Ministry of Energy and Water Resources

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Comprehensive Assessment for Flood Mitigation in Jowhar Riverine Areas

January 2022

Contents

List of Figures

List of Tables

List of Abbreviations

CDI	Combined Drought Index
CORDEX	Coordinated Regional Downscaling Experiment
DRM	Disaster Risk Management
ENSO	The El Niño Southern Oscillation
EWS	Early Warning Systems
FAO	Food and Agricultural Organization
FEWS NET	Famine Early Warning System Network
FRRMIS	Flood Risk and Response Management Information System
FSNAU	Food Security and Nutrition Analysis Unit
JOSR	Jowhar off Stream Storage Reservoir
GIS	Geographic Information System
ICPAC	IGAD Climate Prediction and Applications Centre
IGAD	Intergovernmental Authority on Development
MoEWR	Ministry of Energy and Water Resources
NDVI	Normalized Difference Vegetation Index
NGO	Nongovernmental Organization
SWALIM	Somalia Water and Land Information Management
UN	United Nations
UNDP	United Nations Development Program
UNOCHA	United Nations Office for the Coordination of Humanitarian Affairs
USGS	United States Geological Survey
WMO	World Meteorological Organization

Executive Summary

Severe flooding occurs frequently in Jowhar area along Shabelle River Basin. This flooding is causing catastrophic loss of human lives, damage and economic loss. Effective flood management requires a broad and practical approach. Although flood disasters cannot completely be prevented, major part of potential loss of lives and damages can be reduced by comprehensive mitigation measures. The river flood and retention have been analyzed by using integrated hydrologic and hydraulic modeling. Every flow has been simulated by a process-based 1D/2D hydrological model (HEC-RAS) coupled with the GIS analysis. Model simulation results under the design rainfall event, i.e. flood depth, flood extent, and risk/damages for the situation with and without flood mitigation measures have been compared and evaluated to determine an optimal set of mitigation measures. The results reveal that a combination of full rehabilitation of both the JOSP and upstream DFRC schemes and rehabilitation of Kalunde, 21 Oct, Labaa, Abdi Isse, Ahmed Isse, Akhwaan and Qarfaxyaale canals as well as rehabilitation of breaches and breakage points on the river embankment might reduce the occurrence of major out of bank flooding by approximately 34% and 41% for the economic damage so that it is no longer an annually expected event in the lower reaches of the River Shabelle. With some river bank raising and strengthening, and dredging of the river channel might expect up to a 1 in 5 year standard of protection. The results of this study will be useful for improving the present flood defense practice in Jowhar area.

1. Introduction

1.1 Background and Rationale

Somalia has frequently been affected by Floods, droughts, and famines due to highly variable rainfall, infrastructural breakdowns and the collapse of the national administration as a consequence of civil war. Floods and water-related humanitarian crises have always been great concerns. Climate change projections for Somalia indicate changes in both temperature and precipitation regimes in the future (WB, 2021). These changes in temperature and precipitation regimes will, in turn, impact the magnitude and, in some cases, the seasonality of peak runoff and floods throughout the country.

The Juba and Shabelle Rivers are the only perennial trans-boundary streams in Somalia and constitute the basis for the country's most productive agricultural zone originating from the Ethiopian highlands where the main streams and their tributaries are deeply incised into the steep slopes of the upper reaches while the Juba River possesses an additional seasonal tributary from the Kenyan catchment Lag Dera (Artan et al. 2007, Basnyat 2007). However, in Somalia, in the middle and lower reaches, there is a virtual absence of tributaries and other drainage channels; there are some spring-fed streams and some local runoff, but these contribute to river flow only in times of heavy rainfall. It is estimated that more than 90 percent of the runoff for the Juba and Shabelle Rivers is generated in Ethiopia (Kammer 1989, Artan et al. 2007, Basnyat 2007, Mutua and Balint 2009).

The Juba and Shabelle Rivers are the main elements of the water resource base in south Somalia and assessing their water availability in time constitutes a fundamental piece of research for planning purposes in the basins. Both the two rivers constitute the basis for the country's most productive agricultural zone in Somalia. Despite Somalia's vulnerable downstream position, there are neither bilateral treaties (Salman, 2011) nor any national or subnational arrangements for a strategic or integrated use of the Juba and Shabelle Rivers on the Somali side.

The Shabelle River, with its very special nature, fed by rains on Ethiopian highlands, forced its people all through the years to face great challenges to survive in spite of the periods of abundant floods. The threat of natural flooding arises whenever there is heavy and continuous rainfall in a basin. While artificial flooding of agricultural land is largely due to illegal manmade openings on the dikes and high natural embankments to create an outlet for irrigation water in the dry season. This flooding is causing catastrophic loss of human lives, infrastructure damage and economic loss. The downstream segments of Shabelle River Basin are marked by an inverse topography, with water courses at some locations on higher elevation than the adjacent land; as a result, the lower parts of the riverine floodplains are highly susceptible to flooding (an attribute widely used in gravity-fed irrigation and deshek farming).

Somalia has been under civil unrest since the mid-1980s, with the unrest degenerating to civil war in 1991. The conflict has caused destabilization and instability throughout the country, with a series of clashes between the various militant factions and loss of central government control. The destruction of social and economic infrastructure, asset stripping, ethnic cleansing and the disruption of food supplies have, sometimes, been compounded by drought, causing famine and additional deaths. After the outbreak of war, agricultural production fell by about 50%, largely due to a reduction in cultivated area, and the abandonment of irrigation schemes and collapse of irrigation infrastructure (Mbara et al. 2007). Problems were compounded by damage to the remaining schemes caused by severe flooding associated with the 1997/98 El Niño event, hence resulting in increased unemployment, frequent occurrence of floods and above all substantial decrease in crop production leading to chronic food insecurity at national and household level. These floods force thousands of people living in the lowlands to move to higher grounds. The people affected are mostly in Hiran, Middle Shabelle and Lower Shabelle regions. In recent years Somalia has seen an increase in frequency and intensity of floods, the damage from the floods has become much more severe, with 1981, 1997, 2005, 2006, 2011, 2013, 2015, 2016, 2018, 2019, 2020, 2021 causing tremendous more damage than previously.

Due to the country's economic disparity, those affected are often affected severely. With little technology to forecast the floods, and little money to build adequate housing, or provide transportation away from affected areas, the number of people affected increases dramatically. Along with the flooding, the population of Somalia suffers from food crises and diseases. Some diseases become prevalent directly from the flooding and mosquito population increases. Malaria outbreaks and virus outbreaks are direct results of the massive flooding, which have devastating effects on the human population. The communities in the flood areas are not resilient to the problems the floods bring, and this causes massive damage to human life, infrastructure and cropland, all worsening an already fragile humanitarian situation.

In 2018, 215,000 people have been displaced and over 630,000 affected by floods.[1] In 2019, over 500,000 people were displaced by the floods. In 2020, almost 1 million people were affected by the floods, with 400,000 being displaced (OCHA, 2020). Jowhar District was the worst hit region, with 40% of residents were displaced from their homes[2] with Jowhar city toping the hardest hit areas and more than 66,000 people from 27 villages were displaced, the flood destroyed over 40,000 hectares of farmland, disrupting learning in 12 schools and damaging 82% of WASH infrastructures.

Unless appropriate actions and mitigation in Jowhar Riverine areas are taken quickly, the consequences can again turn into disastrous for the country. A successful 'flood mitigation and management' requires proper comprehensive assessment in Jowhar area and understanding of the problem, long-term planning, availability of resources for taking immediate action during flood events and coordination between different public and private agencies.

1.2 Study Objectives

The overall objective of this study is to carrying out of a comprehensive study for assessing flood risks, preparing flood maps, and developing mitigation plans intended to protect the community from flooding in Jowhar riverine areas along Shabelle River.

It is important to note that this work will produce a general overview assessment of flood risk; information that could help inform future planning; analysis of risk mitigation options and improve the resilience of the communities from recurrent floods and identifying areas unsuitable for urban expansion. Further detailed site-specific analysis will be conducted when determining specific

---

[1] *Okiror, Samuel (8 May 2018). "Lethal flash floods hit east African countries already in dire need". The Guardian. Retrieved 18 May 2018.*

[2] *Jump up to: a b "UN: Floods in central Somalia hit nearly 1 million people".* AP.org. May 18, 2020.

vulnerability, risk and mitigation actions, as well as cost estimate as and when they decide to pursue further action.

Three specific objectives are identified:

- Reduce the adverse impact of floods and the likelihood in Jowhar riverine areas
- Conduct comprehensive detailed hydrological investigations using in-situ measurements coupled with remote sensing and GIS analysis and propose possible solutions or recommendations for flood mitigations activities.
- Propose an integrated flood management plan for Jowhar riverine areas that can be used for other areas in Somalia.

1.3 Study Approach and Activities

The current study:

- Identified, accessed, and reviewed relevant documents, to the degree possible within the timeframe and resources.
- Met with a wide range of stakeholders, in international and local organizations working in various projects in Somalia. This included Somali government officials.
- Collect data on irrigation and other infrastructures.
- Synthesized and critically analyzed the information obtained, and developed preliminary ideas.
- Prepared the current Final Report

1.4 Data for the Study

Data collection and review to the study consisted of reports, land and water data include streamflow data, rainfall data, storage data (primarily from SWALIM and McDonald), field data collected for the study (topographic and physical survey), and discussions with stakeholders.

The chosen method for evaluating and further develop the available surface water management methodologies was performed as a multi-loop process (Fig 1.1). which includes a computer model part, the top loop describes a classic model creation process where data about the system was gathered, simplifications were made and a computer model was created and calibrated. This model could then describe flood scenarios with precipitation data as input. The next step was to test measures by implement them into the model and run new simulations.

The analysis undertaken is substantially dependent on data avilable. It was not within the resources of the study to verify data/information received; conclusions reached are, inevitably, subject to the quality and completeness of data received. The focus of the study was mainly on the implementation and assessment of flood mitigation measures in form of surface water control and only briefly handled general flood risk management.

2. Study Area Description

2.1 Study Area

Jowhar is the capital city of HirShabelle State and also the administrative city of Middle Shabelle Region. The Shabelle River passes through the town of Jowhar, which is located 90 km north of Mogadishu and it has strategic importance because of its location. It’s connects Mogadishu to the rest of the central regions through the main road that crosses the country. Jowhar town consists of four urban villages, namely Horseed, Bulosheikh, Kulmis, and Hantiwadag. The first two villages are located on the east side of the town, and the last two are on the west side. The built-up area of Jowhar town is with different types of shelters, huts, iron sheet roofs, public buildings and IDP tents.

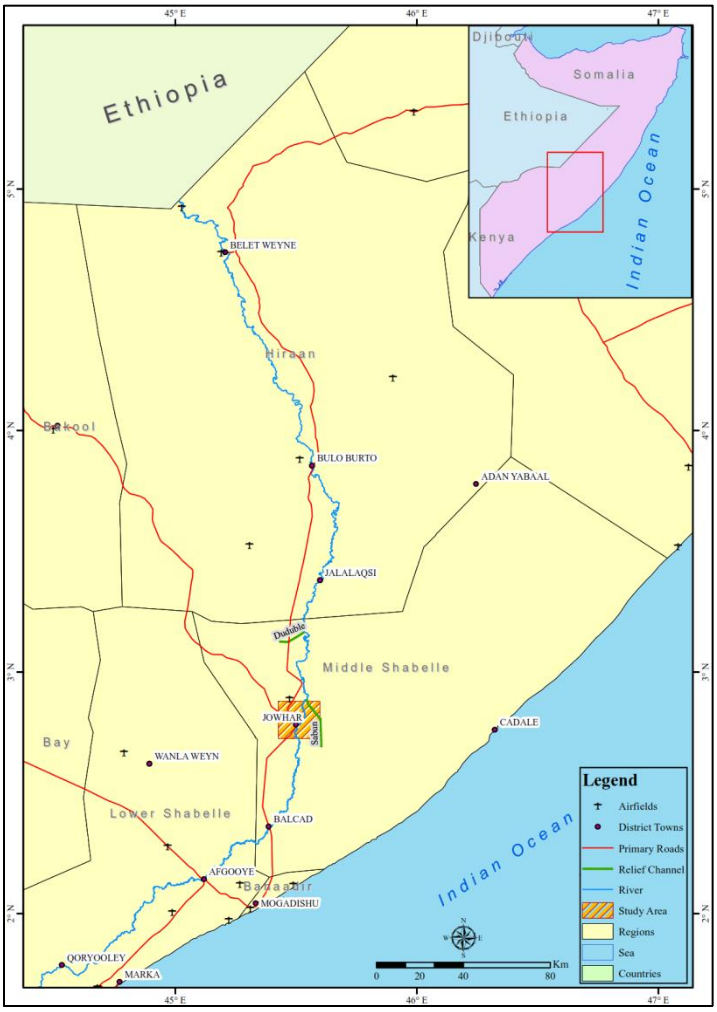


Figure 2-1 Study area and catchment

During the Italian colonialism in 19th century Jowhar was developed as an agricultural center experimenting with new cultivation techniques and dams, roads, schools, hospitals, a church and a mosque and railroad system that linked Jowhar to Mogadishu to export the products from their large-scale farms were built by the Italians. There is an airstrip in the north of the town. In 2016 Jowhar became the capital city of the newly formed HirShabelle State of Somalia.

Figure 2-2 Old sugar cane factory and train in Jowhar area

UNFPA Somalia population estimates of 2014 indicate that Jowhar district has a total population of 179,097; comprising an urban population of 63,090, a rural population of 89637 and 26,370 IDPs[3]. Jowhar has the highest percentage of rural population living within the rural settlements after Balcad district. Demographic estimates of the urban villages of Jowhar that have been developed are not considered reliable. Analysis through satellite imagery shows some horizontal growth in Jowhar city in the last 20 years surrounded in all directions by crops but in a very different way between Hantiwadag, Kulmis, Horseed and Buulo Sheikh leaving an area along the river without new constructions. Without regulating and managing the new construction in Jowhar there will be a risk of loss of fertile agricultural land, urban fragmentation, illegal occupation, land disputes and difficulties to provide basic services and infrastructure.

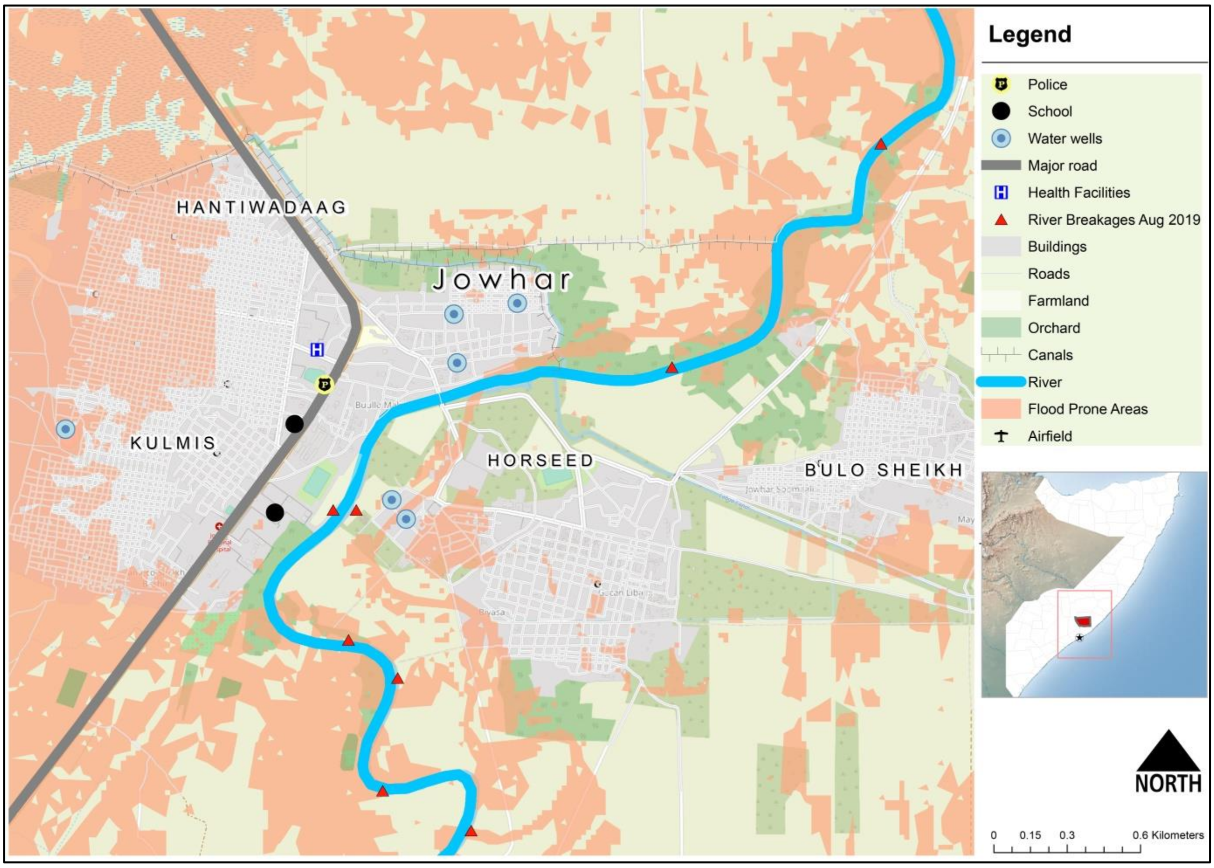


Figure 2-3 Project area with main reference features

Floods, low-rainfall and chronic food shortages as well as clan conflicts have caused movement into the regional capital since 2013, when the Somali national army supported by AMISOM liberated the city. The estimation of IDPs within the urban area about 5,820 in seven settlements, all of them in the east side of the town called Teyaglo, Sheikh Omar, Jilaly and Biaso camp.

2.2 Socio-Economic Context

Somalia's economy is largely consumption-based and dominated by agriculture, while it is also supported by remittances and large aid flows. Agriculture plays a key role by constituting 75% of GDP, and 93% of total exports. The supply of water from the Shabelle River has allowed the

[3] UNFPA Population Estimation Survey 2014

agricultural development of Jowhar district to the extent that became one of the major suppliers of food and export crops for the country. Due to the lack of maintenance of the infrastructures and absence of river management, Jowhar has lost this protagonism.

The majority of the population is engaged in the agricultural or livestock sectors. The common types of agricultural products include maize, beans, rice, sesame, onions and sorghum and also fruits that grow in the area such as mango, guava, tomatoes, lettuce, onions, peppers, cabbages, oranges, lemons, and papaya. Livestock production such as cattle, goats, camels, sheeps and poultry is also a productive sector. However, there is no official data about the exact livestock numbers in Jowhar.

The local markets functions relatively well, the main market is in Hantiwadag village. It is an open market where people sell and buy different items ranging from food, clothing, and utensils to medicines. About 69% of Somalis live below the poverty line. Poverty is thereby most acute among children, youth, and IDPs, as well as persons living in rural areas.

Jowhar has two main roads and two minor roads that connect it to other main town or its neighboring village. The main highway starts from Mogadishu, passes through Jowhar, and then goes further to the central regions of the country. Another one is the one that comes from Jalalaqsi on the north. However, the conditions of these roads are very poor which makes the exploitation of Jowhar’s potential very difficult. Jowhar has a functioning airstrip, 17km outside of the town. There are seven schools in Jowhar, five of them are private while the other two schools are public. In addition, Jowhar has two universities and 1 public hospital and three other private hospitals.

Jowhar experiences pockets of insecurity and some lack of access on key routes out of the town. These continued conflict and frequent natural disaster have contributed to significant poverty in Somalia. The social impacts and potential aggravation of resource-related conflicts is well documented in previous studies. The district remains under the control of pro-government forces. A sizeable portion of these forces are Burundian troops of the African Mission in Somalia (AMISOM). Troops of the Somali National Army (SNA) are also present. The Islamist group Al-Shabaab still active in the rural areas surrounding Jowhar district, providing harsh treatment, forced recruitment vis-à-vis the local populations. It infiltrates other areas and conducts deadly attacks on citizens.

2.3 Generalized Characteristics of the Area

2.3.1 Climate

Climate is semi-arid and Jowhar town is relatively wet, compared to many other parts of Somalia. There are two wet seasons (Gu and Deyr) and two dry seasons (Jilaal and Hagaa). The Gu rain season starts as early as the second half of March with around 400mm rainfall on an annual average. The second rainy season (Deyr) is characterized by a shorter duration and less amounts of precipitation in the months of October to the end of November. The mean annual rainfall is approximately 367mm/yr, most of which falls in the Gu and Dayr rainy seasons. Variability is high in space and time. The dry seasons are very dry and warm, with mean monthly temperature is in the range of 27.45 - 29.8°C. Rainfall has been modeled from 1901 to 2020 (WB, 2021) data from meteorological stations (Figure 2.4).

Potential Evapotranspiration rates are high ranging between 120 to 189 mm per year because of the vegetation density is relatively high and high soil water content in the floodplains. Evapo-transpiration exceeds rainfall in the area and it means that water demand by plants is much higher than the available rainfall and explains the high sensitivity of the area to droughts.

