 500 – 1000 metre >1000 metre	1 2 3 4 5
Distance to road	0 – 50 metre 50 – 250 metre 250 – 500 metre	1 2 3

Indicator Name	Original Classification	New Classification
	500 – 1000 metre	4
	>1000 metre	5

From steps 2 to 4, the user/stakeholder assigns weights to each indicator reflecting their importance to the estimation of physical, economic and social components of vulnerability. In these steps, the tool applies a weighted overlay procedure consisting of overlaying the different indicators and affecting these with their respective weights. The weights assigned must add up in all cases to 100 per cent and are multiplied by the value of each indicator for each household point, which are subsequently summed up.

To illustrate the application of the approach, Figure 3.14 shows the workflow as applied to the calculation of social vulnerability using three indicators: employment status, flood experience and number of floods. This serves as an example and is not meant to indicate that only those three specific indicators are the ones that need to be used when estimating social vulnerability.

In step 5, the final step of the workflow, the same approach is repeated, and weights must be attributed to the physical, social and economic vulnerability components as illustrated in Figure 3.14, where the user placed higher importance on the social component at 50 per cent.

Once the workflow is complete, the left hand-side panel of the Risk Assessment app is populated with the results of each step of the assessment.

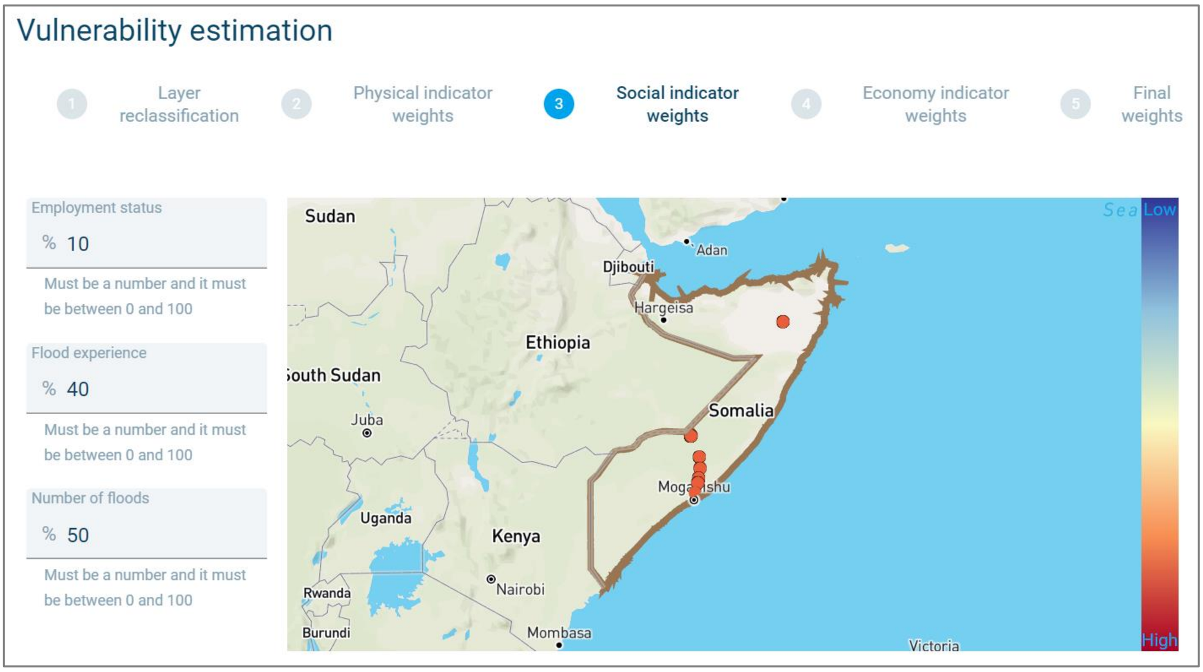

Figure 3.14 Snapshot of the vulnerability assessment workflow at step 3 to illustrate the method, as applied to the calculation of the social component of vulnerability