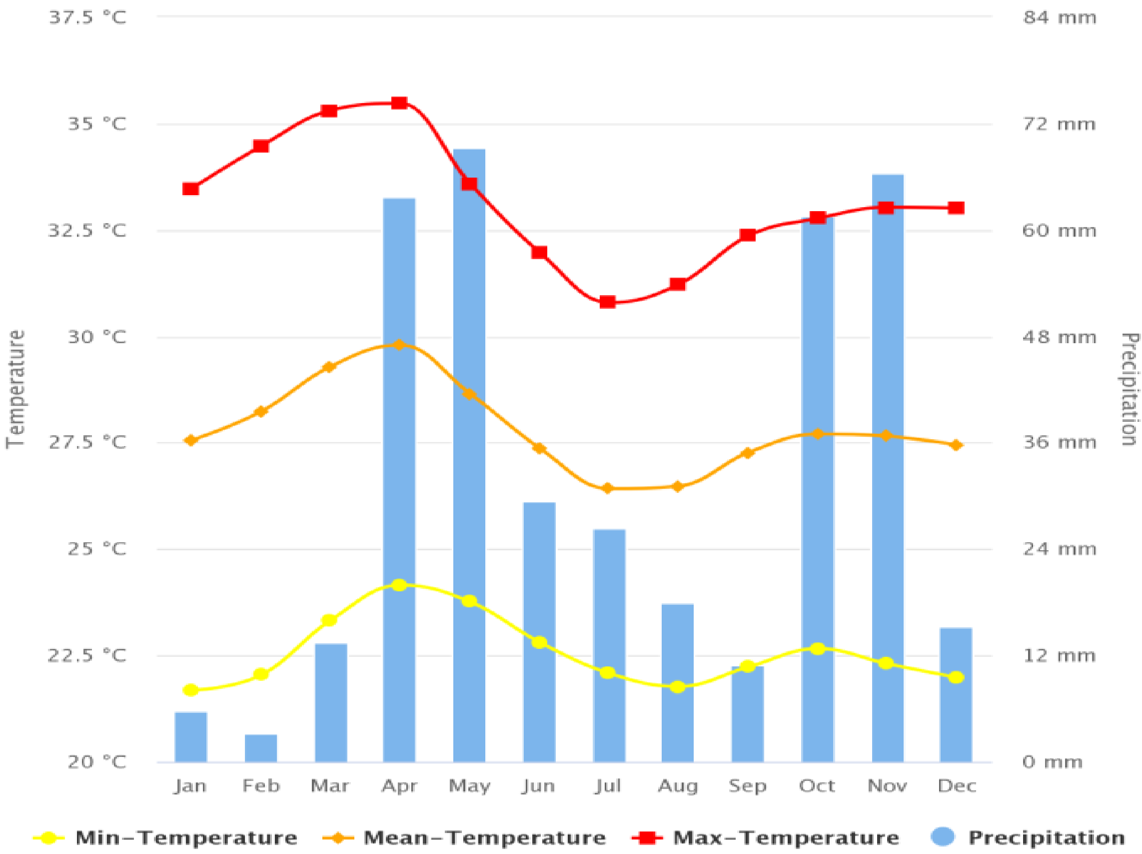


Figure 2-4 Monthly rainfall and temperature variations of Jowhar area for the period of 1901 to 2020 (source: World Bank, 2021)

2.3.2 Topography

Morphologically, the Shabelle River flows within almost a flat valley due to the sediment loads deposit led the river bed to be elevated above the plain in the areas downstream of Bulo Burti towards the Jowhar making it more vulnerable to flooding. Irrigation is widely practiced any breakage of the river embankments can lead to extensive devastating flooding. The surroundings of Jowhar are characterized for being vast extensions of crops fields. Downstream of the town, the elevation is about 90m a.s.l. and the terrain is flat. The small hills in the lower right corner of the map mark the end of stabilized sand dunes. The contours depict higher elevation close to the river and lower elevation further away from the river. The two branches on the left side are areas where the water diverts during heavy floods. Longitudinal profile along the valley and shows elevation changes gradually with higher elevation close to the river and lower elevation further away from the river and with the very low slope of the river. Here several irrigation canals depart from the river.

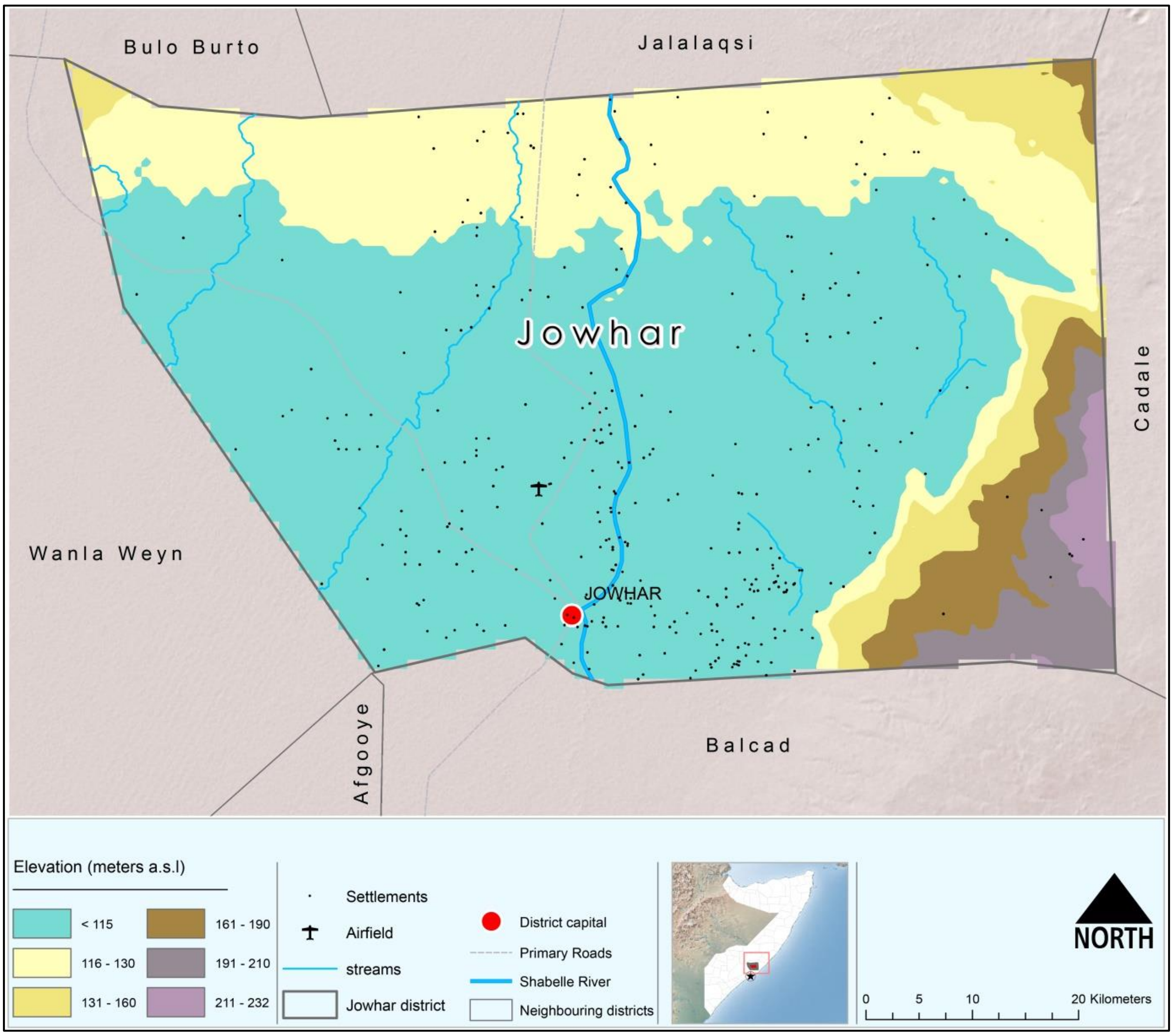


Figure 2-5 Generalized topographic relief of Jowhar area

2.3.3 Land Use and Land Cover

The landscape of the area is strongly conditioned by Shabelle River. Land cover in the study area consist urban and associated areas (settlement/towns, roads and airport), Natural Water bodies and in the surroundings of Jowhar are characterized for being vast extensions of crops fields. Mango crop fields are common along the river while the cereals crop fields occur further away from the river.

Smaller areas of mixed crops include rice, banana, mango, coconut and sesame. These crops are irrigated under gravity from the river through an extensive irrigation network developed in period between 1920s and 1990s. Irrigation water is abstracted by barrages with weirs controlling water flow into primary canals that commandeer water into secondary canals.

Half of the Jowhar Sugar Estate comprises of abandoned fields due to waterlogging and salinity problems. While the canals that used to irrigate these areas are still present, they are only functional in the upstream reaches, with the channels substantially silted up in the abandoned areas of the estate. This orthogonal network is specially developed at the east side of the town while the flood prone areas of the west are reserved for rice plantations. Land is affected by moderate to strong degradation, especially in the east side, mainly due to increasing farming, reduction of vegetation cover, and tree cutting.

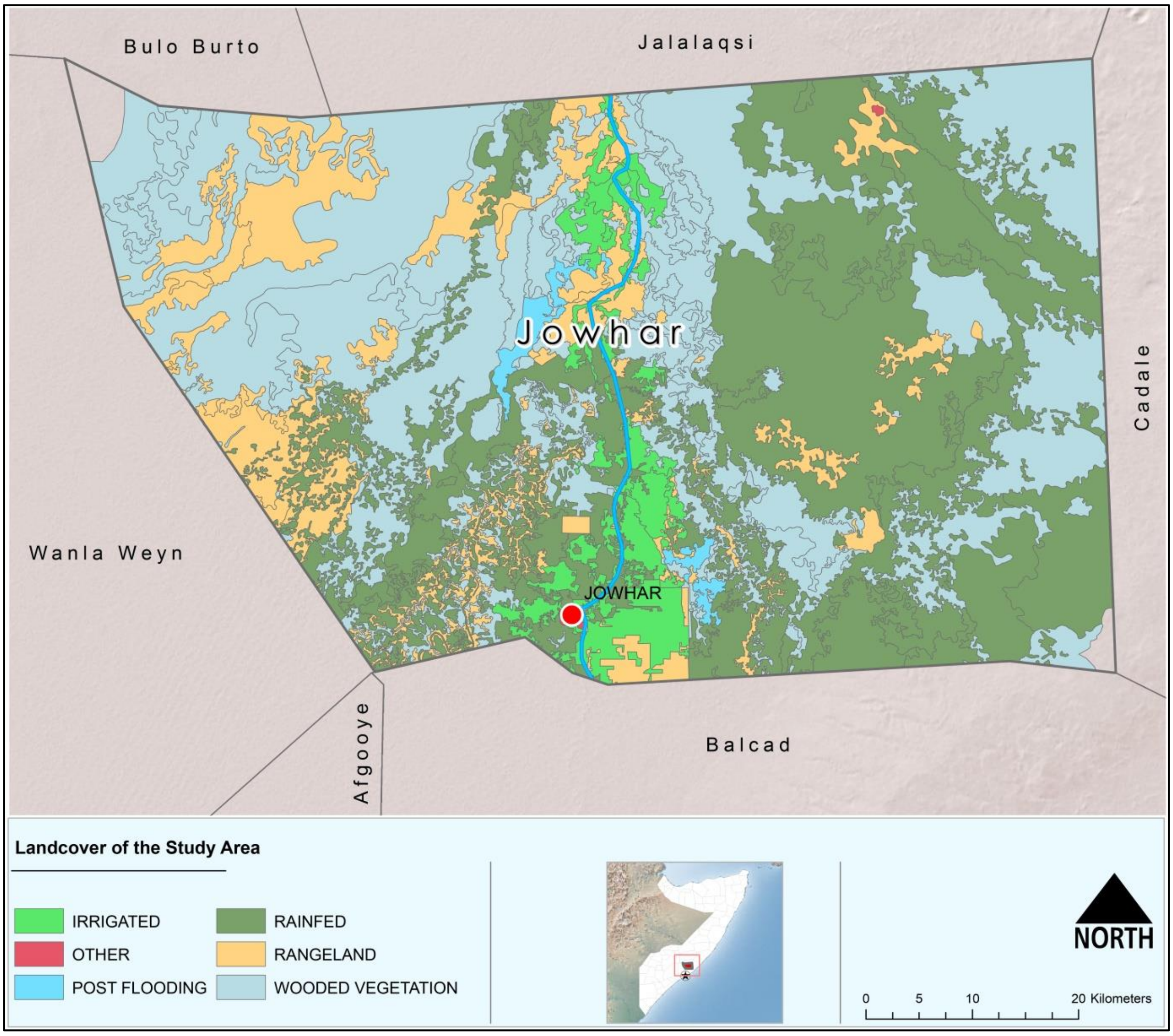


Figure 2-6 Land cover of Jowhar area

2.3.4 Soil

The soil of the region is typically Haplic Vertisol which is characterized by its low nutrient availability, poor workability and imperfect drainage. From Mahadey Weyne to Jowhar the soils on both banks adjacent to the river consist of fine- textured brown vertisols with good water-holding capacity and have been extensively used for rain-fed agriculture and flood - and controlled irrigation on the Jowhar Sugar scheme. Between Jowhar and Balcad the soils adjacent to the river were grey vertisols, suitable for irrigated agriculture. Infiltration rates for such soils are low, frequently less than 25mm/hour. They have high water holding capacities, usually as much as 200-240mm/m or more. In some cases, soils have salinities above 5µS/cm leading to serious salinity problems unless careful irrigation practices are followed.

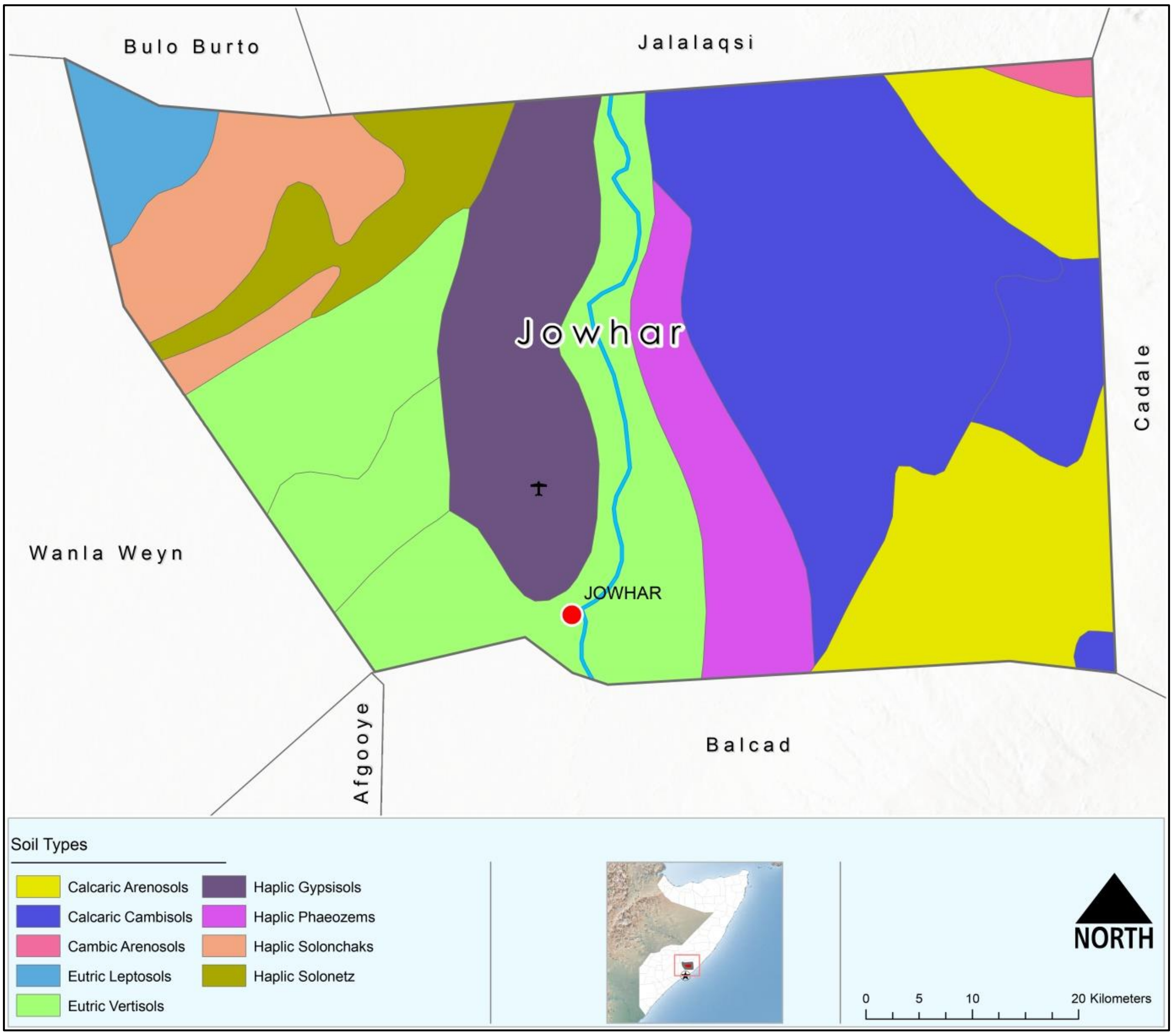


Figure 2-7 Soil map of Jowhar area. Classification codes are based on (FAO, 2009)

2.3.5 Geology and Hydrogeology

Most of the southern parts of Somalia consist of the basement complex rocks, overlain by Mesozoic sediments of limestone, marls, sandstones and alluvial sediments. The area surrounding Jowhar is constituted by black and dark-brown alluvial clay and sandy clay with widespread secondary gypsum crystals. There is a great difference in the lithological sequence of the alluvial deposits penetrated by wells drilled in the area. Majority of the population in Jowhar uses river water for drinking beside hand-dug wells and few boreholes during the months when the river gets dry for domestic consumption and for irrigation purposes, the population rely more on water from the Shabelle River. Most of the wells are unlined and unprotected; some have concrete linings, but are not covered.

A large groundwater reservoir yielding water of good quality has been identified in the area of the Sugar Factory. Its extension, thickness, vertical and horizontal lithological changes, as well as water quality variations, have not been defined yet. The uppermost water-bearing zone of the alluvial aquifer between 7 and 17 m generally has a low productivity and a high salinity with EC value up to 9,000µS/cm and there are, however, some hand-dug wells 10-12 m deep, with EC values of less than 2,000µS/cm; water salinity in boreholes should decrease by sealing off the top 20 m of the alluvial sediments.

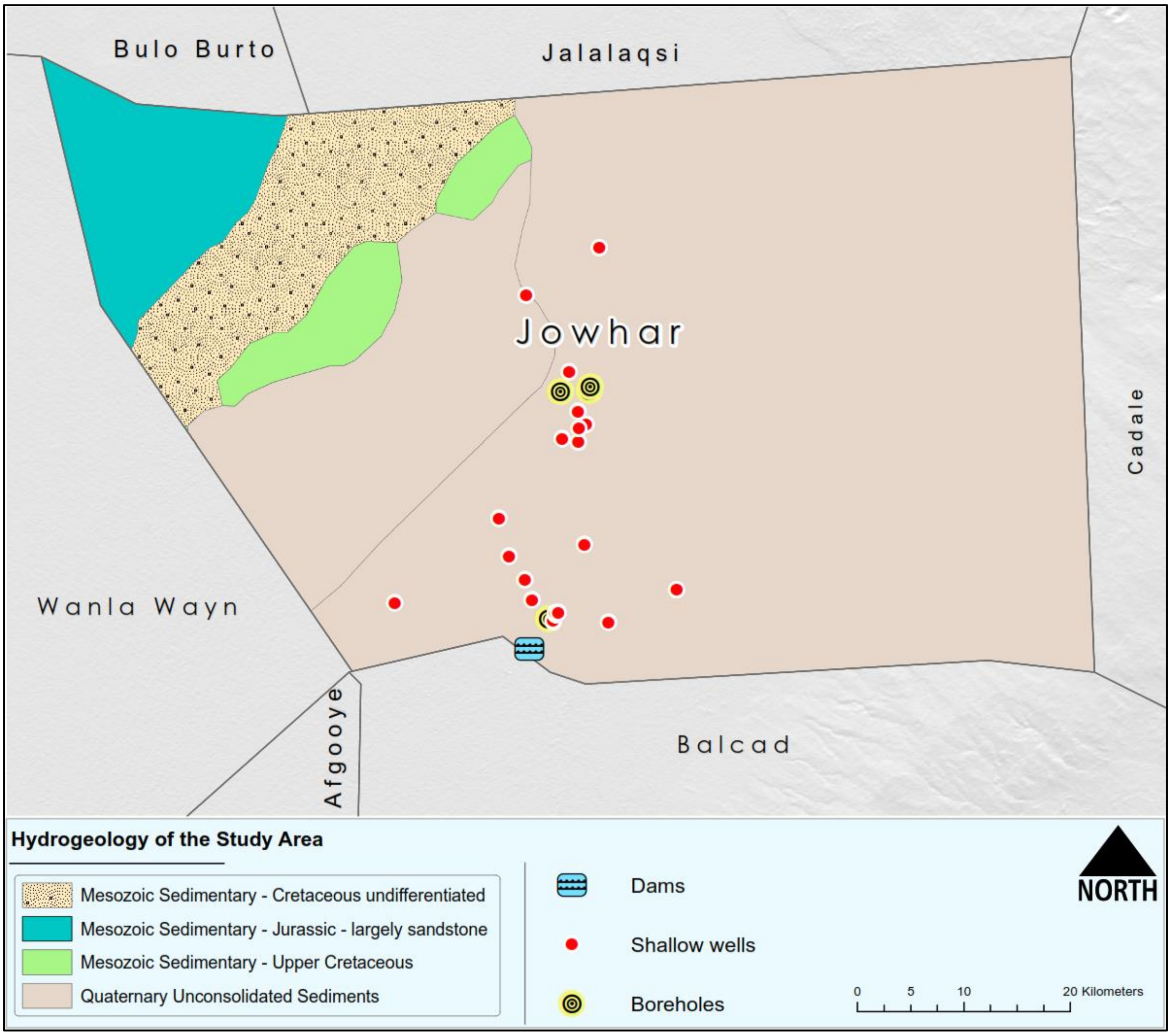


Figure 2-8 Generalized hydro-geology and available water sources in Jowhar area

Water-bearing layers tapped by these wells are most probably hydraulically interconnected with the river water. A decrease in salinity with depth has been observed in drilled wells. Low permeability and the widespread presence of secondary gypsum in the clay and sandy clay layers down to a depth of 20m are the main reasons for the higher salinity of the upper sediments compared with the lower ones. In addition, the shallow depth of the water table in large areas, used by the intensive irrigation during the past 50 years, has built up soil salinity which leeches into the upper part of the aquifer. In several boreholes where the upper part of the aquifer has not been sealed off, water quality changes during pumping and water of better quality is generally obtained after a certain amount of pumping, indicating that the lower water-bearing zone produces water of better quality than the upper water-bearing zone.

2.3.6 Hydrology

Shabelle River begins in the highlands of Ethiopia where the main stream and its tributaries are deeply incised into the steep slopes of the upper reaches, and then flows southeast into Somalia through Bulo Burti, Mehaddey Weyn and Jowhar to Balad, where it turns south-west and runs roughly parallel to the coast from which it is separated by a range of sand hills about 25 km wide. After passing through Afgoy, Audegle and Coriole the river becomes seasonal.

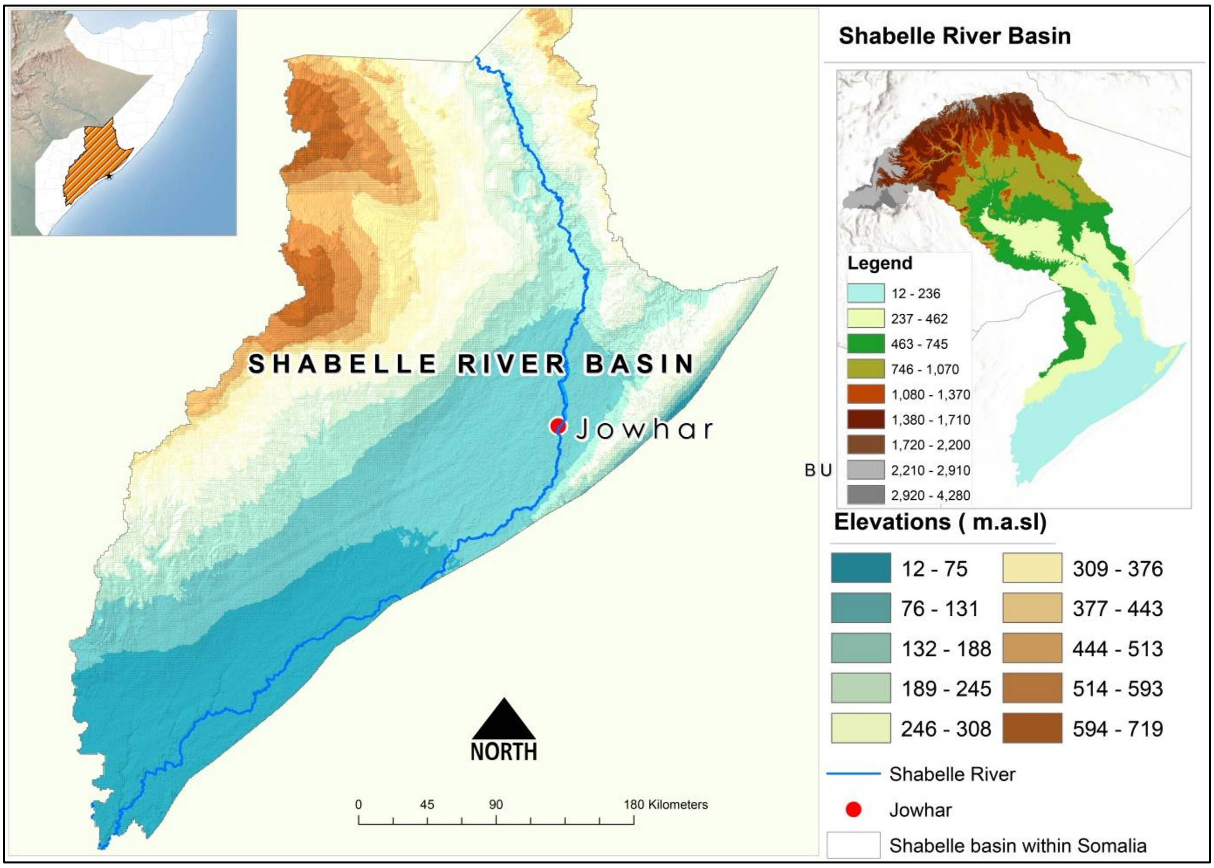


Figure 2-9 Shabelle River Watershed

During most years, the river dries up near the mouth of the Jubba River, while in seasons of heavy rainfall; the river actually reaches the Jubba and thus the Somali Sea. The river has a total catchment area of approximately 307,000km^2, of which 65% lies within Ethiopia. In the middle and lower reaches, there is a virtual absence of tributaries and other drainage channels. Over long reaches, particularly Shabelle River banks lie above the level of the surrounding land, so that any spillages are lost permanently from the river and no return flow occurs (MacDonald 1983, IUCN 2006). Shabelle River suffers from flow variability, both inter-annually and intra-annually, resulting in both water shortages and flooding depositing vast amounts of sediment which make the river valleys the most fertile areas in the country.

Jowhar is located in the Hirshabelle river floodplain, an area that is susceptible to floods in times of high water discharges from the adjacent rivers and bursting, poorly maintained irrigation channels. While the town itself is not located on the most flood prone area, torrential rains and floods turn Jowhar into an island accessible only by boat from Balcad, south, as recently as November 2021.

Meteorological and hydrological observations constitute the first step in producing high-quality weather and flood forecasts with proper lead time, as well as providing baseline data for water resources management, drought forecasting, and a long-term climate trend. Juba and Shabelle rivers are the only gauged rivers in Somalia. Hydrological and meteorological data collection and observation in Somalia started in the late 1894 by installation of first weather station in Kismayo. The hydro-meteorological network expanded rapidly and other stations were located in the coastal areas where Italian and British colonizers settled at the turn of the twentieth century.

Hydrological data collection and analysis started in Somalia with the installation of hydro-meteorologicalric stations in Jubba and Shabelle Basin which started in the late 1894 by installation of first weather station in Kismayo. The hydro-meteorological network expanded rapidly and other stations were located in the coastal areas where Italian and British colonizers settled at the turn of the twentieth century. Currently in total 7 River Gauging stations (staff gauge readings) installed along Shabelle River, some of them are not functional, and albeit at different levels of data reliability and latency (see Table 2.1). There is limited information available on river flows in the Ethiopian portion of the catchment. The earliest level readings still available in Somalia date back to 1951 at Beled Weyne.

Table 2-1 Location and operation status of river gauging stations in Shabelle Basin

#	Station Name	River	Longitude	Latitude	Operation Status
1	**Belet Weyne**	Shabelle	45.20596	4.73598	Functional
2	**Bulo Burti**	Shabelle	45.56727	3.85702	Functional
3	**Mahadey Weyne**	Shabelle	45.53038	2.97098	Functional
4	**Jowhar**	Shabelle	45.50486	2.77872	Functional
5	**Balad**	Shabelle	45.39167	2.35000	Non-Functional
6	**Afgoi**	Shabelle	45.12500	2.14444	Non-Functional
7	**Audegle**	Shabelle	44.83333	1.98611	Non-Functional

From the end of 1990 to 2000, the hydrometric network collapsed completely and the river gauging stations were not monitored. No data is available for this period. These gauges were rehabilitated previously by the SWALIM, CEFA, CARE and World Vision International. An effort was made by IGAD-ICPAC to fix new staff gauges at the same level datum of the gauges that were maintained before the war. The recent data shows distinct differences from the earlier pre-war data in terms of the magnitude of flow. Houghton-Carr et al. (2011) reviewed the trends between 1963-2010 and 2002-2010 at Belet Weyne and Bulo Burti and found no significant trends at the 95% confidence level. Analysis of the differences in the 1963-1990 and 2002-2014 records shows an increase in average flows at Belet Weyne by 58% and at Bulo Burti by 50%. Due to the high uncertainties in the current stage-discharge relationship, the confidence in this data is low and it should not really be used to conceptualize the current state of the river. On face value though the recent record appears to support the notion that accretion is increasing water levels within the river channel.

The absence of accurate forecasting and weather information resulted losses of economic and thousands of lives in the past two decades. Somalia in general is lacking technical and institutional capacity to analyze, forecast, develop and disseminate timely early warnings messages for floods and flash floods, drought, cyclones and accurate hydrological, hydrogeological and meteorological information to enable the efficient and economic management of water resources.

2.3.7 River Characteristics

The peak discharge on the Shabelle occurs in Ethiopia and annual flows decrease progressively as the river flows downstream. Based on stream flow data from 1963 to 1990, the long-term mean annual flows in the Shabelle River at Belet Weyne (catchment area of 207,488 Km^2) and at Balcad (catchment area of 214,516 Km^2) are 2.4 and 1.5 Billion cubic meters (BCM) respectively. This is mainly due to various factors such as: not much contribution to flows from the Somali catchment areas, frequent occurrence of bank full condition and spilling of flood water into the flood plains and natural flood relief channels, river diversions for irrigation both during low and high flow periods, and losses due to evaporation and infiltration/recharge of the groundwater along the river.

Table 2-2 Long-term Average Flows in some stations a long Shabelle River (m3/s)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Belet Weyne	13.5	13.8	30	79.8	151.2	82.7	57	110	151.8	129.6	77.5	36.9	75
Bulu Burti	14.3	9.8	14.5	31.9	65.6	56.1	40.8	67.3	74.8	71.9	57.2	31.7	44.7
M.weyne	17.2	13.1	21.1	53.6	104.5	74.8	52	98.3	122.8	111.4	74.6	37.5	65.1
Balcad	17.2	13.1	21.1	53.6	104.5	74.8	52	98.3	122.8	111.4	74.6	37.5	65.1

The Shabelle river channel does not have the capacity to carry much more than the typical annual flood. Despite a history of embankment construction, out-of-bank spill occurs yearly in Mahaday Weyne, Jowhar, Balcad and Afgoye during the flood periods when the capacity of the channel is exceeded and flooding occurs. Unregulated settlement in flood plains and the recent practice of breaching river embankments for informal flood irrigation has progressively increased flood risk to the riverine communities.

Flood control and river regulation infrastructure has continued to decline. Unregulated settlement in flood plains and the recent practice of breaching river embankments for informal flood irrigation has progressively increased flood risk to the riverine communities. There are two distinct flood seasons on the Shabelle, coinciding with the Gu and Deyr rains. Over the 1963 to 1990 recorded data period, the Gu and Deyr floods are similar in terms of the percentage of annual flow though the Deyr floods are sustained for longer (Houghton-Carr et al., 2011). During the period of 1970 to 1980 the peak flows in the river at Afgoy are shown to be approximately $100m^3/s$. In the period after construction of the JOSP, maximum flows were around 80 to $90m^3/s$, reflecting the influence of the active operation of the scheme at that time.

2.3.8 Shabelle River Hydrological Challenges

Despite being the largest basin of Ethiopia's twelve basins, the Shabelle has the least runoff of all rivers of Ethiopia. This is due to its physical geography and limited rainfall. However, despite being a little resource in Ethiopia, it is a major source of water for Somalia, albeit not developed to its full capacity. The length of river valley from Mahadey Weyn to Balad, which is the reach serving irrigated agriculture in the Middle Shabelle, is some 80km, typically the river embankments are 0.5m to 1.5m high, reasonably well formed and grass covered. Locally, flood embankments may exceed 2m in height. The topography in Mahadey Weyn to Jowhar area is particularly unfavourable to containing the river, with the riverine areas being raised above the surrounding flood plain (Fig 2.10). This means that even a minor breach in the river embankment can result in widespread flooding as the river escapes from its perched position into the surrounding floodplain which is located at a lower elevation. Damages from low return period flooding are therefore high when compared to areas where the extent of flooding is confined by rising topography away from the river.

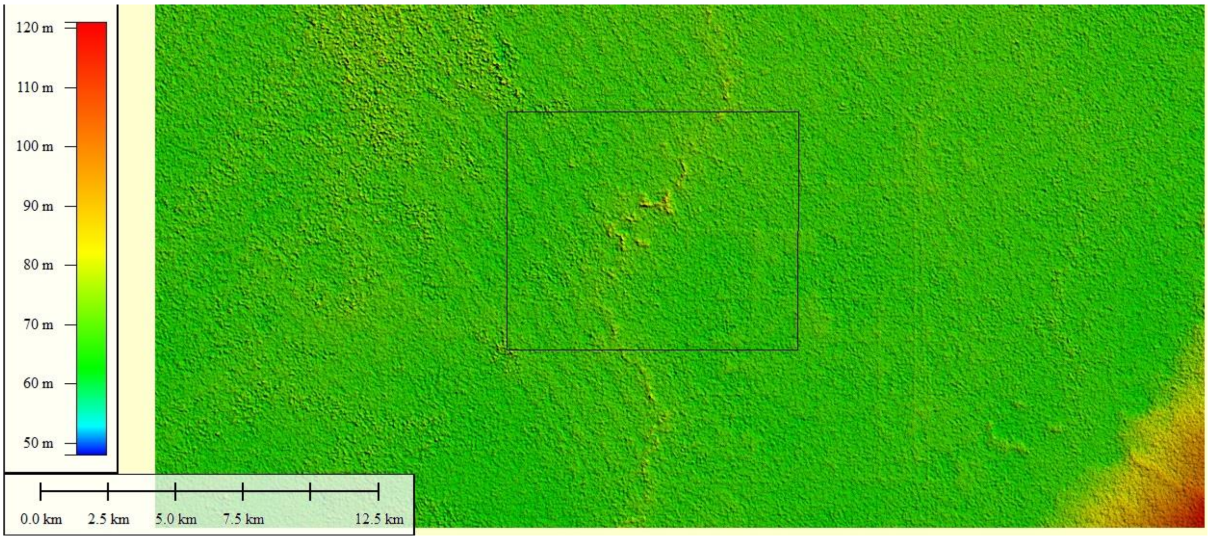


Figure 2-10 DEM map shows riverine areas raised above the surrounding flood plain

Due to climate conditions, the basin is also frequently affected by recurrent droughts, causing major water problems to both Ethiopia and Somalia. For the last four year (2016 – 2019) Shabelle River have experienced unprecedented hydrological conditions, as it has turned totally dry (Fig 2.11), mainly due to lack of rains, climate change effects, and increased utilization in upstream areas.

Figure 2-11 Photos shows the river running dry

These hydrological conditions have already negatively impacted the lives of many vulnerable downstream communities as well as the river ecology. These effects on the Shabelle River are the worst in living memory. As an effect of on-going climate change combined with other changes in the physical environment, the Shabelle River is currently undergoing major hydrological changes which may result in unknown outcomes in terms of its capacity to maintain communities and a healthy environment. Somalia is therefore concerned about the hydrological changes of the river.

2.3.9 Sedimentation

The heavy sediment loads in the river water during times of high flow have presented severe operation and maintenance problems for the Jowhar sugar estate and the Jowhar Offstream Storage Project in the past, specifically with the sedimentation of canals and the occlusion of intakes. The Duduble and FAO Flood Relief channel have also experienced similar problems. Particularly high sediment concentrations were recorded during 1980 and 1981 as part of the Jowhar Offstream Storage Reservoir operation. The major land use types driving this rate of topsoil loss were noted to be livestock grazing, fuel-wood collection, and the negative effects of expansion of urban centers It seems that sediment concentrations are very high in the Gu season, especially when the river flow has been lower than average in the preceding months. The inference is that the Ethiopian catchment contributes high sediment loads when the Gu season rains fall on a drought-stricken catchment.

2.3.10 The River Management Challenge

The Shabelle River is important resource bases for Somalia, as they supply the country's rice bowl. Traditional socio-economic activities in southern Somalia are strongly based on the availability of water in the river. Water resource in the river is strongly linked to the very survival of the Somali national economy, as well as its social and environmental well-being in the riverine areas. The river is therefore vital to the well-being of the nation. Unlike Ethiopia, which has larger rivers in its territories, Somalia lacks significant alternatives to the Juba and Shabelle rivers as long as water development for agricultural productions is concerned. In addition, the rivers pass through ecologically sensitive areas of both inland and coastal ecosystems. The dependency ratio of Somalia to the waters of the Juba and Shabelle are extremely high. In Somalia, where agriculture is impossible without irrigation, water security is one of the most important issues.

Due to its length and the area it covers in Somalia, the Shabelle River is the most important source of water for irrigation activities and domestic water supply to many communities in central-southern Somalia. The river was the most developed river in Somalia before the state collapse in 1991. Before the outbreak of the civil war in 1991, nine barrages in the Shabelle River with irrigation canals were built. Inside Somalia, no dam was built on the Shabelle River, but there were many major agricultural development activities taking place along the river, that used much of the available water. Before the civil war started in 1991, plans were in hand to further increase utilization of the river water resources, as the capacity to expand irrigation schemes remained high.

However, the civil war damaged the river infrastructures; structures that are today in great need for rehabilitations and improved management. During the civil war years, there were no proper operation and maintenance of the barrages, canals and river beds. The river and the infrastructures suffered mainly from uncontrolled siltation, in turn caused by land degradation and soil erosion. This led to the river and all its irrigation channels were filled with sands that have reduced the river capacity to carry water. As a consequence, the agricultural communities have then started to break up the river banks to irrigate their land. This has in turn affected the river morphology.

2.3.11 Gauging Stations

There is limited information available on river flows in the Ethiopian portion of the catchment. The earliest level readings still available in Somalia date back to 1951 at Beled Weyne. As there is very little inflow in the Somalian portion of the catchment, this gauge is important for estimated water availability in Somalia. Before the outbreak of the civil war, there were six gauging stations each in operation in Juba and Shabelle rivers within Somalia. River gauges (staff gauge readings) and discharge measurement records are available for these stations up to 1990.

In the late 1970's there was a gradual deterioration in the state of the hydrometric network, and records at many stations became intermittent, unreliable or non-existent. In 1981 began the re-establishment of staff gauges and river level recorders, with an extensive program of discharge measurements to determine new stage-discharge rating curves. These measurements covered the full range of the flow duration curve, covering both the severe drought on the Shabelle in 1981 and the exceptional flood events in the following year.

A further decline in monitoring and maintenance after this period necessitated another program of rejuvenating the hydrometric program in 1983. From the end of 1990 to 2000, the hydrometric network collapsed completely and the river gauging stations were not monitored. No data is available for this period. In recent years recording stations were rehabilitated and staff gauges have been installed by SWALIM. River level observations have continued since then at these sites.

2.3.12 Vulnerability

Jowhar is located in the Hirshabelle river floodplain, in an area that is extremely disaster prone including floods in times of high water discharges from the adjacent rivers and bursting, poorly maintained irrigation channels. Recently the floods of 2021 turn Jowhar town into an island accessible only by boat from Balcad town with more than 27 villages located along the riverbank in Jowhar district have been affected effected with an estimated 27,541 people having fled their homes and moved to nearby highland villages and approximately 3,865 households are isolated. Most displaced people are arriving in Tawakal, Jiliyaale, Sheikh Omar, Biaso and Waqwaqley IDPs camps. The increment of temperature combined with lack of water availability as result of climate change increase the prevision of droughts frequency and persistency that cause crop loss, livestock loss and affect human health. These are one of the most prevailing reasons for internal displacements of population and force the communities to depend on humanitarian resources and other relief providers, including Al-Shabaab, for survival. Communities are vulnerable to those risks and will further threaten livelihood, water insecurity, food security, biodiversity and soil fertility, enhancing the prevalence of pests and water-borne diseases.

According to the communities environmental degradation and health problems, such as malaria, are amongst the main threats. Hydro-meteorological hazards, resource based and political conflicts, land degradation, and the lack of coping mechanisms and adaptive capacities are amongst the root-causes of vulnerability. Very limited effort is being made towards systematic disaster risk reduction.

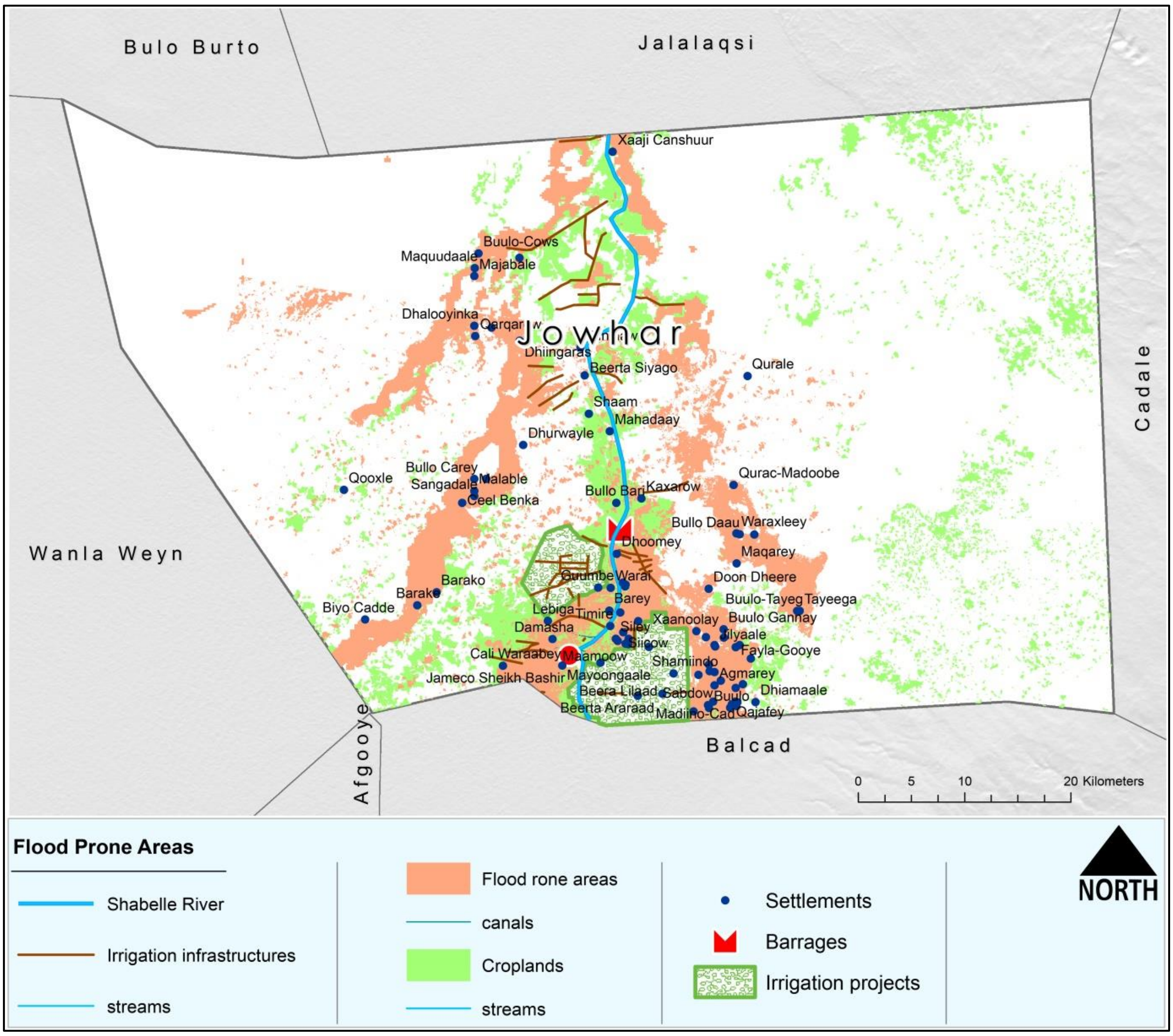


Figure 2-12 Flood prone areas within Jowhar district

In the area there are flooding prone areas that affect communications, livelihoods and health conditions. Tawakal, Jilyale, Biaso, Sheikh Omar and Waqwaqley IDPs camps are identified as one of the most vulnerable structures, given their lack of physical sturdiness, poor sanitation and health conditions. They are also, generally, very exposed to flood points as their location tends to be near the river, which makes them highly vulnerable to river breakages. Public facilities are also vulnerable since many of them are concentrated around the main road going south on the edge of Kulmis settlement. The concentration of public facilities and the proximity to the river make it a highly vulnerable zone.