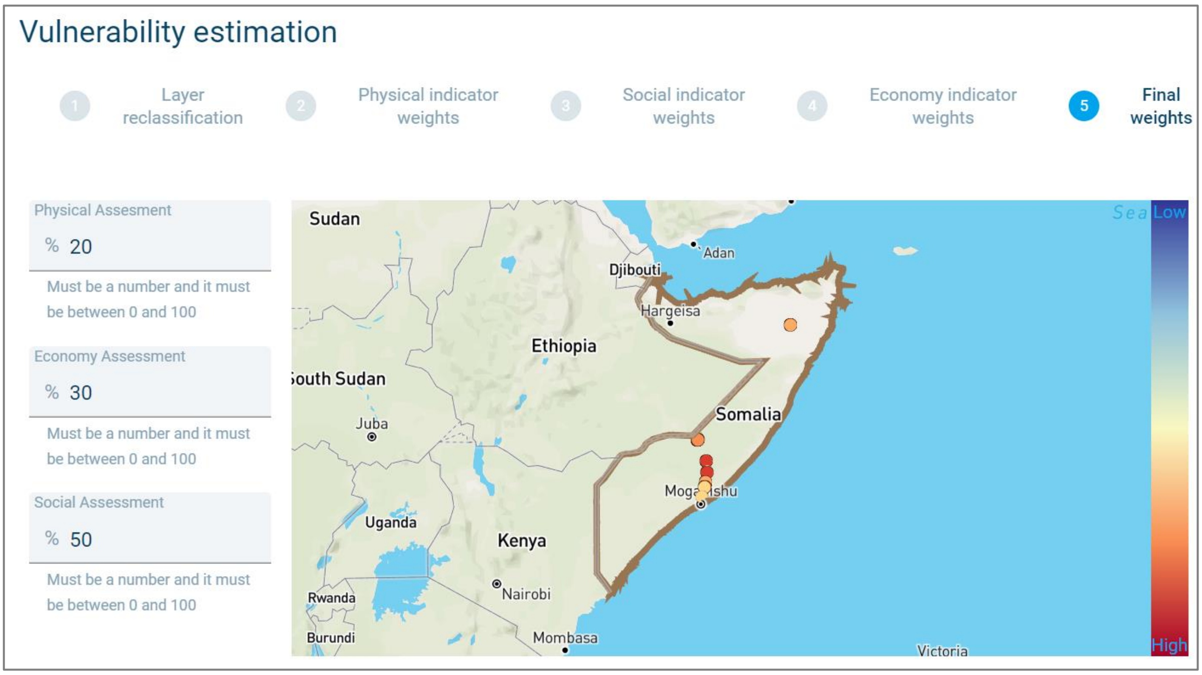

Figure 3.15 Step 5 of the workflow, illustrating the calculation of total vulnerability as a combination of the three components (percentages are examples only)

3.3 Exposure

Exposure is a consequence of the intersection between human activities from an agricultural, commercial, industrial or domestic perspective and flood hazard threat. Most communities in many areas around the globe tend to congregate around water resources such as rivers where the water is used to support various activities. While there are obvious benefits associated with these development patterns, they often place communities at risk of being impacted by floods.

The Risk Assessment application has a number of available base maps as well as satellite imagery. By overlaying hazard potential indicators, such as those mentioned in section 3.1, onto the map it is possible to assess exposure.

3.4 Risk Assessment

The Risk Assessment application allows the user to overlay the hazard potential indicators explored in this study, namely HAND, FFPI, GPM 30 min Early and other existing publicly available data for river flood hazard for the Shabelle River, with the vulnerability indicators of exposed areas, thus allowing the user to locate and identify areas at higher risk, as illustrated in Figure 3.16.

A tool for classification of vulnerability indicators and calculation of total vulnerability following the methodology described in section 3.2.4 of this report is available via the “Assessment” workflow on the left hand-side panel.[8]

All data produced by this research study is available for inspection and/or downloading by National Flood and Drought Task Force members and state-level task force members, as are the

[8] A detailed user guide is included in the “Documents” application of the www.jubashabelle-tmo.org portal.

tools for implementing the methodologies and approaches described in this report for assessing risk in cities within the study areas.