It is observed that river breakage points coincide with areas where the riparian vegetation around the river is absent. These are points where the water floods unconstrained by riverside vegetation, increasing exposure on already sensitive living structures. When the riparian forest is thicker, the vegetation seems to hold water, mitigating the extension of the flooded area, protecting the living structures on the area.

2.4 Climate Change and Floods

Climate variability and change already strongly affected population food security, drinking water supply and irrigation, public health systems, environmental management, and lifestyle across Somalia. Over half of the populations are pastoralists where the timing and amount of rainfall are crucial factors determining the adequacy of grazing and the prospects of prosperity. Unfortunately, Somalia has been highly susceptible to the effects of climate change and extreme weather conditions, such as periods of extended drought, flash floods, erratic rainfall, and disruption to the monsoon seasons, strong winds, cyclones, sandstorms and dust storms which has been exacerbated by conflict and limited governance that persisted for decades. The following is key historical climate trends are summarized for the country (since 1960, unless otherwise noted):

- Since the 1960's, a warming trend has been observed in Somalia.
- All average temperatures in the past decades have been higher than normal, and the period between 1991 and 2016 was one of the warmest periods on record.
- An increase of between 0.5°C and 1.5°C has been observed in the absolute maximum monthly temperatures in the past three decades. The average increase in minimum temperature is 1.5°C and the increase is most significant in April and May.
- Rainfall is increasingly erratic, with marked seasonal deficits when compared to long term past averages. The changing dynamics are associated decreases in crop and livestock production and increasing food deficits.
- Significant increase in rainfall has been registered for the months of April – May and October – November and the period between 1991 and 2016 was recorded high rainfall rates.
- Heavy rainfall events appear to be increasingly frequent, with changes in rainfall patterns, including decreased reliability and less predictability.
- The number of extreme events is likely to increase and droughts appear to be increasingly frequent.

The simulated temperature and rainfall data derived from the Coordinated Regional Downscaling Experiment (CORDEX) RCMs of three models HadGEM-ES, MPI-ESM-LR and GFDL-ESM2M were compared with the observed data from stations, some with pre-war data and others with both pre-war and post war data. The models have been run for historical period covering the period from

1981 until 2005 and future projection 2006 up to 2100. The results for future projections of rainfall and temperature are given for IPCC sub period 2031 – 2060 in the near future, and 2071-2100 in the far future, relative to a reference period of 1981-2010. Analysis of the projected rainfall indicated a decreasing trend in rainfall leading up to 2030 followed by an increase in the near (2031-2060) and far future (2071-2100) compared to the reference period (1981-2010). Under RCP4.5 and RCP8.5 scenarios, mean annual rainfall is expected to increase by between 5% and **10%** over much of Somalia. Future plans should therefore focus in areas and seasons where substantial changes are expected to occur.

Figure 2.14 shows the recorded number of days with very heavy rainfall (20mm/day) each year for 1986-2005, and projected values for 2020-2100 and recorded 5-Day Cumulative Rainfall for 1986-2005 and projected 5-Day Cumulative Rainfall 10-yr Return Level by 2050 under all RCPs of CIMP5 ensemble modeling. Note, the shaded ranges illustrate the inter-model differences. In the case of temperature, the projections from all the models showed increase in minimum and maximum temperatures under both scenarios with RCP8.5 and RCP4.5 in the near (2031-2060) and far future (2071-2100) compared to the reference period (1981-2010), like being observed by temperature projection over other parts of the world.

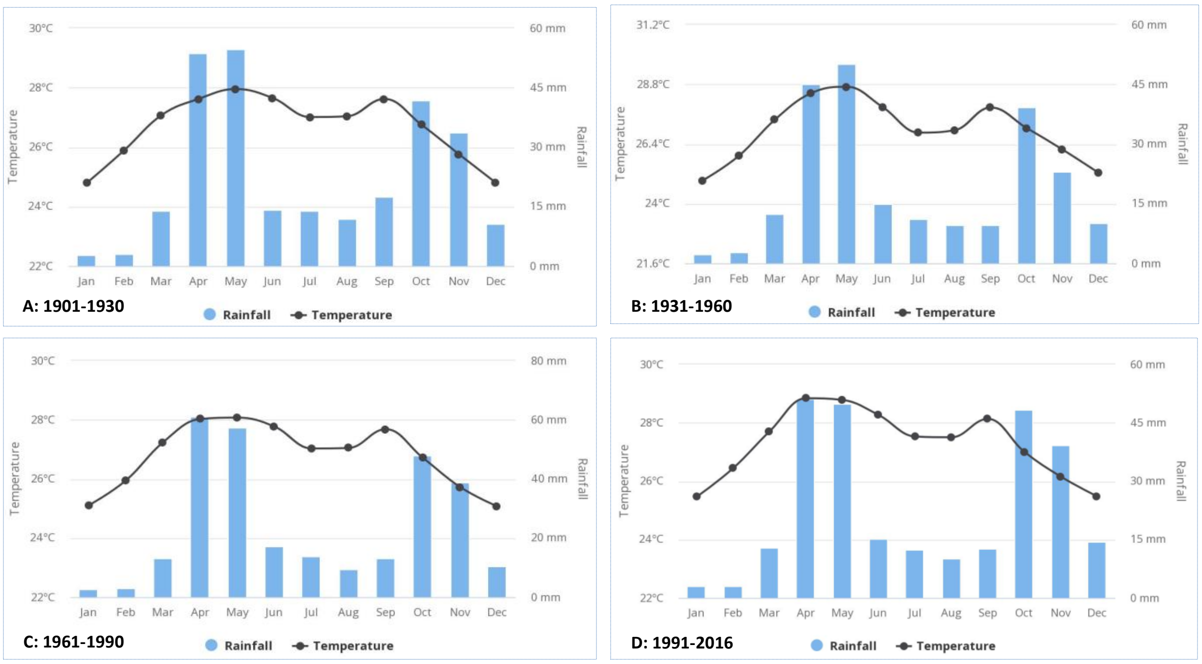


Figure 2-13 igure 2.13: Average Monthly Temperature and Rainfall of Somalia for 1901-1930, 1931-1960, 1961-1990 and 1991-2016

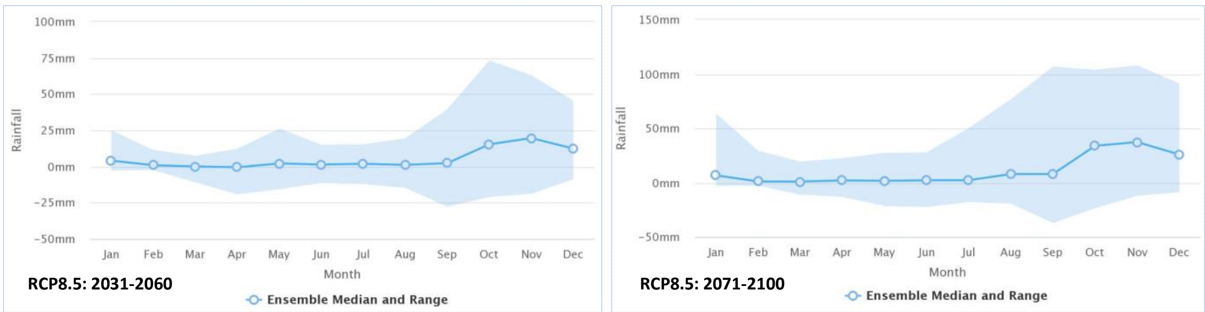


Figure 2-14 Projected change in monthly precipitation for Somalia for near future (2031-2060); far future (2071-2100) during RCP8.5 scenario

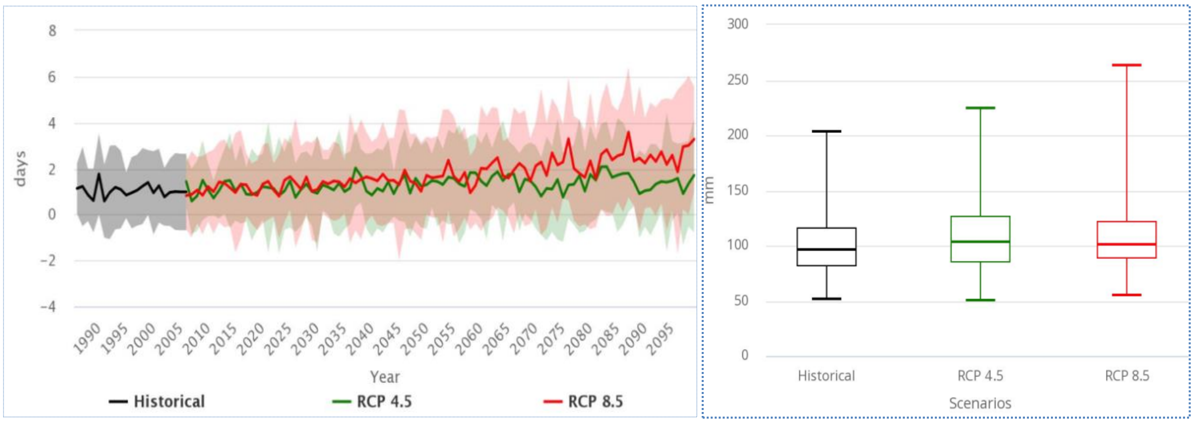


Figure 2-15 Number of days with very heavy precipitation in Somalia for period: 1986-2099 (left) and 5-Day Precipitation: 10-yr Return Level in Somalia for period: 2040-2059 (right)

The projected temperature change scenarios show that Somalia future development and livelihoods will in future face increased threats of climate extremes unless effective climate smart adaptation systems form integral components of national development strategies. Results however show that projected change in temperature will vary from season to season and district to district. The northern parts of the country are more likely to be warmer compared to the southern parts. Under RCP4.5 scenario, the temperature increase by the end of the century relative to the reference period (1981-2010) is expected to be between 1.5 and 2.5°C.

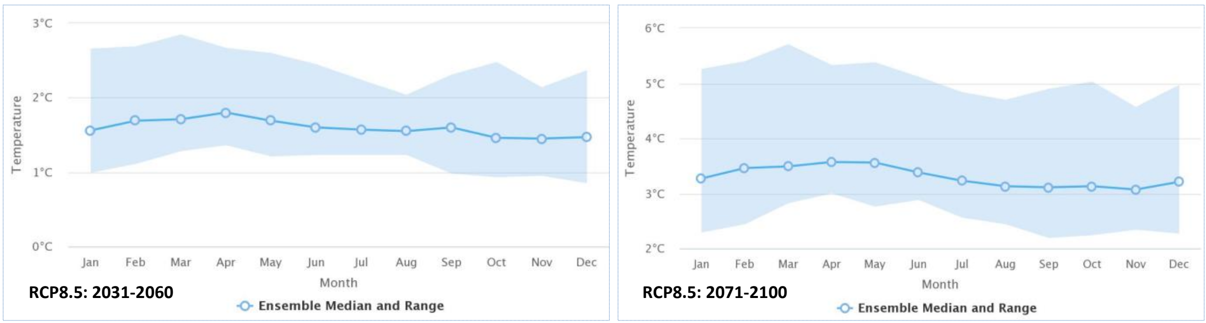


Figure 2-16 Projected Change in Monthly Temperature for Somalia for near future (2031-2060); far future (2071-2100) during RCP8.5 scenario

The spatial patterns of temperature changes in the far-future (2071-2100) were similar to those in the near future despite the changes are much bigger under RCP8.5. The warming is likely to be less in the southern parts of the country compared to the northern parts. The northern parts are expected to experience up to 3°C under RCP4.5 scenario compared to 5°C under RCP8.5 scenario. Results from the temperature time series (Fig 2.17) show an increasing temperatures in both the near to long term future. This is in line with global and regional reports that project an increase in the average temperature by 2060 and a further increase by 2100[4, 5,6.]

[4] IPCC. (2014), Africa. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects.*

[5] Few, R., Seytal, P., McGahey, D., Leavy, J., Budd, J., Assen, M., Bewket, W., et al. (2015) Vulnerability and Adaptation to Climate Change in Semi-Arid Areas in East Africa. ASSAR Working Paper, 111

[6] Anyah, R.O. and Qiu, W. (2012) Characteristic 20th and 21st Century Precipitation and Temperature Patterns and Changes over the Greater Horn of Africa. International Journal of Climatology, 32, 347-363. https://doi.org/10.1002/joc.2270

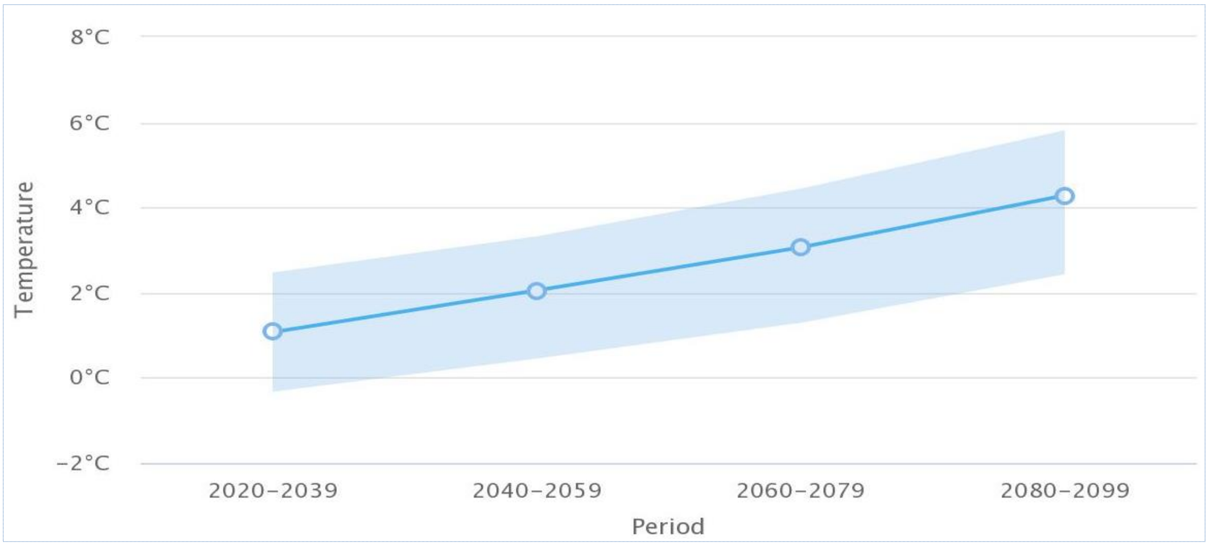


Figure 2-17 Projected change in average temperature 2020 -2099

2.5 Historical Background of Climate-Induced Natural Disasters

Many of the hazards affecting Somalia that originate from hydro-meteorological events such as heavy precipitation prolonged dry spells or extreme temperatures that have adversely affected the lives, property, and livelihoods of the Somali people for centuries. These are primary hazards which lead to secondary and tertiary hazards, including floods and flash floods, drought, cyclones and other climate-related diseases and epidemics. Floods and flash floods follow weather events, either heavy rain. While droughts could result in heat waves and water scarcity, both droughts and frosts will result in damage or loss of crops and important impacts on human and animal health. Pest and disease outbreaks may be triggered by drought or excess precipitation. The distinction of hazards in such a cascading manner is the first step in progressing from weather forecasts and warnings to multi-hazard, impact-based forecasts and warnings (Table 2.3).

Table 2-3 Table Primary, Secondary and Tertiary Hazards Cascading from Hydro-meteorological Events

Event	Primary Hazard	Secondary Hazard	Tertiary Hazard
Thunderstorm	- Heavy rainfall - Strong winds - Lightning	- Flash floods - River floods	- Damage to structures, embankment, irrigation and drainage facilities, pumping facilities - Submerging fields - Loss of infrastructure systems and services (shelter, energy, transport, schools, hospitals, communications) - Widespread economic losses - Infectious disease - Insect and pest problems - Sand and silt deposition - Waterborne diseases - High sediment runoff into reservoirs
Drought	- High temperatures - Heat waves - Less rainfall	- Water scarcity - Low flow - Less inflow - Crop damage	- High evaporation loss in reservoirs - Shortage of storage water in reservoirs - Insufficient diversion in channels - Salt-affected soil - Salt-affected soil - Energy shortages

			- Pumping system difficulties
- **Extreme** - **Temperature**	- Heat waves - Heat-related complications with livestock and animals	- Heat stroke - Biological hazards - Stress on vegetation - Water insecurity	- Socioeconomic impacts - Changes in groundwater level - Waterborne diseases - Food shortages

During the past 28 years, Somalia has been affected by six moderate-to-strong El Niño events in which floods of different magnitudes were reported (Fig 2.18). These floods led to the collapse of virtually all large irrigation schemes and damaged the major flood relief channels, roads and other major infrastructure. The flood recurrence at the Jubba and Shabelle Rivers pose significant flooding risks along the two rivers, mainly in the middle and lower reaches. Observational data for the 1985-2018 period show that drought, floods, cyclones, and climate-related diseases and epidemics, whose frequency, occurrence, and impacts have increased in recent years, already pose a significant risk to the country's vulnerable population. In recent decades, this has led to massive problems of food insecurity and population exodus from the worst-hit areas.

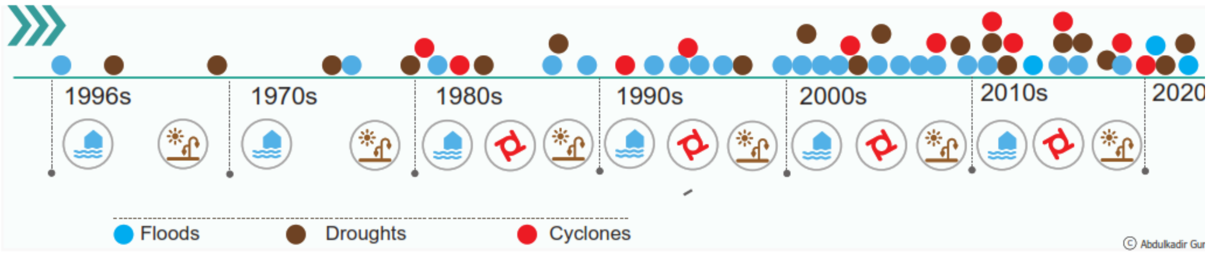


Figure 2-18 Historical natural disasters (droughts, floods and cyclones) in Somalia (Source: Gure, 2021)

2.5.1 Historical Flood Records

During the rainy season, the Jubba and Shabelle river basins in southern Somalia are often impacted by extreme flooding in the riparian zones. Temporal patterns of high rainfall variability exacerbate flood events (UNDP/ICPAC, 2013).[7] When mild and frequent droughts occur, they are often followed by devastating floods (Roba et al, 2013; SWALIM, L-14, 2009). Intense rainfall and flash flooding contribute to sedimentation of the river channels and deterioration of the riverine bunds. Flood diversion schemes are often required (e.g., Duduble Flood Relief Channel (DFRC) and Jowhar Off stream storage Project (JOSP)). However, the topography in the lower reaches of the Shabelle River is particularly unfavourable to containing the river, with the riverine areas being raised above the surrounding flood plain. This means that even a minor breach in the river embankment can result in widespread flooding as the river escapes from its perched position into the surrounding floodplain. Damages from low return period flooding are therefore significantly higher than one might expect when compared to areas where the extent of flooding is confined by topography rising away from the river.

The river system in the Middle Shabelle has now declined to the point where some flooding is expected during each high flow season (i.e. twice per year). This has become the expected course of events during a typical year and causes significant hardship through destruction of infrastructure,

[7] Somalia National Action Programme (NAP) to the United Nations Convention to Combat Desertification (UNCCD)

inundation of crops, loss of livestock, loss of life and in some cases the relocation of many thousands of people.

Jowhar town has been affected by the major historical river flood events which occurred in Deyr of 1961, Deyr of 1977, Gu of 1981, Deyr of 1997, Gu of 2005, and Deyr of 2006, Gu of 2010 and Gu of 2015. Since then the flooding has become progressively more frequent and in recent years has become a twice yearly event, with some flooding occurring during each high flow period. Jowhar will continue to be vulnerable to any future floods due to its location in the river plain. A number of historical flood events were investigated during this study. This included photographs, videos and personal interviews. From this data some preliminary models were developed for calibration purposes. These were reviewed and comments provided, examples of the preliminary maps can be seen in Figure 2.20 below:

Figure 2-19: Photos shows damages by the floods in Jowhar area

2.5.2 Recent Flood Events

Three relatively recent flood events occurred over the last 5 years. These events are of particular relevance as a large amount of documented evidence for these events can be found. A number of pictures, personal experiences and videos of these events have been collected and in some cases used for verification in this study. These events included floods of 2016, 2018, 2019, 2020 and 2021 that caused tremendous more damage than previous. From this data some preliminary models were developed for calibration purposes.

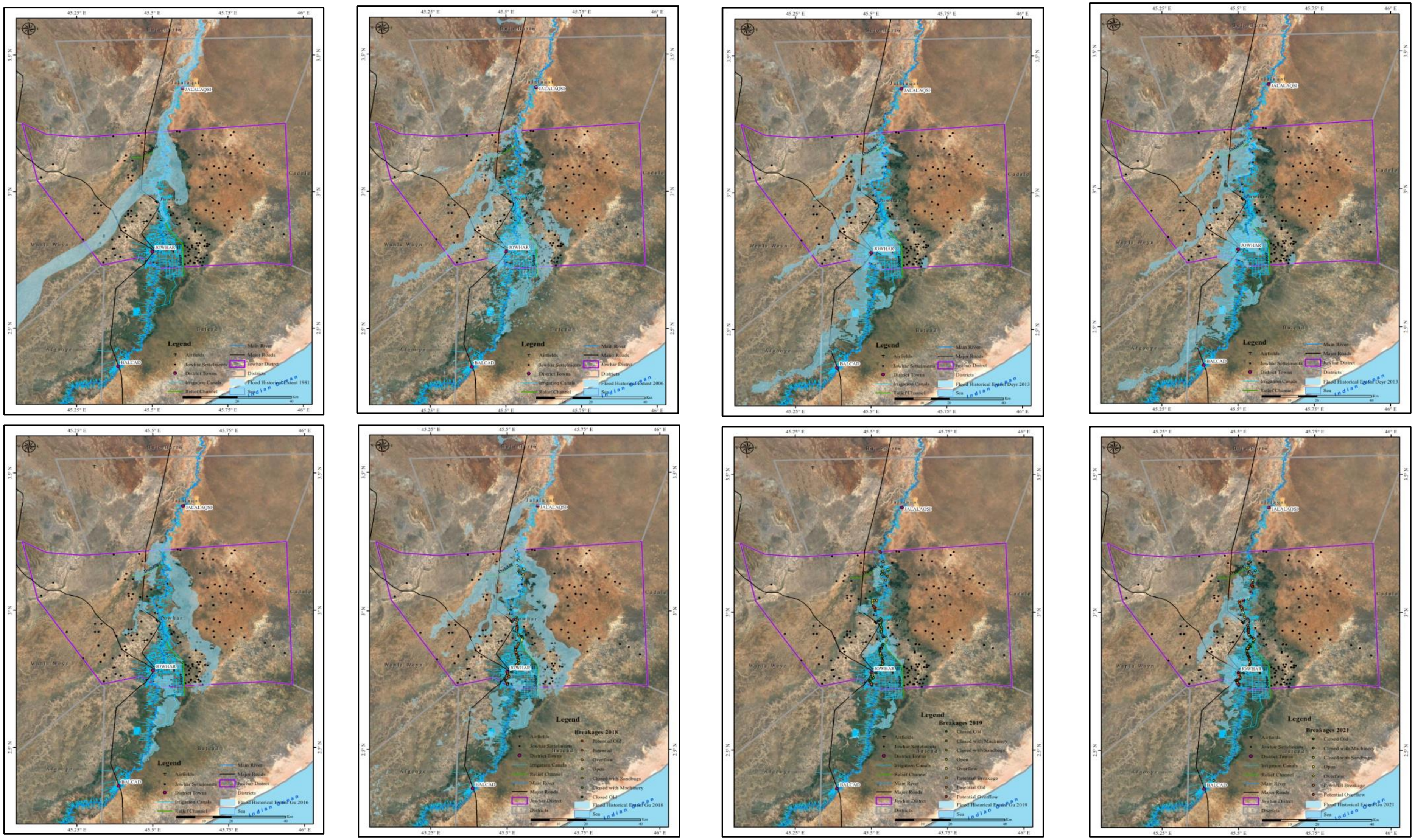


Figure 2-20 Historical Shabelle River flood extents 1981, 1997, 2006, 2013, 2015, 2018, 2019, 2020

3. Existing Irrigation and Flood Control Infrastructure

3.1 Schemes History of Irrigation Development:

Irrigated agricultural development started in 1920 with the implementation of Jowhar Sugar Estate and Baro Weyne rice plantation to provide food security and alleviate poverty for the people living along the riverine areas. The Jowhar Sugar Estate was irrigated from the 24.2 km Jowhar off-stream canal. The scheme, located in Jowhar/Balcad district, initially used to obtain water from the Luigi di Savoia and Duchess d`Aosta canals on the left bank of the Shabelle River. The initial canal was constructed in 1920 to irrigate sugarcane on 10,579 ha of low-lying floodplain through a gravity-fed irrigation system. Potential for scheme extension was estimated to be 32,357 ha. The Baro Weyne rice plantation is located upstream of Jowhar Sugar estate, the scheme was initiated in 1982 to grow rice and maize under a gravity-fed irrigation system. The irrigated area covered 180 ha and extension potential was estimated at 4,200 ha. Between 1950 and 1960, certain areas were brought under controlled irrigation. In 1967, UNDP conducted feasibility studies on the irrigation and flood water controls on the Shabelle River basin and as result canals were constructed to divert water from the Shabelle to low-lying tracts of land. In 1976, a controlled irrigation system was established at Jowhar to provide irrigation water to sugar plantations. Between 1980 and 1990 the irrigation areas largely benefited from a well-established network of canals and drains that controlled by barrages with weirs, allowing for a consistent supplement to the scarce and unreliable rains, with abundant waters from the Shabelle.

The scale of irrigation development increased rapidly thereafter and by 1980 some 60,000 hectares had been developed in Jowhar and Balcad Districts. Between 1980 and 1990, irrigated areas benefited from a well-established network of canals and drains that controlled by barrages with weirs, allowing a consistent supply of water that was supplemental to the scarce and unreliable rains. Irrigation systems were originally based on a limited number of gated gravity – fed river intakes, feeding primary canals (>2.5m wide approx.) controlled by barrages and designed in such a way as to have enough head to command the fields through secondary canals (<2.5m wide approx.) controlled by barrages and, further down, smaller tertiary canals to individual farms' intakes. There are uncontrolled (informal) irrigation systems served by canals directly from the river with no, or limited, control by barrages. Thus, water is only available in these canals at periods of peak river flow.

Much of the infrastructure is in a state of disrepair, either due to direct damage during periods of conflict and civil disorder, or because of simple neglect, although the exact current situation is uncertain. River embankments have eroded, and barrages, pump intakes and canal systems show some degree of sedimentation and vegetation growth which have reduced the canals' hydraulic sections. Silting up of the drainage system was accelerated by the lack of terminal outlets and the flat topography of the irrigation area which restricted drainage water to return by gravity into the rivers. As a result, only fractions of design discharges were delivered, thus considerably reducing the area under irrigation. At present, only certain parts of the irrigation facilities in the area operate, at diminishing levels of efficiency, and only a limited percentage of the area is currently irrigated.

Another result of the dysfunctional canal system is the breaching of riverbanks by farmers to obtain irrigation water, which causes uncontrolled flooding and water wastage. Water shortages have also caused conflict when farmers blocked canals and breached riverbanks for irrigation, thus depriving farmers further downstream of water. Farmers have done their utmost to take over management of irrigation systems from the dissolved government agencies and to some extent have partially succeeded.

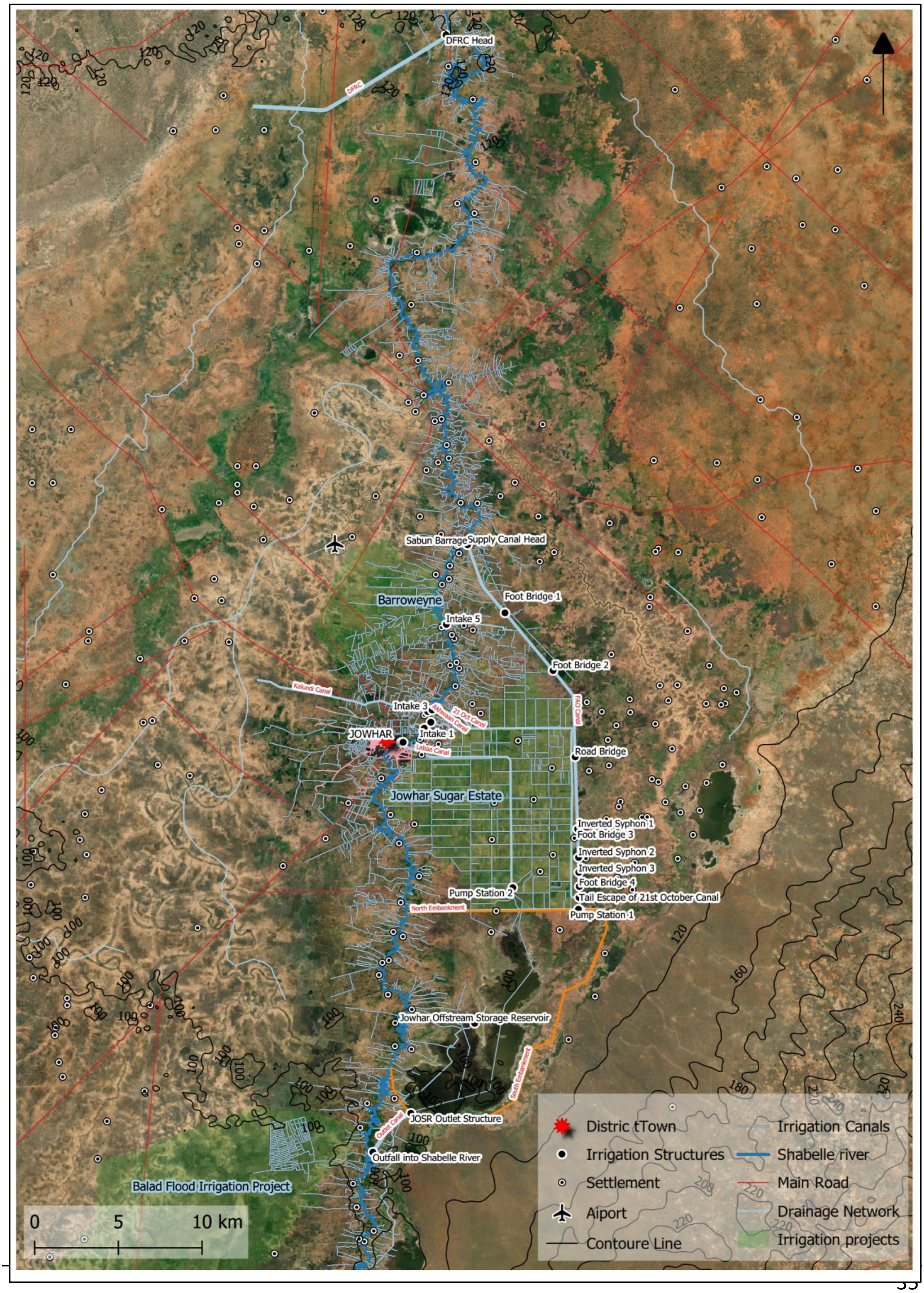


Figure 3-1 Irrigation schemes and flood control infrastructures along Jowhar area

3.2 Flood Control Infrastructures:

Due to the limited capacity of Shabelle river channel to carry much more than the typical annual flood and despite a history of embankment construction, some flooding occurs in most years. Flood control and diversion infrastructures were constructed in the study area e.g., Duduble Flood Relief (Chinese) canal, Jowhar Off stream Storage Project (JOSP) to regulate the uncontrolled flooding and divert water from the river during periods of high flow. Operation of these flood relief schemes significantly reduced uncontrolled flooding, bringing benefit to the entire catchment downstream of the flood diversion.

3.2.1 Duduble Flood Relief (Chinese) Canal:

Duduble relief canal was constructed between Jalalaqsi and Mehaddey Weyn located about 43 Km north of Jowhar town as primary flood control. The feasibility study for the scheme was completed in 1978 by Sir MacDonald & Partner Consulting Engineers and the canal was built in between 1983-85 by a Chinese Construction Company named SIETCO with funds from Saudi Arabian government. The canal was designed with a maximum capacity of 40m^3/s with 10 km length and 25m wide bed by 5 m depth and 1:3 sloped embankment was intended to convey floodwaters from upper section of the river when flows exceed 100m^3/s into the then-proposed 1 million m^3 Duduble Reservoir (dam) situated 40 km north of Jowhar to reduce risk of flooding in the Shabelle valley.

Figure 3-2 Duduble (Chinese) relief canal

A 25 m wide supply canal head regulator with five vertical lift gates 4m wide x 2m high for controlling flow. The regulator is a manually operated wheel and axle type and the head regulator is also fitted with stop log and attendant handling gear. Several control weirs and gates along the length of the supply canal. Specifically the canal was targeted to reduce 40% of the flood while the remaining 60% was to be managed through Sabuun dam. The site was suitable for flood relief works, being a natural spillage area. A 20m wide reservoir outlet regulator fitted with four 4m×1.8m vertical lift gates for controlling water flow is provided to allow excess flood water to be released to open grassland to irrigate pasture.

Figure 3-3 Photos shows Dudable (Chinese) relief canal and head regulator

Due to neglect and lack of maintenance, the canal became completely silted, not delivering any water. Major rehabilitation work was done by UNDP Somalia in 2006. The gates were replaced, walk ways and barrage deck rehabilitated. Although the canal was meant for flood relief, 10 tertiary canals during the rehabilitation process by UNDP were constructed to assist the communities make use of diverted flood waters for irrigation. 9 of these canals measure 5 km long, 4 m wide and 2m deep and the remaining one canal measures 7.5km in length, 8 m wide and 2 m deep. Each is fitted with a single sluice gate measuring 1m by 2m and two concrete single box culverts.

3.2.2 Jowhar Offstream Storage Project (JOSP):

The Jowhar Offstream Storage Project (JOSP) was conceived in the late 1960s, planned in the mid-1970s and implemented in 1980 to divert water from the river during periods of high flow and store excess water in reservoir for later irrigation use downstream during the following dry seasons. The reservoir was operational between 1980 and 1990 and during that time had a significant impact on flows in the lower Shabelle River. It should be noted that the JOSP also included works within the Jowhar sugar estate to improve drainage of the estate. The layout of the project components is illustrated in Figure 3.1. The Jowhar Off-stream Storage Project scheme comprises the following:

1) Sabuun barrage
2) Supply canal (FAO) and head regulator
    - Foot bridges (4)
    - Road bridge (1)
    - Inverted syphon's (3)
    - Pump stations (2)
    - Supply Canal Outfall (JOSR inlet structure)
3) Jowhar off-stream storage reservoir
    - JOSR North Embankment
    - JOSR South Embankment
4) Reservoir outlet regulator

5) Outlet canal and Outfall into Shabelle River

3.2.3 Sabun Barrage

Sabuun barrage/bridge was the most important barrage across the river in Jowhar district. The barrage was constructed in 1925 and was combined with the FAO canal to regulate supply of irrigation water and to protect irrigated lands from flooding in Jowhar area. The barrage has an irrigable command area estimated at 50,942ha (McDonald, 1996). The barrage is a concrete structure with seven 2.5m high by 4m wide hand operated radial gates separated by 1m wide piers. The gate sill is positioned 4.7m below the top structure level and 2.2m above the river bed level. To enable upstream water levels to be lowered below the weir sill level at times of low flow 1.2m square hand operated by-pass penstocks are provided in both abutments with stop-log grooves are provided upstream and downstream of the gates.

Figure 3-4 Upstream and downstream of Sabuun Barrage

The gates and all are stuck and embedded in mud, making it completely non-operational. The upstream of the barrage is blocked by tree trunks, silted up and overlaid by a thick layer of sediment blocking the inlets to the flood relief canal and the Jowhar off-stream supply canal. The gears are broken some of them beyond repair, possibly by explosives and the walk rails are missing as a result of looting and vandalism after the break out of the civil war. The concrete structure itself is in bad conditions and the bridge deck is damaged in many places with no gantry rails, hoists and stop-logs present at the structure in barrage. The concrete block work protection is still present downstream of the barrage, although there is considerable damage and movement of the blocks.

3.2.4 Supply (FAO) Canal and Head Regulator

Supply canal and head regulator was constructed in 1980 between Mehaddey Weyn and Jowhar town. The canal head regulator structure is combined with the barrage at Sabun to conveyance of floodwaters from the Shabelle River to Jowhar Off-stream Storage Reservoir during the Gu and Deyr flood seasons when river flows reach a prescribed minimum discharge. The canal was designed with a length of 24.2km with a bed slope of 0.16m/km, bed width of 27m and internal side slopes of 2:1 and design capacity of $50m^3/s$.

Figure 3-5 Sabuun Barrage, supply (FAO) canal and head regulator

The canal head regulator is a concrete structure with five 1.8m high by 4m wide hand operated vertical lifting wheel and axle type gates, separated by 1m wide piers. The gate sill is positioned 5.4m below top structure level, 1.5m above the river bed level and 1.2m above the canal bed level. The gated openings are provided with reinforced concrete breast walls allowing sealing on all four edges of the gates on closure. The head regulator structure was rehabilitated around 2008 as part of the UNDP project. During the first year of operation the canal capacity was around $40m^3/s$ and in later years the typical maximum flow reduced to $30m^3/s$ and then to less than $20m^3/s$ in 1989 (MacDonald, 1996).

A large accumulation of silt has formed immediately in front of the offtake of the canal and Jowhar off stream supply canal and head regulator gates were found to be completely buried and presently the canal being used to grow banana plants. In general the concrete structure of the head regulator appears to be in a fair condition and the vast majority of the operating gear is no longer present but still need renovation. Small hole has been made in the breast wall of head regulator to allow water for passing into a farm allocated along the canal through small canal when river level is sufficiently high.

In total, four foot-bridges and one road-bridge were constructed in different locations along the supply canal to allow movement of people with two further crossings at the head regulator and outfall structure. Some of these bridges are still present and in a serviceable condition and some are no longer functional and in most cases only the concrete piers remain, with the steel spanning members having been removed from the structures.

Figure 3-6 Upstream and downstream of supply (FAO) canal and head regulator

Table 3-1 Supply canal monthly mean flows (cubic meters per second) from 1980 -1989:

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual mean
1980	0.0	0.0	0.0	0.0	6.7	0.3	0.0	2.7	12.3	0.0	0.0	0.0	1.8
1981	0.0	0.0	0.1	39.2	40.5	3.4	0.0	4	20.5	26.4	1.3	0	11.3
1982	0.0	0.0	0.0	1.1	15.6	13.5	0.0	5.8	14.3	12.9	26.0	0.6	7.5
1983	0.0	0.0	0.0	0.0	6.1	17.0	1.5	13.6	28.4	26.8	10.7	0.0	8.7
1984	0.0	0.0	0.0	0.0	0.0	0.0	4.5	10.9	14.5	16.2	1.4	0.0	4.0
1985	0.0	0.0	0.0	4.8	28.2	21.3	3.7	19.1	21.7	15.3	0.0	0.0	8.8
1986	0.0	0.0	0.0	106.0	12.3	15.2	16.1	16.4	16.6	7.6	0.0	0.0	7.2
1987	0.0	0.0	0.0	0.0	11.8	34.5	31.2	18.8	1.3	0.0	0.0	0.0	8.2
1988	0.0	0.0	0.0	0.1	8.4	0.0	6.3	20.2	21.4	21.6	14.8	0.1	7.8
1989	0.0	0.0	0.0	2.4	17.5	17.5	16.0	13.7	14.2	13.0	3.6	0.0	8.2
Mean	0.0	0.0	0.0	4.9	14.7	12.3	7.9	11.6	16.5	14.0	5.8	0.2	
Max	0.0	0.0	0.1	39.2	40.5	34.5	31.2	20.2	28.4	26.8	26.0	1.0	
Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	1.3	0.0	0.0	0.0	

Siphon structures were constructed along the supply canal including three inverted siphons for irrigation canal offtaking from 21st October canal; tail escape of the 21st October canal discharging into the supply canal; two pumping stations for disposal into the reservoir or into a drainage evaporation area east of the reservoir perimeter. The drainage pump station was equipped with five diesel driven inclined axial flow pumps each with a nominal capacity of 900l/s and pumped drainage outfall culvert allows the drainage water to be discharged from the pump station pond to the reservoir and Its comprised two 1.2m diameter pipes with outlets fitted with flap gates and inlets fitted with hand operated sliding gates. The concrete structure has significant damage and the pipework and pumps have been removed.

The siphon structures are in a universally poor condition with the culvert barrels under the canal completely silted up in all cases and the inlets and outlets obstructed by vegetation. The concrete inlet and outlet structures appear in most cases to be in a serviceable condition but with concrete repairs required in most cases. The tail escape structure of the 21st October canal which is in a particularly poor condition and requires complete replacement (MacDonald, 2015).

3.2.5 Supply (FAO) Canal Outfall

At the downstream end of the supply (FAO) canal there is an outfall structure with bridge deck controlling the drop in water level from the supply canal into Jowhar off-stream storage reservoir. The outfall comprises a 19m wide weir placed in the northern reservoir embankment, close to a high ridge to the east of the reservoir. The weir crest is set 0.75m above the design level of the canal bed. The downstream face of the weir includes eight rows of baffle blocks, a gravel-filled basin and dry stone pitching providing protection against erosion up to 25m downstream of the weir base.