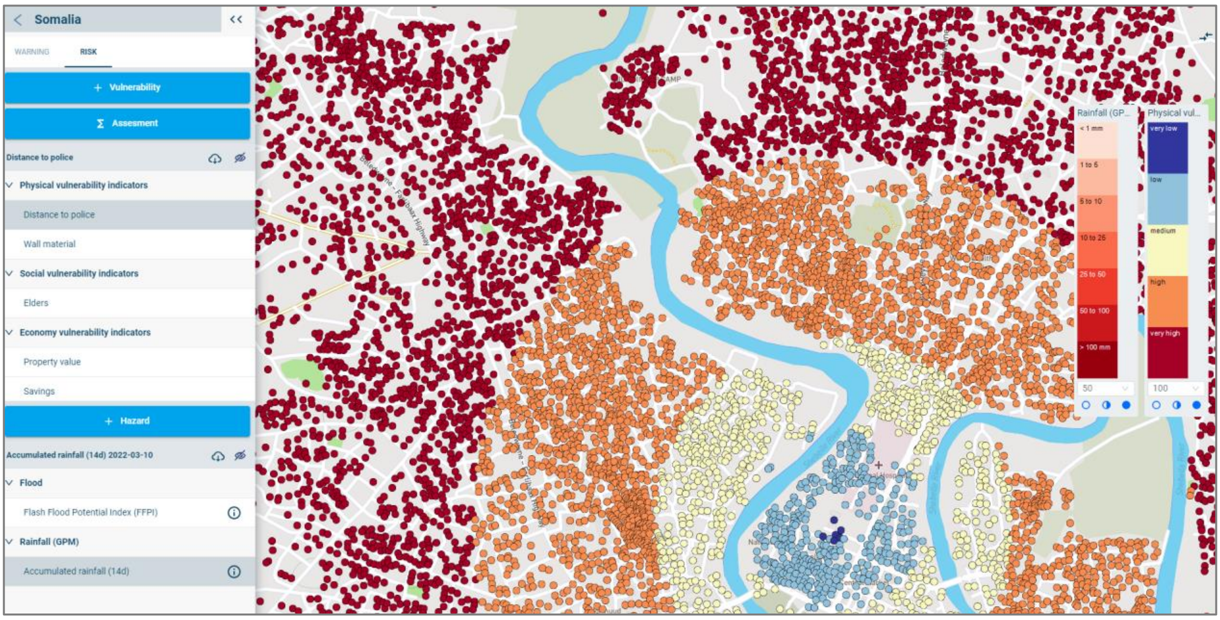

Figure 3.16 Screenshot of the Risk Assessment application of the portal overlaying a vulnerability indicator and a hazard indicator

The aim was to provide the National Task Force members with data, information and tools to carry out a flash flood risk assessment. For this purpose, flash flood hazard potential approaches were investigated, and vulnerability indicators calculated for the areas of study based on a surveyed household sample. The workflow in the Risk Assessment application available at www.jubashabelle-tmo.org allows determining exposure and identifying areas at higher risk.

Spatially distributed riverine flood hazard data, that is public freely available, such as river flood hazard maps by the Global Assessment Report [9]on Disaster Risk Reduction (GAR) by UNEP and UNISDR were obtained for Somalia and uploaded so that it is available from within the app.

Having this additional hazard data means that the risk assessment workflow demonstrated in this project, may also be used to assess riverine floods as the vulnerability indicators remain applicable, thus affording the task force also the capability of conducting risk assessment focused on riverine floods within the study areas.

[9] The GAR 15 global flood hazard assessment uses a probabilistic approach for modelling riverine floods for major river basins around the globe. For access to the source visit: https://preview.grid.unep.ch/index.php?preview=data&events=floods&evcat=1&lang=eng

4 Recommendations

Assessing flash flood hazard potential

Static and/or dynamic assessments of flood risk across Somalia can provide an improved basis for planning emergency actions and flood mitigation measures. Different methodologies to assess and map the risk of flash flooding have been outlined here, i.e. the Flash Flood Potential Index (FFPI), the Height Above Nearest Drainage point (HAND) and the Morphometric approach. Information was not available to fully assess the applicability and relevance of these methods for Somalia. However, these datasets are available within the Risk Assessment application. It is recommended that further detailed information on the occurrence and severity of flash flood events in the country is collected and compared with these indices to assess their applicability and the potential for practical application of the most promising method(s).

Real-time monitoring

Flash flood forecasting is, as mentioned, quite difficult to implement in a way that ensures sufficient lead time to save lives and property at flood-prone locations. It is, nevertheless, recommended that the potential for this is assessed.

This would require:

- Identification and ranking of vulnerable sites where flash floods occur and potential losses are high
- Assessment of the lead-time from heavy rainfall to flooding at these locations. This will require detailed information on the timing of the rainfall, e.g., using GPM-Early data, and the timing of the flood, collected at the site. As measurements of river water levels are rarely available, this would typically be based on interviews with the local population.
- Assessment of the applicability of available sources of real-time rainfall data to enable early warning. If none of these are suitable, the potential for possible future sources, such as weather radars or automatically-reporting rain gauges in the catchment area, should be assessed.
- Finally, the path towards an operational early warning system for (some of) the identified vulnerable locations should be outlined, with a description of the required activities and investments.