Figure 3-7 Photo shows supply (FAO) canal outfall structure (Source: WOOCA)

At present, the weir crest is completely eroded and is inseparable from the canal bed. The downstream face of the weir has been eroded and does not provide protection against erosion as was intended. This level of siltation is high in canal bed about 1.5m above the crest of the outlet structure and prevents all flow down the canal. The concrete structure itself appears to be in a serviceable condition only some minor cracks. The area around the structure is heavily vegetated with trees and brush. The hand railing on the bridge crossing the weir has been removed and needs to be replaced. The downstream erosion protection is apparently still present. It would seem sensible however to make some allowance for replenishment of this protection to the original design thickness and extent.

3.2.6 Jowhar Off-Stream Storage Reservoir

Jowhar off-stream storage reservoir located in a natural depression downstream of the Jowhar Sugar Estate on the left bank of the Shabelle River and extending over approximately 100km^2 with maximum live storage capacity of 205 million m^{3}at the time of design. It comprises two low earthen embankments (North and South Embankments) closing against the left bank river levee to the west and a high ridge to the east.

Figure 3-8 Photo shows Jowhar off-stream storage reservoir and embankment

The reservoir was designed to collect surplus river flows during the Dyer season for subsequent release for irrigation during the following dry season (i.e. November to March approx.). The reservoir was commissioned in 1980 and was operational between 1981 and 1990 and during that time had a significant impact on flows in the lower Shabelle River. Table 3.2 shows monthly mean volumes of water stored in the reservoir. The reservoir was filled to capacity in late 1989, and close to capacity in December 1982, November 1983, August 1987 and December 1988.

The operating rules at the reservoir at the point of commissioning are set out in the Operation and Maintenance Manual (MacDonald 1981). Currently the reservoir has a thick layer of sediment and does not contain any water.

Table 3-2 Monthly mean volumes (million cubic meters) from 1980 -1989:

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mean
1980	0	0	0	0	1.2	6.3	0	0	12.7	11.5	3.7	0.1	2.9
1981	0	0	0	28.2	111.6	141.1	96.8	56.8	78.5	130	156.1	136.2	78.3
1982	104.2	72	39.7	10.6	24.1	69.7	67.9	58.8	80.4	104.8	160.2	198.5	82.7
1983	175.2	128.1	78.5	37.5	29.2	45.4	70.3	65.7	107	152.9	189.2	173.4	104.3
1984	143.5	110.9	68.4	25.2	5.4	0.6	0.4	6.2	21.9	45.1	65.8	56.3	45.6
1985	34.2	13.1	3.6	3.9	38.4	84.2	86.5	80.9	101.2	122.7	125.2	111.6	67.4
1986	89.3	58.1	31.5	21.1	40.9	78.8	106.8	136.3	160.6	176.7	163.2	144.8	101
1987	99	57.9	27	11.3	15.2	79.6	155.6	192.5	188.3	169.7	170.4	149.5	110.1
1988	104.2	45.5	18.7	9.7	13.1	15.8	13	28.7	76.8	128.1	171.3	182.1	67.4
1989	158.9	127.2	94.1	73.1	90.3	118.7	141.5	158.7	171.5	189.4	208.8	205.9	145
Mean	90.9	61.3	36.1	22	37	64	73.9	78.5	99.9	123.1	141.4	135.8	
Max	175.2	128.1	94.1	73.1	111.6	141.1	155.6	192.5	188.3	189.4	208.8	205.9	
Min	0	0	0	0	1.2	0.6	0	0	12.7	11.5	3.7	0.1	

The North Embankment, with a length of 11.32km running from the River Shabelle flood bund to the supply canal outfall structure, and it has an interceptor drain on its northern side that designed to collect drainage water from the Sugar Estate and convey it to the pumping station for disposal into the reservoir or into a drainage disposal area. The South Embankment has a length of 14.6km and is the higher of the two embankments with a maximum height above ground level of 4.30m. These embankments have been breached by flood waters many times and the banks are poorly defined in some locations. Extensive rehabilitation and strengthening of the existing embankment will be required, although this can only really be determined once the vegetation has been cleared and a full topographical survey has been completed.

3.2.7 Outlet Canal and Head Regulator

The reservoir outlet canal is situated at the lowest point of a natural depression controlled by outlet regulator structure and its joins the Shabelle approximately 40km downstream of the intake to the supply canal crossed by the south embankment 3.1km from the Shabelle River flood bund. The design of the outlet canal is trapezium-shaped with an internal berm at ground level and a bed width of 19m the canal is designed to convey 25m^3/s to return the flows to the river and it was commissioned in June 1980. The embankments of the outlet canal are covered in dense bush but the canal is completely silted, overgrown by trees and no water outlet. The channel bed is seasonally cultivated in some locations. The end of the outlet channel has been deliberately closed off by local villagers to stop backflow of water from the Shabelle River which causes local flooding (MacDonald 2015).

Figure 3-9 Outlet canal and head regulator

A 20m wide reservoir outlet Regulator Structure comprises 4 x 4 meter-wide sluice gates with a total capacity of 25m^3/s at full supply level for controlling the return flows to the river, via the outlet canal. For the outlet canal, little flow data was available after 1985 and there were several short periods of missing data. The flows for these periods were therefore set to zero. The maximum flow ever passed down the supply canal was about 23.4 million m^3 (in 1988).

Figure 3-10 Photo shows outlet canal and head regulator

Table 3-3 Monthly mean flow rates from the outlet channel:

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mean
1980	0	0	0	0	1.4	9	0	0	2.4	5.2	0	0	1.5
1981	0	0	0	0	0	0	0	0	0	0	6.4	8.1	1.2
1982	10.8	10	8.9	3.6	0	0	0	0	0	0	0	0	2.7
1983	8.1	21.9	19.3	11.9	0	0	0	0	0	0	9.7	22.4	7.7
1984	19.9	17.9	19.8	16.6	8.7	0	0	0	0	0	13.9	8.6	8.7
1985	13.6	12.8	9.6	1.5	0	0	0	0	0	0			
1986	*	*	21.7	*	*	*	*	*	*	*	*	*	*
1987	*	*	20.2	*	*	*	*	*	*	*	*	*	*
1988	23.4	*	*	*	*	*	*	*	*	*	*	*	*
1989	*	*	*	*	*	*	*	*	*	*	*	*	*
	*	*	*	*	*	*	*	*	*	*	*	*	*
Mean	10.8	10.4	12.4	5.6	1.7	1.5	0	0	0.4	0.9	6	7.8	
Max	23.4	21.9	21.7	16.6	8.7	9	0	0	2.4	5.2	13.9	22.4	
Min	0	0	0	0	0	0	0	0	0	0	0	0	

The concrete structure of the outlet regulator appears to be in a good condition; the gates are apparently all present and in a closed position and most of the operating gear are no longer present.

It is likely that minor concrete repair works are required in places; however, there are no obvious signs of major problems.

Flood control and river regulation infrastructure has continued to decline. The sedimentation that made the riverine areas being raised above the surrounding flood plain, unregulated settlement in flood plains and the recent practice of breaching river embankments for informal flood irrigation has progressively increased flood risk to the riverine communities.

3.2.8 Other Structures

Baroweyne rice plantation and Jowhar sugar estate benefited from water diverted using the Sabuun barrage and there were irrigation system and drainage infrastructure constructed to irrigate these schemes *(see Fig 3.11).*

- **The Jowhar Sugar Estate**

Both the supply and outlet canals of JOSP used as flood relief infrastructures and also feed secondary canals serving irrigated areas under Jowhar Sugar Estate. The Jowhar Sugar was founded in 1920 and originally grew cotton.

Following independence in 1960, a new sugar factory was built in 1965, with an annual capacity of 40,000 tons of sugar. In 1983, the gross irrigated area of the Jowhar Estate was some 10,500 ha, with a net cultivable area of 8,230ha with upgrade of the irrigation system and drainage infrastructure. Between 1983 and 1990 the lack of proper maintenance coupled with civil war, poor irrigation techniques had resulted in low irrigation efficiency and poor irrigation distribution led to water logging and salinity problems. Currently the factory and all the buildings on the estate had been destroyed or stripped to a skeletal frame. Most of the canals are silted up and/or overgrown and the regulating structures in poor condition. The drains remained largely ineffective.

Around 50% of the estate area is under cultivation, with a mixture of irrigated and rain-fed crops including sesame, maize and vegetables (SWALIM 2015). Water levels for irrigation abstractions in the reach upstream of Jowhar are controlled by operation of Sabun barrage and a fixed crest weir in Jowhar town. Irrigation for part of the estate is provided by two secondary canals, namely the Labaa and 21st October (Gomey) canals and irrigation west of the river is also by secondary canals such as Kalundi canal which are operated and maintained by the collective of farmers benefiting from the irrigation.

- **Jowhar Weir**

A concrete weir was built in 1924 by Italians upstream of Jowhar town (Fig 3.12) to raise water level and control water getting into the canals (21st October, Labaa and Kalundi) that irrigate the sugarcane plantations its play a significant obstruction on reducing the sediment transport that causing the level of the upstream river bed to rise. In the long term consideration should be given to replacing the weir with a gated structure to better allow the passage of silt. The weir in general in fair conditions and there are signs of cracking and movement of the right weir abutment and the left abutment has almost completely disappeared.

370 meter west of the weir there is a bridge that connects the main part of Jowhar town to the old sugar cane factory and the eastern side of the town. Currently there is less water upstream of the

weir; hence there is no overflow downstream. This has resulted in dry river beds that are currently seen at Jowhar and other locations downstream.

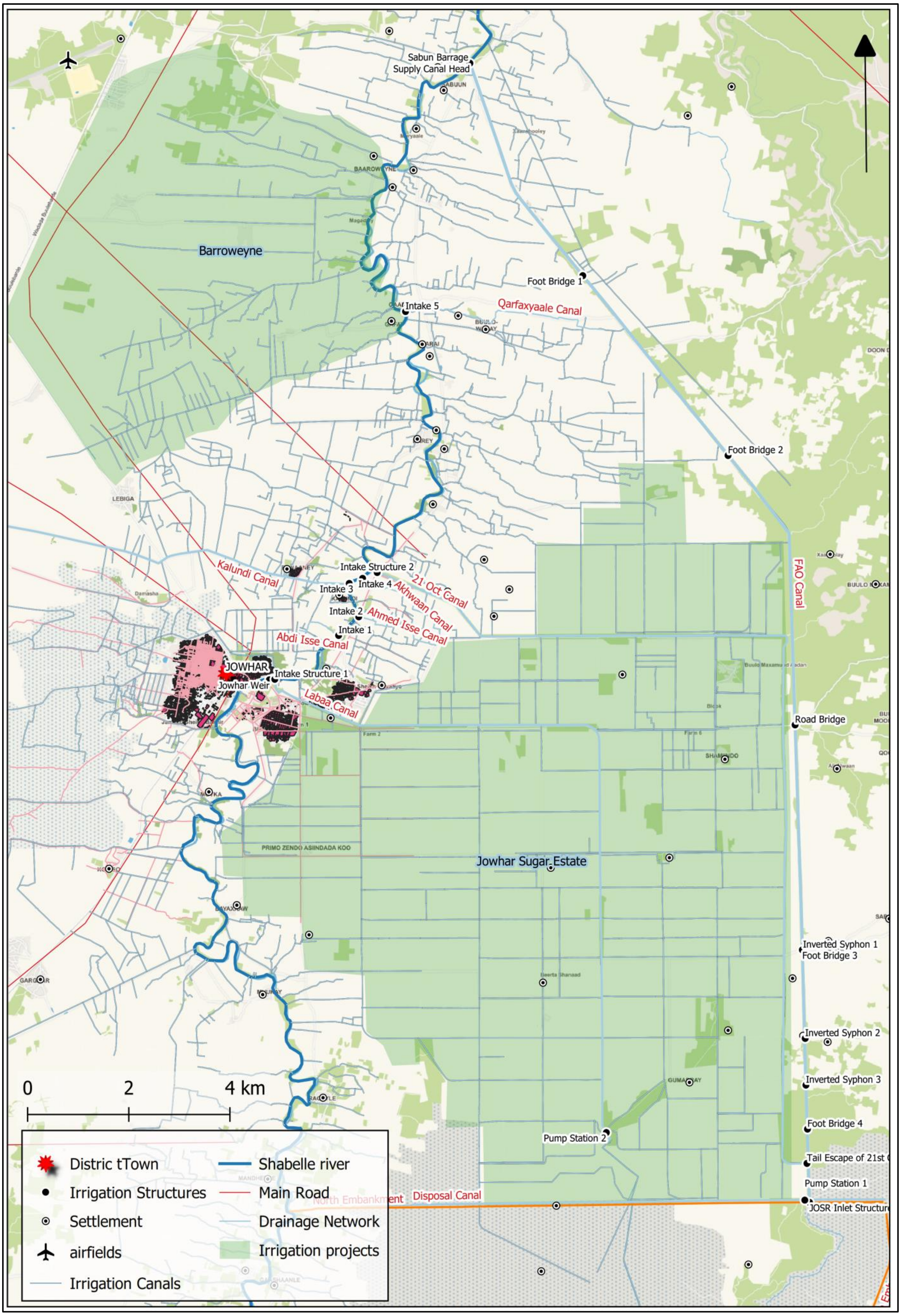


Figure 3-11 Map shows Baroweyne and Jowhar sugar Estate

Figure 3-12 Jowhar weir

- **Labaa Canal**

Labaa primary canal is about 15 km long, draining via sugar estate into JOSR and it feeds number of small secondary canals. The intake structure for the Labaa canal is located immediately upstream of the weir at Jowhar and was constructed in the year 2000. This intake provides water to both the Labaa and 21st October canal. The canal is heavily silted with significant vegetation growth and part of it is no longer used for irrigation.

Offtake structures, bridges and other ancillary infrastructure down the canal are in varied conditions states and need rehabilitation. The gates became corroded and were replaced by the local farmers and support from FAO. The river embankment has been damaged by the river and the canal banks have been breached in some locations and subsequently repaired using sandbags. There is also a significant area of scouring downstream of the structure which has washed material behind the wing walls on both banks and is beginning to encroach on the foundations of the adjacent pump house on the left and the river bank on the right. These issues should be addressed in the near future to avoid a future breach in this location. Raqayle and Azenda villages are heavily affected by the flood.

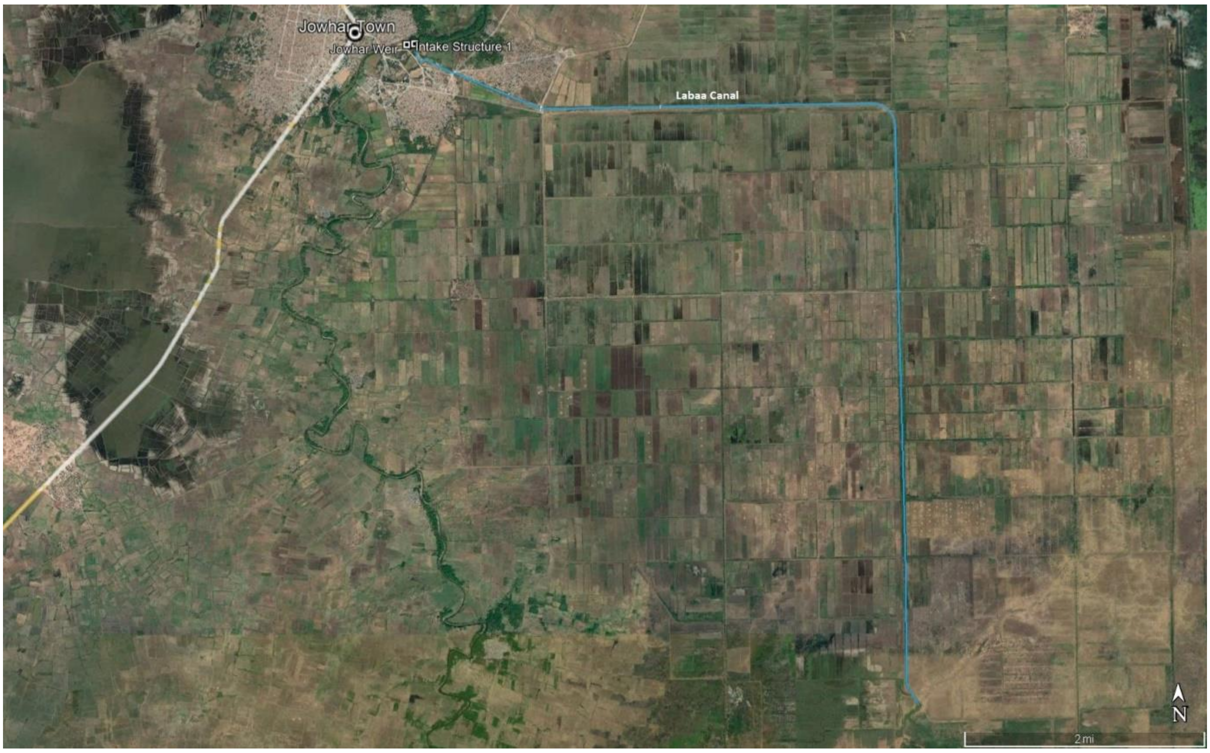


Figure 3-13 Figure 3.13: Labaa Primary Irrigation Canal

Figure 3-14 Intake structure and down reaches of Labaa Primary Irrigation Canal

- **21st October (Gomey) Canal**

21st October or Gomey primary canal is about 20km long with designed top width of 7m, a bottom width of 3m and a depth of 2.5m, the current depth is varies from 0.8m to 1.5m in some locations., draining via sugar estate into JOSR and it feeds number of small secondary canals. The canal has two intake structures; one for Labaa canal that also provide water to 21st October canal and other one a located upstream the weir and Labaa Canal Intake. This intake has three vertical lift steel gates of dimension 2m width and 3m height were originally operated within the three gate bays of the concrete intake structure.

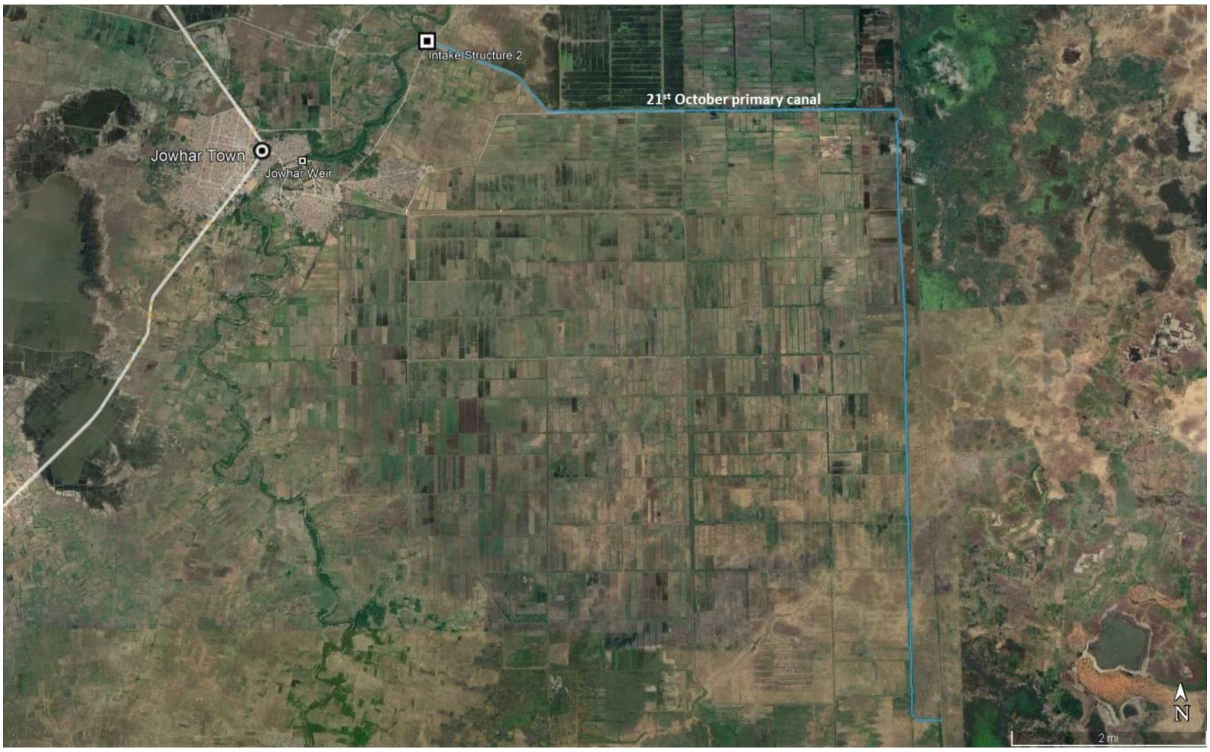


Figure 3-15 21st October (Gomey) primary canal

Figure 3-16 21st October primary canal intake structures

The structure normally and only passes water at high river levels, through the open gate bay. These bays are sealed with sandbags when flows are no longer required. The structure also supports a reinforced concrete bridge deck carrying the Jowhar to Sabuun road over the canal. The concrete structure and bridge deck itself appears to be in reasonable condition. The channel and banks appear to be not well formed in some locations and becoming more progressively more silted from upstream to downstream and heavily vegetate. The canal is maintained by the farmers benefitting from the irrigation. Towards the tail end of the canal, the channel becomes progressively less well defined and eventually heavily vegetated, with an abundance of large trees. A tail escape structure is provided at the downstream end of the canal to allow excess flows to be discharged through a culvert running under the FAO feeder canal. This structure is completely silted up and is no longer in a serviceable condition. The culvert is broken at the upstream and downstream end.

Figure 3-17 Intake, upper reaches and tail escape of 21st October Canal into supply canal

The Baro Weyne rice plantation is located upstream of Jowhar Sugar estate, on the Shabelle River in Jowhar district. The scheme was initiated in 1982 to grow rice and maize under a gravity-fed irrigation system. The irrigated area covered 180 ha and extension potential was estimated at 4,200 ha. The scheme is currently operating partially.