Validation of vulnerability indicator values

In this report an approach is proposed and demonstrated to extrapolate the indicator values that were deemed possible to be estimated based on the field survey carried out during the KAP study.

The approach assumes that the cluster categories a household falls within can be used as a basis to set the indicator values for those households to an equal expected value, based on the KAP study measured sample.

This approach was not validated in this project, and hence it is recommended that future data collection efforts – either by resorting to data repositories of local institutions or through field campaigns – are carried out to conclude whether the proposed approach performs to an acceptable level.

A dataset was created for households with existing raw data for each vulnerability indicator and made available via the Risk Assessment application of the portal. The extrapolated dataset has not been made available online to avoid misuse but has been delivered to MOEWR for further investigation.

Capacity-building programme

The findings of the flash flood research described in this report were presented to National Flood and Drought Task Force members, including members from Hirshabelle, Jubaland and South West states at a two-day workshop in Mogadishu on 2–3 March 2022, chaired by the Ministry of Energy and Water Resources. During the workshop participants acknowledged the need for a large-scale capacity-building programme. This is seen as a crucial next step for the sustainable application of the project's outcomes, and a means of effectively supporting the National Flood and Drought Task Force.

The workshop provided an opportunity for a broad screening of the different levels of capacity. This provides a good starting point for next steps in the collaboration between MOEWR and UNEP aimed at strengthening the capacity of the federal and state-level authorities as coordination platforms and for monitoring and reporting on flood and drought response, including humanitarian support resources.

It is recommended that a broader scale capacity assessment is carried out, and a capacity-building programme designed and implemented as post-project support.

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APPENDIX A

List of Available Vulnerability Indicators

The table presented in this Appendix consist of indicators estimated by the project team. These are available in the Risk Assessment application for inspection, assessment and download by stakeholders.

Type	Name	Description	Classes
Economic	Credit access	Access to credit allows households to be able to recover more easily and rapidly after suffering the impacts of a flood event.	Yes No
Economic	Credit source	The source of the household for credit/loan	Informal group Registered self-help group VSLA Farmer group Friends and relatives Money vendors Shops/ shop keepers Other
Economic	Dwelling ownership	Individuals who own property are likely to insure their property.	Own house/land Rented Occupied rent-free owned by relatives Sharing with parents and relatives Others
Economic	Flood damage	When the household experienced floods, what damages did the flood cause on humans and property.	None Destroyed crops, livestock, and livelihood equipment Destroyed houses Displaced people to other locations Killed people Destroyed land terrain (structure) for farming Disrupted local transport systems Physical impact of public facilities Loss of income NA
Economic	Income	Indication of which social stratum the household falls in.	0 – 25 25 – 50 50 – 100 100 – 200 > 200
Economic	Property value	Higher the property value, it would be more expensive to rebuild if affected by hazard.	0 – 250 250 – 750 750 – 1250 1250 – 2000 > 2000
Social	Bathing access	The source of water for the following hygienic practice: bathing.	Piped (Tap) Water In Dwelling Piped (Tap) Water On Site Or In Yard Well/Borehole On Site Protected Well/Borehole On Site Unprotected

Type	Name	Description	Classes
			Rain-Water Tank On Site Neighbour's Tap Public/Communal Tap Water-Carrier/Tanker Well/Borehole Off Site Communal Protected Well/Borehole Off Site Communal Unprotected Flowing Water/Stream/River Stagnant Water/Dam/Pool Spring Other
Social	Disability	Indicate if special needs are required	Yes No
Social	Domestic water source	The main source of water for domestic use for the household.	Piped (tap) water in dwelling Piped (tap) water on site or in yard Well/borehole on site protected Well/borehole on site unprotected Rain-water tank on site Neighbour's tap Public/communal tap Water-carrier/tanker Well/borehole off site communal protected Well/borehole off site communal unprotected Flowing water/stream/river Stagnant water/dam/pool Spring Other
Social	Early warning	Provides indication of whether there is knowledge in the household on how to behave in case of early warning.	Yes No
Social	Education	Indication of which social stratum the household falls in and determines how well information can be perceived and transmitted.	No Formal Schooling Quranic Primary Secondary Tertiary
Social	Emergency plans	Provides indication of whether there is knowledge in the household on how to behave in case of emergency.	Yes, and I know it. Yes, but it is outdated Yes, but I do not know it/its contents. No, none that I am aware off. I do not know.
Social	Emergency safe place	Determines how informed the communities are regarding how to behave in case of emergency.	Yes No
Social	Employment status	Determines sustainability of the household needs being	Formal Employment Informal Employment/casual on wages

Type	Name	Description	Classes
		met, and response to the impacts of a hazard.	Self-employment/Business Not Employed Don't know N/A
Social	Energy source	The main source of energy/fuel for the household.	Electricity from Mains Electricity from Generator Gas Paraffin Wood Coal Candles Animal Dung Solar Energy Other
Social	Flood experience	Has any member of the household ever been affected a flood event	Yes No
Social	Flood mitigation	What the community is doing to mitigate against the identified promoters of flooding	Construction of water flow trenches Repairing and maintaining river embankment Reforestation programs Monitoring and Reduction of sand mining Urban planning and control of settlements Trainings and awareness creation on causes and effects of flood Nothing is being done Others
Social	Handwash access	The source of water for the following hygienic practice: hand washing	Piped (Tap) Water In Dwelling Piped (Tap) Water On Site Or In Yard Well/Borehole On Site Protected Well/Borehole On Site Unprotected Rain-Water Tank On Site Neighbour's Tap Public/Communal Tap Water-Carrier/Tanker Well/Borehole Off Site Communal Protected Well/Borehole Off Site Communal Unprotected Flowing Water/Stream/River Stagnant Water/Dam/Pool Spring Other
Social	Health access	Determines if individuals affected by hazard can recover with the aid of the public health system.	Public Hospital Public Clinic Public Health Center Public Other Private Hospital

Type	Name	Description	Classes
			Private Clinic Private Health Center Private Private Doctor/Specialist Private Traditional Healer Private Pharmacy/Chemist Private Health Facility Provided By Employer Private Other Don't Know
Social	Literacy	Indication of which social stratum the household falls in, and determines how well information can be perceived and transmitted	Yes No
Social	Number of floods	How many flooding episodes has the respondent experienced during the time they have stayed at this location.	0 1-2 3-5 6-10 more than 10
Social	Schooling impact	Indication of which social stratum the household falls in.	Sickness Work Household Work Floods Hunger or Lack of Food Taking Care of Siblings Long Distance to School School Fees arrears Insecurity Refused to go Other
Physical	Condition of dwelling	Different materials represent a different degree of resistance to side effects of flood hazards.	Very weak (appear neglected, at very high risk of collapsing) Weak Needs minor repairs Good Very good (appear regularly maintained, no risk of collapsing whatsoever)
Physical	Embankment breaching	What is being done in the respondent's community to curb embankment breaching.	Flood-prone areas awareness creation Flood maps awareness/information sharing from experts Early Warning Signals and Awareness Awareness creation on river management and negative human activities Conserving vegetation in upland areas e.g. by planting trees Avoiding over stocking of livestock Resettlement of communities to

Type	Name	Description	Classes
			higher grounds Maintenance and repair of riverbanks Crack down on culprits Capacity building on bank repair and or maintenance Development of a risk reduction plan Other, please specify: Don't know
Physical	Embankment repair	Embankment breakages are monitored and repaired regularly	Strongly Disagree Disagree Neutral Agree Strongly Agree
Physical	Embankment stabilization	Embankment stabilization is done in the respondent's community every season and throughout the full flooding season	Strongly Disagree Disagree Neutral Agree Strongly Agree
Physical	Emergency transport	Determines how informed the communities are regarding how to behave in case of emergency.	On foot Public transport Own transport
Physical	Distance to hospital	The distance from hospitals determines how long an affected community can receive assistance.	0 – 50 meter 50 – 250 meter 250 – 500 meter 500 – 1000 meter >1000 meter
Physical	Distance to police	The distance from police stations determines how long an affected community can receive assistance.	0 – 50 meter 50 – 250 meter 250 – 500 meter 500 – 1000 meter >1000 meter
Physical	Distance to road	The distance from roads determines how long an affected community can receive assistance.	0 – 50 meter 50 – 250 meter 250 – 500 meter 500 – 1000 meter >1000 meter
Physical	Population density	Higher population density can lead to increase in the impact of a hazard, apart from the fact that more people would be affected	0 – 0.01 people/m^2 – 0.015 people/m^2 0.015 – 0.1 people/m^2
Physical	Roof material	The main material used for the roof of the main dwelling.	Asbestos Corrugated Iron/Zinc Wood Plastic Cardboard Tile Mud