- **Kalundi Canal**

The canal has a length of about 10.25km long and top width of 7m, a bottom width of 3m and a depth of 2.5m, located west of the river (right bank) and north of the town before 21st October canal intake. The canal is heavily silted and need rehabilitation. The intake of the canal has three vertical lift steel gates of dimension 2m width and 3m height were originally operated within the three gate bays of the concrete intake structure. The concrete structure of the inlet appears to be in reasonable condition with some cracks. The channel and banks appear to be in fair conditions and more progressively more silted from upstream to downstream. The canal is maintained by the farmers benefitting from the irrigation and a rudimentary repair has been carried out using sandbags.

Figure 3-18 Intake structure and down reaches of Kalundi Primary Irrigation Canal

4. Hydrologic Analysis

4.1.1 Overview

The main aim of this study initially is to assess the existing flood risk, evaluate and develop available flood control planning methodologies, with main focus on how to provide aid for preventing and mitigate future flooding due to extreme weather using hydrological and hydraulic modeling. Filed survey and community consultation were undertaken in February 2022 and through that process a large number of options were collated to reduce flood risk which had been suggested by the community, government and other stakeholders. The study was performed as a multi-loop process, see conceptual model in Figure 4.1 which includes a computer model part, the top loop describes a classic model creation process where data about the system was gathered, simplifications were made and a computer model was created and calibrated.

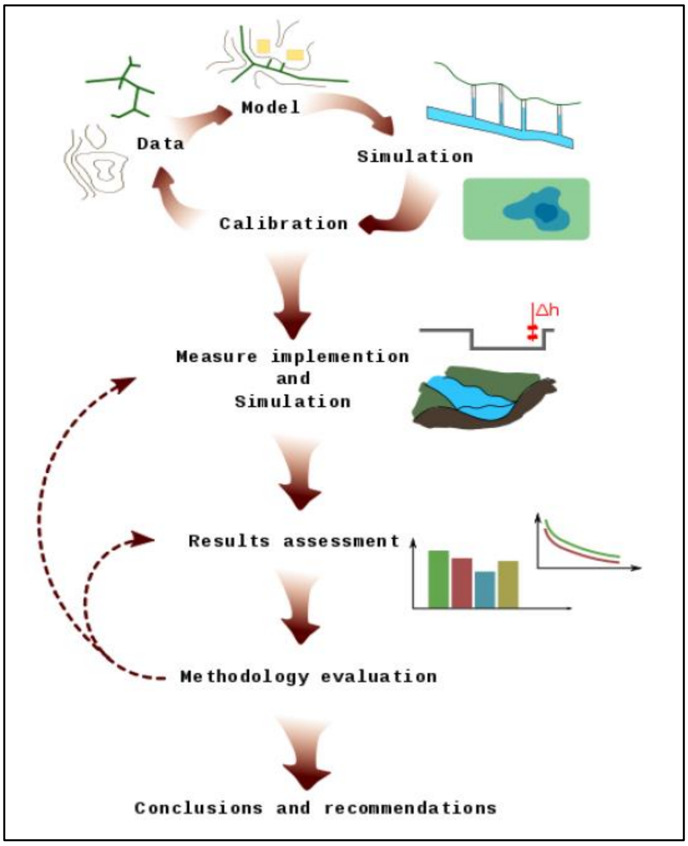


Figure 4-1 Conceptual model of the method used.

This model could then describe flood scenarios with precipitation data as input. The next step was to test measures by implement them into the model and run new simulations.

The analysis undertaken is substantially dependent on data avilable. It was not within the resources of the study to verify data information received; conclusions reached are, inevitably, subject to the quality and completeness of data received. The focus of the study was mainly on the implementation and assessment of flood mitigation measures in form of surface water control and only briefly handled general flood risk management.

The early stage of the study involved determining the existing level of flood risk through Jowhar area. This included collecting of topographical data, field measurement and observations to generate models that will represent current conditions and to ensure consistency with current best practice. This process ensured the modeling complied with relevant guideline.

4.2 Hydrologic Modeling and Calibration

A hydrologic model of the catchment with selected segment of river channel within the study area was developed for the purpose of extracting flows to be used as boundary conditions in the 1D-2D 'HEC-RAS' hydraulic model.

4.2.1 Topographic and Physical Survey

- **DEM Data**

Digital Elevation Model (DEM) data for the study area was made available from the USGS website. DEM was available in 90 m grid resolutions for the entire catchment. This data was checked against known data and cross referenced against existing survey cross-sections. Digital elevation model was used to analyze topography and to identify water pathways and natural ponds which then were used to create a surface flow path model.

- **Filed Survey**

A field survey was conducted during February 2022, with the aim to:

1. Survey the drainage and irrigation infrastructure
2. Check the flood control structures conditions, and measure geometry where possible of these structures to ensure accuracy and appropriateness for use in hydraulic modeling;
3. Identify the location and characteristics of additional structures
4. Record the locations and characteristics of all structures assessed during the field trip using a differential GPS unit.
5. Conduct topographic cross sections along the river and selected irrigation canals

Topographic cross sections were conducted in Jowhar area using the total station a long Shabelle river, Kalunde, 21 Oct, Labaa canal, Abdi Isse, Ahmed Isse, Akhwaan and Qarfaxyaale canals. The cross sections were designed to be roughly perpendicular to the direction of the river course (Fig 4.2).

A selection of the photos taken during the field survey is presented below. It shows quite unique infrastructure that requires the geometry and losses to be represented accordingly in the hydraulic model.

Figure 4-2 Photos shows the field data collection.

4.2.2 Hydraulic Model Development

The modeling software used in this study is HEC-RAS, consists of two coupled models, a one-dimensional model and a two-dimensional model for the water flow on the ground surface. Two-dimensional steady flow routing model option has been utilized to model flood depth and width which capable of integrating complex channels and structures under certain hydrologic conditions. HEC-RAS also has the capability of modeling drainage structures of road embankment such as culverts and bridges under a wide range of scenarios.

The HEC-RAS hydraulic model development requires a number of steps:

- Document past flood history, including recent and recorded flood events as well as historic and observed events; information gathered from a variety of sources,
- Input geometric data to HEC-RAS from the surveyed cross sections and DEM, with sections extending beyond largest floodplain expected identified.
- Input roughness based on observations obtained in the field.
- Input expansion and contraction coefficients for crossing structures, such as bridges and culverts.
- Input geometric data to HEC-RAS for flood control structures, bridges, weir, and other significant river and flood plain features. Locations of cross sections, placement of ineffective flow areas, and the other parameters for modeling the structures follow accepted and recommended procedures and guidelines as described in HECRAS.
- Calibrate to previous flood study.
- Calibrate the model with reference to other historical, surveyed high water mark data from past floods where this information is available.

GIS technology plays a useful role in all dimensions of drainage basin management, ranging from evaluating drainage basin characteristics all the way to modeling of human activities impacts. This study involved use of various datasets includes climate data, road, settlements, water points, Normalized Difference Vegetation Index (NDVI). The data required was governed by a number of criteria that affect site selection which included slope (topography), geology, soil type, catchment size, land cover…etc. The following methodology was applied for the HEC-RAS modeling:

1- GIS software was used to provide an initial delineation of the model area
2- The resultant delineated catchment was then inspected and manually adjusted based on the site's topography
3- The model was constructed, selecting reach types, slopes and subarea fraction impervious values;
4- Flood frequency analysis was carried out
5- The model was run in design mode to determine flood peaks. These were compared to flood frequency analysis at Belet Weyne gauge station to determine design loss parameters;

The work includes incorporation of all pertinent topographic, geometric, geomorphologic and hydrologic data into a single, calibrated, backwater model that accurately represents flood conditions, including hydraulic and energy grade lines, and estimated flow depths and velocities. This task is central to the entire flood hazard study.

Additional data not extracted by HEC-RAS from GIS data was defined in the HEC-RAS model, such as the dimension of road embankment lateral structures. HEC-RAS utilizes user-defined GIS layers to extract information from the terrain data, for generating the cross sections the USGS hybrid digital elevation model DEM of 90 m resolution was used.

Field cross-section data are used in HEC-RAS to characterize the flow carrying capacity of the river and irrigation canals and adjacent floodplain to capture the maximum probable inundation over the study area. The cross section data defines the river bank lines, which separate the main channel from the over bank as shown in annexes.

The cross sections for the general stretch of the river were done at different interval. In places where there exists hydraulic structures, transects were taken at closer intervals both upstream and downstream of the structure. The downstream reach of the channel is also calculated from one cross section to the next cross section, and parameters such as roughness coefficients, contraction and expansion coefficients determined for that reach length.

Additional cross sections, stream centerlines, and other geometric features of the stream out of Jowhar area were extracted from GIS using HEC-RAS and ArcGIS based plat from due to some security challenges with access. After determining the boundary of the catchments, sub catchments, a flow direction and accumulation, through computing TOPAZ, the Hydrological Model input parameters of these small catchments were computed with aid of soil and Land-use created earlier.

4.2.3 Model Construction

The model used for the analyses consists of two parts, a one-dimensional network model and a two-dimensional ground elevation model. These were configured separately before they were coupled. First intention was to also include the JOSRP infrastructures in the model, but this was later decided not to be included since the flows to this area would be very hard and tricky to describe.

4.2.4 Model Calibration

The HEC-RAS model was run in unsteady conditions, where flow at a particular location varies with time. The model calibrated to the gauge record at Belet Weyne and data was used as precipitation input. The main parameter for HEC-RAS calibration is the Manning's coefficient of the main river channel and over bank. For this study, the assumed Manning's values for the main channel and over bank were estimated from literature, and varied from 0.025 to 0.035. Further calibration is expected with more realistic values from the aerial photography results on land use and land cover along the riparian areas of the two rivers.

The results of the calibration are shown in Figure 4.3 below. The result was calibrated against data on water depths and spreading in the form of eye witness reports and photographs as no real measurements on flows were available. The model was first ran as a pure 1D model since this was much faster than running the coupled model and thus some calibration and assumptions could be handled quicker.

The first 1D result showed that in the north part the water level exceeded bank level, which was correct as flooding did occur in this part. If the capacity was exceeded as much as in the real rain event could however not be determined before the first coupled 1D-2D simulation results. In the southern part the water level did not exceed banks level thus causing no flood, which was not correct since this area was subjected to severe flooding during the real rain event. In this manner a pre-calibration was performed for the 1D model and this mainly by adjusting the catchments imperviousness to increase the runoff. Setting up the coupled model turned out to be a struggling process as the numerical calculations reached instability in several occasions.

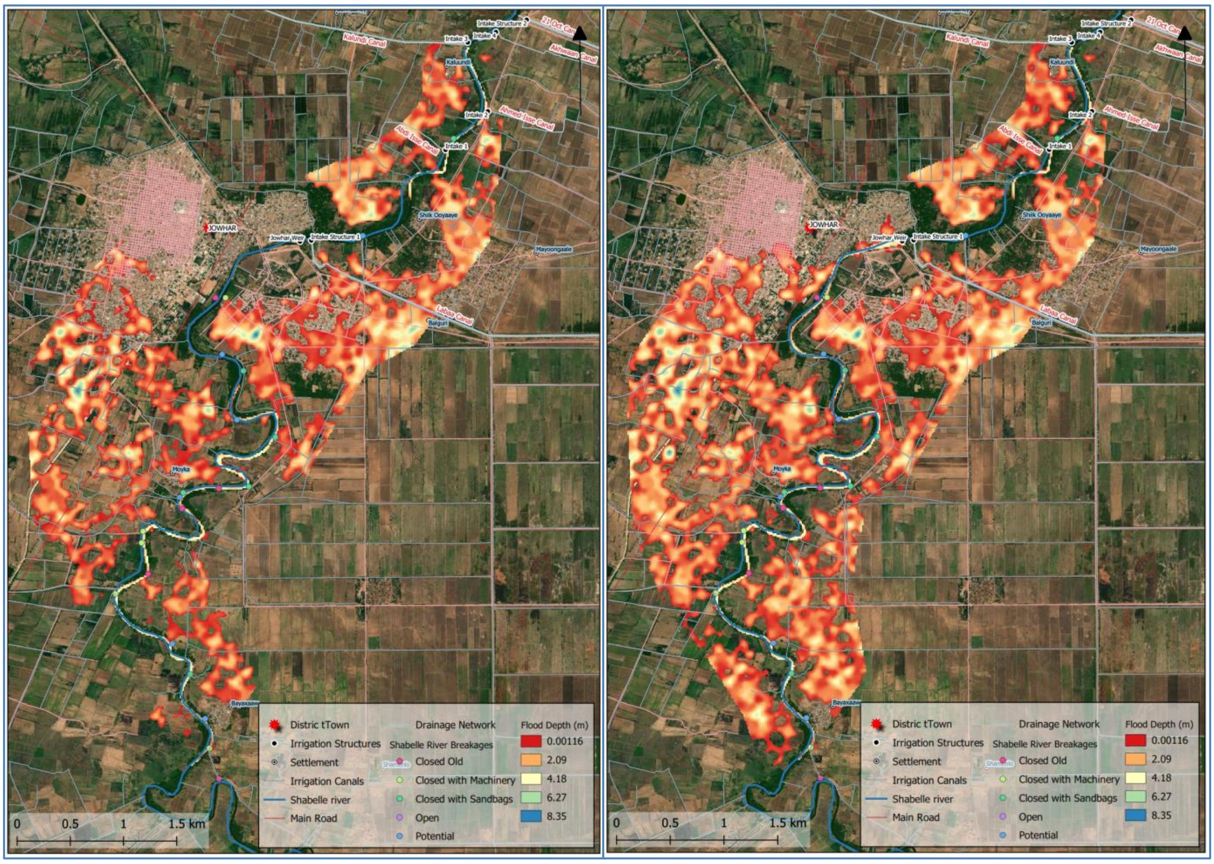
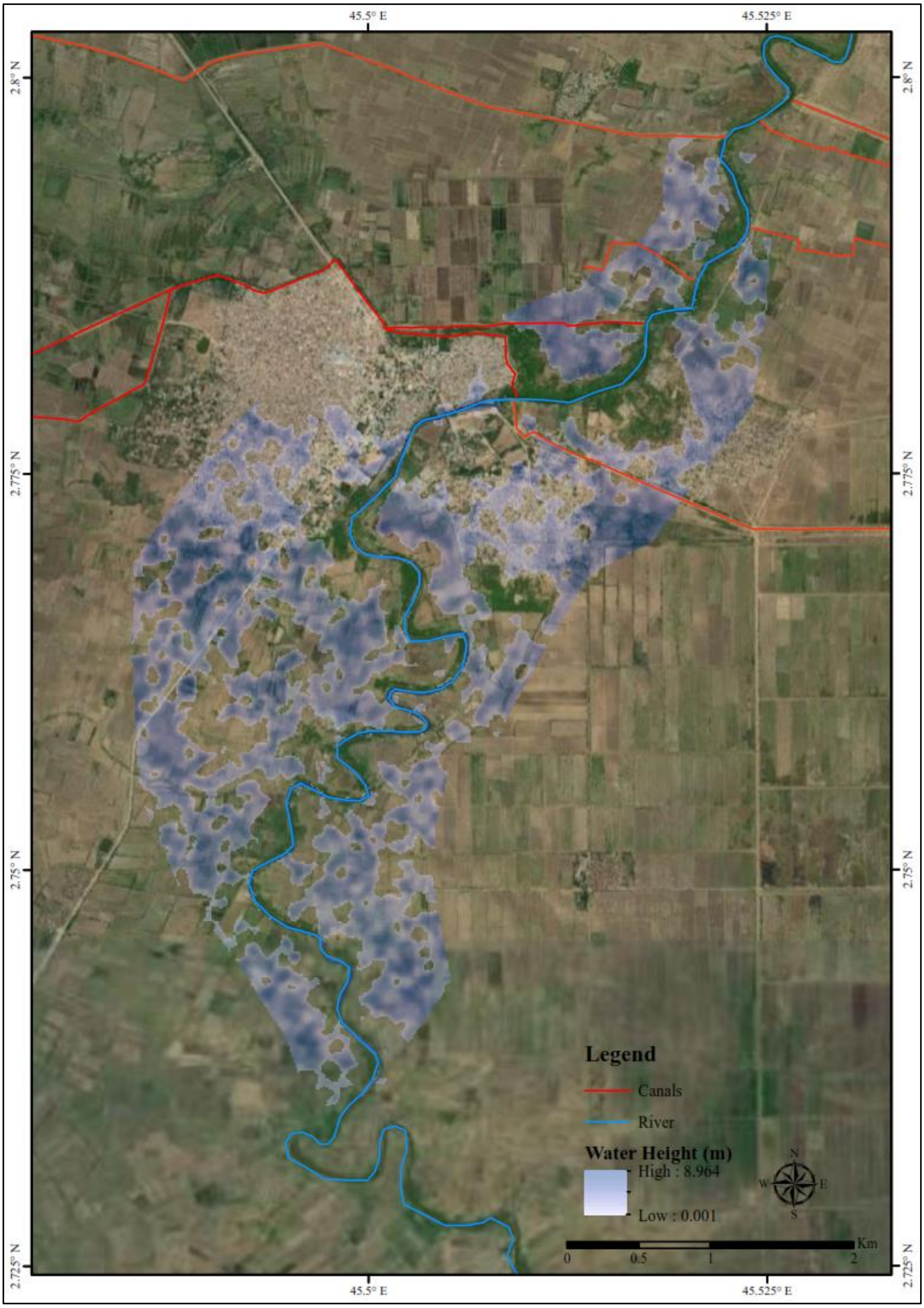


Figure 4-3 Maximum flood depth in meters; Left: a result that did not correspond with the real rain event. Right: results from final calibration

After many different set-ups and trial runs the most likely reason to the blow-ups were considered to be the high resolution that lead to the numerical calculations becoming very sensitive. This meant that very small changes could make the model stable. Biggest stabilizing action was the exchange of the DEM, but still some blow-ups occurred.

The first simulation results from the coupled 1D-2D simulation showed a flood evolution (how the flood started and how it spread) that did not coincide well with the real rain event. The area around Hantiwadag and Kulmis showed no flooding in some areas at all which was also incorrect compared to the real scenario. As is seen in Figure 4.4, these areas had a severe water gathering in the area and a couple of houses suffered from flooding. There are a lot of river bank breakages along the Shabelle Rivers which divert water from the channel to irrigation fields. These cuts/breakages need to be incorporated into the model, as well as tributaries which contribute to flow into the rivers to further improve the results. Much of errors in flood extent were explained by the errors in the first DEM. Its sprawling surface made the water gathers in deep ponds and prevented the water from spreading in a natural manner. With the new DEM used in the model the simulated water flow paths were more realistic and the locally deep depressions were removed.



·Figure 4-4 Figure 4.4: Flood depths for a 50 year rain event

s

and used in the assessment methods. However, here is a potential source of error. It was identified that the land use maps and the DEM did not always synchronize.

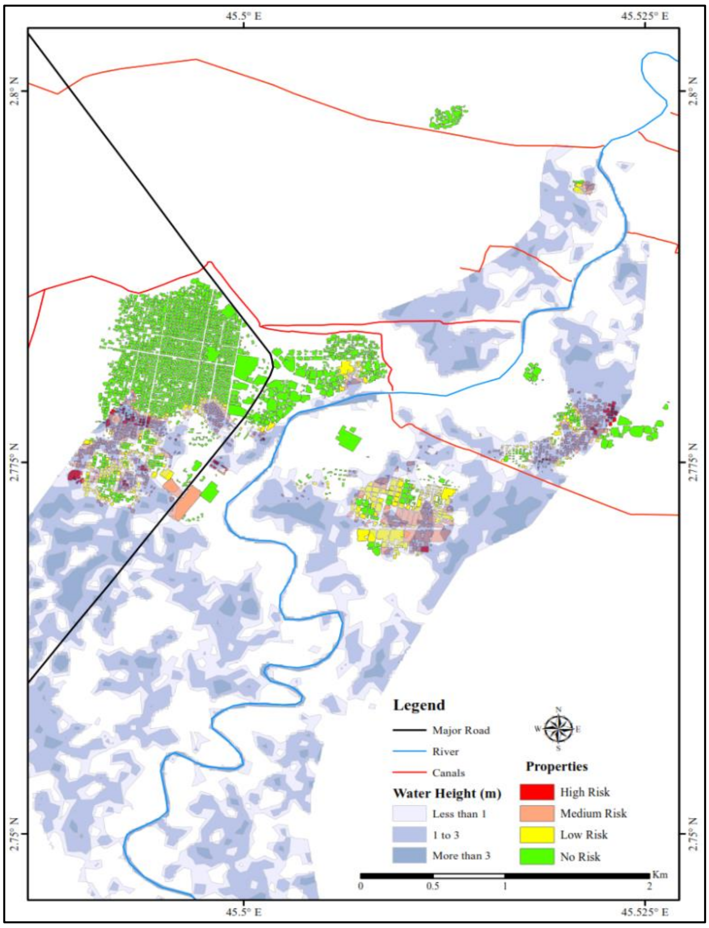


Figure 4-5Figure 4.3: Flood risk map

The major part of the calibration was to adjust the imperviousness of the catchments. Since model was showing no flood, or lower flood extent than the real scenario, the modeled runoff was too low and hence the imperviousness was too low. The natural areas to the east of the residential areas consist of a fairly high amount of outcrops, which also makes a higher imperviousness reasonable. The maximum risks and the damage probability in flooded area and maximum flooded buildings were calculated by GIS analyses of the maximum flood extent. The results are shown in Figure 4.5

4.2.5 Model Limitations

The model validation indicates that the model is generally performing through much of the study area. There are some locations, where further localized modeling would be recommended as part of the next stage of design.

4.2.6 Detailed Mitigation Option Assessment

The analysis carried out under the current study confirms that, when operable, the JOSP improves resilience to both flooding and drought in the Middle Shabelle. Full rehabilitation of both the JOSP and upstream DFRC schemes might reduce the occurrence of major out of bank flooding so that it is no longer an annually expected event in the lower reaches of the River Shabelle. With some river bank raising and strengthening, and dredging of the river channel one might expect up to a 1 in 5 year standard of protection.