Type	Name	Description	Classes
			Grass Thatching Other
Physical	Trend breakages	Looking at the last 12 months, can the respondent say embankment breakages have increased, decreased, or remained the same.	Increased Decreased Remained the same Don’t know
Physical	Wall material	The main material used for the walls of the main dwelling.	Mud Bricks Cement block/concrete Corrugated iron/zinc Wood Plastic Cardboard Mixture of mud and cement Wattle and daub Tile Thatching Asbestos Animal dung Other

APPENDIX B

Example of Reclassification of Selected Indicators

The table that follows describe the indicators' original scales and a reclassification into a vulnerability scale where 1 correspond to low and 5 to high vulnerability.

PHYSICAL		
Indicator Name	Original Classification	New Classification
Disability	1 = Yes 2 = No	1 5
Emergency safe place	1 = Yes 2 = No	1 5
Emergency transport	1 = On foot 2 = Public transport 3 = Own transport	5 3 1
Condition of dwelling	1 = Very weak (appear neglected, at very high risk of collapsing) 2 = Weak 3 = Needs minor repairs 4 = Good 5 = Very good (appear regularly maintained, no risk of collapsing whatsoever)	5 4 3 2 1
Distance to hospital	0 – 50 meter 50 – 250 meter 250 – 500 meter 500 – 1000 meter >1000 meter	1 2 3 4 5
Distance to police	0 – 50 meter 50 – 250 meter 250 – 500 meter 500 – 1000 meter >1000 meter	1 2 3 4 5
Distance to road	0 – 50 meter 50 – 250 meter 250 – 500 meter 500 – 1000 meter >1000 meter	1 2 3 4 5
SOCIAL		
Literacy	1 = Yes 2 = No	1 5
Education	1 = No Formal Schooling 2 = Quranic 3 = Primary 4 = Secondary 5 = Tertiary	5 4 3 2 1
Employment status	1 = Formal Employment 2 = Informal Employment/casual on wages 3 = Self-employment/Business 4 = Not Employed 5 = Don't know 999 = NA	1 3 1 5 3 5
Schooling impact	1 = Sickness 2 = Work 3 = Household Work 4 = Floods 5 = Hunger or Lack of Food	1 1 1 5 1

PHYSICAL		
Indicator Name	Original Classification	New Classification
	6 = Taking Care of Siblings 7 = Long Distance to School 8 = School Fees arrears 9 = Insecurity 10 = Refused to go 11 = Other (Specify)	1 1 1 1 1
Health access	Public sector (i.e. government, provincial or community institution) 1 = Hospital 2 = Clinic 3 = Health Center 4 = Other In Public Sector, Specify ______________ Private Sector 5 = Hospital 6 = Clinic 7 = Health Center 8 = Private Doctor/Specialist 9 = Traditional Healer 10 = Pharmacy/Chemist 11 = Health Facility Provided By Employer 12 = Other In Private Sector 13 = Don't Know	 1 1 1 1 1 1 1 1 1 1 1 1 5
Emergency plans	1 = Yes, and I know it. 2 = Yes, but it is outdated 3 = Yes, but I do not know it/its contents. 4 = No, none that I am aware off. 5 = I do not know.	1 1 3 5 5
Early warning	1 = Yes 2 = No	1 5
ECONOMIC		
Income	0 – 25 25 – 50 50 – 100 100 – 200 > 200	5 4 3 2 1
Credit access	1 = Yes 2 = No	1 5
Property value	0 – 250 250 – 750 750 – 1250 1250 – 2000 > 2000	1 2 3 4 5
Condition of dwelling	1 = Very weak (appear neglected, at very high risk of collapsing) 2 = Weak 3 = Needs minor repairs 4 = Good 5 = Very good (appear regularly maintained, no risk of collapsing whatsoever)	5 4 3 2 1
Dwelling ownership	1 = own house/land 2 = rented	1 2

PHYSICAL		
Indicator Name	Original Classification	New Classification
	3 = occupied rent-free owned by relatives 4 = sharing with parents and relatives 5 = others, please specify	3 4 5