A number of options or scenarios were suggested for modeling's which aren't true structural mitigation options but nonetheless add considerable value to the study in term of understanding flood behaviors and future impacts related to increased development and climate change. The following options have been classed as options for sensitivity modeling and have also been modeled and assessed:

- A climate change sensitivity analysis involved increasing design rainfall intensity based on recommendations in relevant guidelines. Both mid and high-range projected increases in rainfall intensity modeled.
- Land use sensitivity involved modeling increased development to understand the future development capacity of existing drains and future requirements.

Based on the findings above and consideration for the feedback form the community the following activities will be supported and used as an entry point to support community driven initiatives including flood mitigation, early recovery and livelihood support.

Option 1: Short Term Intervention

1. Rehabilitation of breaches and breakage points on the river embankment
2. Rehabilitation of Kalunde, 21 Oct (Gomey), Labaa canals, Abdi Isse, Ahmed Isse, Akhwaan and Qarfaxyaale canals
3. Improve and maintain the bankfull capacity of the river, support bathymetric and topographic survey of the river corridor, development of a two-dimensional hydraulic model of the river to better understand flood risk, purchase of earth moving and dredging equipment and/or development of private sector capacity in this regard, development of an annual dredging program to remove deposited silt material, strengthening, repair and potentially raising of the river embankments, improved gauging for flow and sediment measurement, proper operation of the water control structures in the river and land use planning and land management to reduce sediment run-off.
4. Improving community access to markets and productive opportunities by supporting community initiatives in rural access road repairs, construction of community market centers and crop production
5. Supporting community productive infrastructure (including floodwater diversion canals, secondary irrigation canals and construction of water catchment facilities), environmental conservation and livelihood gains, including biogas demonstration plants and community agroforestry
6. Strengthening community capacities in the mitigation of emergency disasters conflict management, management of local development initiatives and support to revenue generation for local governance, reintegration of IDPs and resettlement of local freelance militia.

Option 2: Long Term Intervention

7. Rehabilitation of Jowhar Offstream Storage Project (JOSP) including enabling works, bush and silt clearance, survey works, replacement of gates and hoist equipment, repairs and strengthening of the canal and reservoir embankments and construction of a canal closure structure at the downstream end of the outlet canal. The component will also cover upgrades to access roads and inspection tracks and accommodation for the proposed Middle Shabelle River Authority in Jowhar.
8. Rehabilitation of Duduble Flood Relief Channel (DFRC) include replacement of the gates and operating gear for the canal inlet regulator, bush clearance and survey works along the 10km long supply canal, strengthening and re-profiling of the canal embankments and dredging of the canal channel.

9. Rehabilitation of irrigation and drainage infrastructure, Jowhar Estate for commercial irrigation remains an option but would involve significant investment and this is unlikely to be a realistic proposal until the basic irrigation infrastructure and political and institutional arrangements are in place to give commercial enterprises some security around investment. One option which might be more realistic at this stage would be to continue the progressive rehabilitation of the estate as a small holder self-help scheme.
10. Rehabilitation of other irrigation and drainage infrastructure, including for example the barrage and canals and the development of managed flood irrigation offtakes and canals, in order to encourage the use of flood water for irrigation, whilst avoiding damage to the river and canal embankments that has occurred in the past due to unregulated spilling of flood water.
11. Train local authorities on relief coordination, rescue operations, emergency assistance;
12. Support early warning and emergency preparedness. Access to weather and flood related information is crucial to saving the lives and property of farmers and pastoral communities in the entire Shabelle basin. Much of the vital information relates to the upper catchment particularly from the Ethiopian highlands and the Hiiraan basin. Strengthening community access to such information is critical to emergency interventions, livelihood support and overall development.

4.2.7 Efficiency of Alternative Flood Mitigation Measures

In this study, various flood mitigation measures are proposed. It is necessary to evaluate their hydraulic effectiveness as some measures would affect the flood behavior and potentially exacerbate the flood risks in some areas. The extent of flooding potential can be reduced through some flood mitigation measures e.g rehabilitation of both the JOSP and upstream DFRC schemes and rehabilitation of Kalunde, 21 Oct, Labaa, Abdi Isse, Ahmed Isse, Akhwaan and Qarfaxyaale canals as well as rehabilitation of breaches and breakage points on the river embankment, while other measures may increase the potential flood threat with detrimental impacts. These indicate that rehabilitation of the JOSP, upstream DFRC schemes, and irrigation canals as well as rehabilitation of breaches and breakage points on the river embankment are indeed able to reduce flood extents in the flood prone areas of the Shabelle River Basin.

The damage caused by floods is a function of the flood characteristics, i.e. depth and duration of flood inundation, due to physical contact with floodwater per category of element at risk. The flood damage estimation has therefore been considered to facilitate the economic appraisal of flood mitigation measures. In this study, the damage potential is assessed on the basis of the calculated flood depth in order to evaluate the vulnerability to inundation, and to show the spatial distribution of potential damage across the Shabelle River Basin in Jowhar area. Spatial analysis techniques, using GIS, enable integration of flood depth and land use to evaluate which elements or assets are affected by the 50-year flood depth and how much they are affected in terms of inundation depth. The following land use categories were considered in the damage assessment: residential, commercial, industrial, agriculture and infrastructure (note: institutional area, i.e. government offices, is considered as part of the commercial area). Based on land use, asset values and damage functions, direct damage direct damage to infrastructure was not taken into account. To assess the costs and benefits of flood mitigation alternatives, economic analysis of different scenarios should be undertaken. The effects of flooding can be mitigated, and thereby reduce the loss of life and damage to property.

Adoption of a certain flood mitigation alternative depends on the hydrological and hydraulic characteristics of the river system. Flood mitigation measures cannot be evaluated from a single point of view. The technical performance of these measures, in terms of preventing inundation and the resulting damage, needs to be taken into consideration as it is important for an overall appraisal of the acceptability of each alternative. The optimum level of flood mitigation is unlikely to eliminate all flood risk. Realistically, it can be expected to only minimize the total flood mitigation costs and residual flooding. It refers to the point where the sum of implementation cost and damage are minimized for each flood mitigation alternative. No optimal solution of flood management can be termed as the most advantageous as there are no universal solutions, i.e. any method can be adopted in accordance with the circumstances. Therefore, effective responses may involve a suite or judicious combination of flood mitigation approaches rather than reliance on a single one.

The benefits of combination of flood mitigation efforts are a combination of the effectiveness of the mitigation measures in reducing flood losses. In order to obtain the optimal combination, it is therefore necessary to find a cost-effective solution, i.e. total cost, for which the highest mitigation level is found. The total costs are the sum of implementation costs and the expected value of the economic damage. Settlement patterns including development of land and infrastructure in flood prone areas in Jowhar area have been changed dramatically with major portions of irrigation, forest and agricultural lands being converted for residential use. Owing to the fact that inappropriate spatial planning can exacerbate the negative effects of extreme hydrological processes, therefore, flood losses appear to be increasing despite mitigation efforts, as more people and property are situated in locations at risk.

To reduce risks to an acceptable standard, this study attempts to define spatial planning options for adaptation to extreme flood events in order to incorporate this more effectively in flood loss reduction strategies. Alternative spatial planning scenarios should take into consideration a series of management tasks to restrict flood prone areas to particular uses, specify where the uses may be located and establish minimum requirements for them, including the following objectives: to limit construction of structures on land subject to periodic inundation;

- To ensure that development maintains free passage and temporary storage of floodwaters in order to minimize flood damage;
- To ensure that the effect of inundation is not increased through development and will not cause any significant rise in flood level or flow velocity;
- To minimize development and settlement in flood prone areas and prevent inappropriate development occurring in potentially hazardous areas;
- To conserve and maintain the productive potential of prime crop.

The following steps were applied to ensure that spatial planning offers an optimal solution, i.e. the development is appropriately designed and minimizes the need for redesigns:

- To identify high hazard areas which have the greatest risk and frequency of being affected by flooding;

- To identify areas which would be affected by a 50 year flood event to inundation by overland flow

Spatial planning should takes into consideration inputs from flood inundation, flood hazard and flood risk zone maps. Therefore, further steps will need to be explored on how the hydraulic modeling outputs can be incorporated in spatial planning due to anticipated flooding in the area.

5. Conclusions and Recommendations

Severe flooding occurs frequently in Jowhar area along Shabelle River Basin. This flooding is causing catastrophic loss of human lives, damage and economic loss. Effective flood management requires a broad and practical approach. Although flood disasters cannot completely be prevented, major part of potential loss of lives and damages can be reduced by comprehensive mitigation measures. The river flood and retention have been analyzed by using integrated hydrologic and hydraulic modeling. Every flow has been simulated by a process-based 1D/2D hydrological model (HEC-RAS) coupled with the GIS analysis. Model simulation results under the design rainfall event, i.e. flood depth, flood extent, and risk/damages for the situation with and without flood mitigation measures have been compared and evaluated to determine an optimal set of mitigation measures. The results reveal that a combination of full rehabilitation of both the JOSP and upstream DFRC schemes and rehabilitation of Kalunde, 21 Oct, Labaa, Abdi Isse, Ahmed Isse, Akhwaan and Qarfaxyaale canals as well as rehabilitation of breaches and breakage points on the river embankment might reduce the occurrence of major out of bank flooding by approximately 34% and 41% for the economic damage so that it is no longer an annually expected event in the lower reaches of the River Shabelle.

Traditional approaches to flood mitigation have relied heavily on the provision of structural measures for flood containment as they are generally efficient and allow for mitigating the effects of major floods. In fact, a structural measure could be viewed as a stand-alone alternative for flood management. However, it should be implemented in association with other measures to provide considerable benefits to public safety and allows damage mitigation. For these reasons, flood mitigation should be considered as a judicious combination of structural and non-structural measures to optimize the functions of river and floodplain, in case there are no feasible structural measures that can be implemented or leave some at high risk.

To mitigate flood hazard, scenario-based approaches would have to be implemented. The modeled scenarios have shown that in this case only the retention basin alternative does not meet the screening criteria, i.e. consequences in economic and technical terms, which is considered inappropriate. The results indicate that the combined impact provides the greatest reduction in flood propagation and accumulation. The simulated maximum flood characteristics for this scenario decreased the extent of the 50-year flood event by approximately 34% and 41% for the economic damage. Obviously, the overall effects of these measures in terms of optimal long term solution can be quantified with the proposed combined modeling approach. While floods can never be fully controlled, the beneficiary aspects of flooding are indeed appreciated as floods can bring new opportunities of livelihoods as well. Therefore, considerable efforts would have to be made by turning negative impacts of floods into positive aspects.

6. References

1. Anyah, R.O. and Qiu, W. (2012). Characteristic 20th and 21st Century Precipitation and Temperature Patterns and Changes over the Greater Horn of Africa. International Journal of Climatology, 32, 347-363. https://doi.org/10.1002/joc.2270
2. Brazzola N, H. S. (2018). Five approaches to build functional early warning system. United Nations Development Programme.
3. EM-DAT. (2018). The International Disaster Database. http://www.emdat.be/
4. EWC. (2006). Developing early warning system: a checklist. Geneva: UN Inter-Agency Secretariat of the International Strategy for Disaster Reduction. Retrieved September 2, 2020, from https:// www.unisdr.org/files/608_10340.pdf
5. Few, R., Seytal, P., McGahey, D., Leavy, J., Budd, J., Assen, M., Bewket, W., et al. (2015). Vulnerability and Adaptation to Climate Change in Semi-Arid Areas in East Africa. ASSAR Working Paper, 111
6. Giovanni Federico. Feeding the World (2005). An Economic History of Agriculture, 1800–2000. Princeton Economic History of the Western World. Princeton, NJ: Princeton University Press, 2005. Pp. 416.
7. Gure, A. M. (2021). The Role of Climate information and Early Warning Systems in Supporting Disaster Risk Reduction in Somalia, Technical Report No. WC-007.
8. GTZ. (1990). Masterplan for Jubba Valley Development. Main Report. Somali Democratic Republic.
9. ICPAC (2016). IGAD Climate Prediction and Application Centre. http://ftp.chg.ucsb.edu/pub/org/chg/products/GeoCLIM/Geoclim_archives/
10. IPCC. (2014). Africa. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects.
11. IUCN (2006). Country Environmental Profile for Somalia. The European Commission Somalia Operations Office, Nairobi. https://europa.eu/capacity4dev/file/33006/download?token=OUsVfuq
12. Jack E, D. J. (2010). Guideline on Early Warning Systems and Application of Nowcasting and Warning Operations. Geneva: World Meteorological Organization.
13. Kammer, D., 1989. A Brief Description Major Drainage Basins Affecting Somalia. Prepared by. National Water Centre, Mogadishu. Project Field Document No. 14. SOM/85/008
14. Muchiri, P. W. (2007). Climate of Somalia, Technical Report No. W-01.
15. Mumuli, S. O, Alim, M. and Oduori, G., (2010). Monitoring of Mangroves in Somalia (Puntland, Somaliland and South Central Somalia). FAO-SWALIM. Project Report No. L-19. Nairobi, Kenya.
16. Shaie, A.M. (1997). Inventory Report Somalia. FAO Report. Rome, Italy. Vargas, R., Paron, P., Monaci, L., Shaie, M. Oduori, S. Downie, M. and Nduby, A. 2007. Field Survey Manual. Project Report L-01. FAO-SWALIM. Nairobi, Kenya.
17. United Nations/International Strategy for Disaster Reduction (UN/ISDR). 2003b. Information Systems and disaster risk reduction. Geneva, Switzerland: United Nations. [Online]. Retrieved from: http://www.unisdr.org/news/WSIS/WSIS. pdf [2008, July 12].
18. UNISDR, (2009). Global Assessment Report on Disaster Risk Reduction, Geneva: United Nations.

19. UNDP/ICPAC (2013). NAPA Report for Somalia – Climate Variability and Projections. Produced by the InterGovernmental Climate Predictions and Assessment Centre (ICPAC) on behalf of the United Nations Development Programme for Somalia, using (inter alia) data obtained from the Somalia Water and Land Information Monitoring (SWALIM) database.
20. UNDP, (2010). World Environment Day, Biodiversity in Somalia. http://www.so.undp.org/WED/bio_diversty.html
21. UNOCHA. (2017). Horn of Africa: Humanitarian Impacts of Drought. https://reliefweb.int/report/somalia/horn-africa-humanitarian-impacts-drought-issue-11-3-november-2017
22. World Bank Group/GFDRR (2018). Assessment of the State of Hydrological Services in Developing Countries. Washington DC.
23. World Health Organization (2003). Climate Change and Human Health: Risks and Responses. World Health Organization, Geneva.
24. World Meteorological Organization/WMO, World Bank/GFDRR and USAID (2015). Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services, WMO No. 1153. Geneva, Switzerland.

7. Annexes:

1. Long-term Average Flows in Shabelle River

Station		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Belet Weyne	Mean m3/s	13.5	13.8	30	79.8	151.2	82.7	57	110	151.8	129.6	77.5	36.9	75
	Std.	11.1	13.3	35	68.2	88.2	65.6	22.5	32.3	57.3	60.2	62.9	39.8	22.6
	Dv.	82%	96%	117%	85%	58%	79%	40%	29%	38%	46%	81%	108%	30%
Bulu Burti	Mean m3/s	14.3	9.8	14.5	31.9	65.6	56.1	40.8	67.3	74.8	71.9	57.2	31.7	44.7
	Std.	15	12.8	18.1	24.7	19.7	22.4	19.7	19.3	10.3	9.5	20.1	25.5	10.7
	Dv.	105%	130%	125%	78%	30%	40%	48%	29%	14%	13%	35%	81%	24%
M.weyne	Mean m3/s	17.2	13.1	21.1	53.6	104.5	74.8	52	98.3	122.8	111.4	74.6	37.5	65.1
	Std.	12.9	12	25.4	38.1	39	40.7	25.5	27.9	26.9	27.8	37.4	33.7	15.3
	Dv.	75%	92%	121%	71%	37%	54%	49%	28%	22%	25%	50%	90%	23%
Balcad	Mean m3/s	17.2	13.1	21.1	53.6	104.5	74.8	52	98.3	122.8	111.4	74.6	37.5	65.1
	Std.	12.9	12	25.4	38.1	39	40.7	25.5	27.9	26.9	27.8	37.4	33.7	15.3
	Dv.	75%	92%	121%	71%	37%	54%	49%	28%	22%	25%	50%	90%	23%

Station		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Belet Weyne	Mean m3/s	13.5	13.8	30	79.8	151.2	82.7	57	110	151.8	129.6	77.5	36.9	75
Bulu Burti	Mean m3/s	14.3	9.8	14.5	31.9	65.6	56.1	40.8	67.3	74.8	71.9	57.2	31.7	44.7
M.weyne	Mean m3/s	17.2	13.1	21.1	53.6	104.5	74.8	52	98.3	122.8	111.4	74.6	37.5	65.1
Balcad	Mean m3/s	17.2	13.1	21.1	53.6	104.5	74.8	52	98.3	122.8	111.4	74.6	37.5	65.1

2. Annual Maximum Discharge (m3/s)

Year	Belet Weyne	Bulo Burti	Mahadey Weyne	Afgoy
1951	343.2			
1952	NA			
1953	NA			
1954	258.5			
1955	174.5			
1956	377.8			
1957	303.9			
1958	NA			
1959	208.4			
1960	138.5			
1961	395.9			
1962	NA			
1963	351.4	306.2	135.4	96.8
1964	226.5	195	136.7	92
1965	226.1	197.3	134.9	88.8
1966	190.9	160.8	143.2	87.4
1967	284.6	231.7	140.6	98.2
1968	350.2	302.2	145.5	98.5
1969	199.7	175.9	147.1	97.9
1970	229.7	210.1	145.4	99.7
1971	168.2	154.4	140	99.7
1972	227.6	217.7	140	104.7
1973	156.1	145.7	140	96.9
1974	161.2	144.5	130.2	94.3
1975	231.3	203.5	140	98.8
1976	373.1	292.7	147.5	100
1977	345	333.8	151.3	105.5
1978	255.3	218.4	140	108.6

1979	151.1	153.1	140	112.7
1980	164.5	168.7	148.4	89.5
1981	473.6	489.3	163.2	89.5
1982	245.4	228.9	156.8	95.5
1983	361.8	317.8	155.5	96.6
1984	179.3	179.6	144.7	89.7
1985	352.9	307.5	166.3	81.1
1986	165.8	179.2	156.1	89
1987	419.6	322	164.4	93.1
1988	226.9	199.4	172.3	85.5
1989	298.6	240.2	169.8	97.1
1990	242.7	175.5	176	99.2

3. Annual Maximum Discharge Summary for the Shabelle River

Year	Belet Weyne	Bulo Burti	Mahadey Weyne	Afgoy
Maximum (m3/s)	473.6	489.3	176	112.7
Minimum (m3/s)	138.5	144.5	130.2	81.1
Std. Deviation (m3/s)	88.6	78.3	12.4	7
CV	19%	16%	7%	6%

4. Summary of Flow Duration Curves in Shabelle River (m3/s)

Station	Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Belet Weyne	Mean	14.3	13.8	30.3	80.5	152.8	82.8	57	110.7	152	130.2	77.7	37.2	78.3
	20%	21.3	17.9	56.8	129.6	242.4	124.7	82.5	138.3	198.1	184.9	121.9	57.3	137.1
	50%	10.5	8.6	11.3	64.2	130.4	52.6	54.6	116.4	153.2	118.7	46.7	17.9	60.8
	80%	5.8	4.7	3.8	14.6	63.8	28	30.9	77.7	99.1	69.1	22.6	10	14.4
Bulu Burti	Mean	13.3	10.5	20.8	61.3	132.8	78.8	49.9	99.5	136.4	122.9	76.1	34.3	69.7
	20%	21.2	16	21.8	110.1	209.1	115.9	75.5	127.2	173.5	173.3	118.4	46.9	121.6
	50%	8.8	6.4	7.2	42	111.5	50.7	47.6	104.2	138.5	108.7	51	16	49.7
	80%	3.9	2	1.1	5.5	53.9	21.8	22.8	68.7	97.1	70.6	24.1	8.3	10
M.weyne	Mean	17.2	13.1	21.1	53.6	104.5	74.8	52	98.3	122.8	111.4	74.6	37.5	65.1
	20%	25.9	20.3	23.9	107	145.1	129.9	79.1	129.7	140	140.8	125.6	63.3	125.2
	50%	12.9	9.2	8.8	37.2	114.2	63	47.2	104.2	134.5	116	63	22.2	52.9
	80%	6.6	4	2.4	4.9	54.8	29.8	24.1	67.7	101.5	78.9	30.2	12.1	13.3

5. Summary of Flow Duration Curves in Supply Canal (m3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual mean
1980	0.0	0.0	0.0	0.0	6.7	0.3	0.0	2.7	12.3	0.0	0.0	0.0	1.8
1981	0.0	0.0	0.1	39.2	40.5	3.4	0.0	4	20.5	26.4	1.3	0	11.3
1982	0.0	0.0	0.0	1.1	15.6	13.5	0.0	5.8	14.3	12.9	26.0	0.6	7.5
1983	0.0	0.0	0.0	0.0	6.1	17.0	1.5	13.6	28.4	26.8	10.7	0.0	8.7
1984	0.0	0.0	0.0	0.0	0.0	0.0	4.5	10.9	14.5	16.2	1.4	0.0	4.0
1985	0.0	0.0	0.0	4.8	28.2	21.3	3.7	19.1	21.7	15.3	0.0	0.0	8.8
1986	0.0	0.0	0.0	106.0	12.3	15.2	16.1	16.4	16.6	7.6	0.0	0.0	7.2
1987	0.0	0.0	0.0	0.0	11.8	34.5	31.2	18.8	1.3	0.0	0.0	0.0	8.2
1988	0.0	0.0	0.0	0.1	8.4	0.0	6.3	20.2	21.4	21.6	14.8	0.1	7.8
1989	0.0	0.0	0.0	2.4	17.5	17.5	16.0	13.7	14.2	13.0	3.6	0.0	8.2
Mean	0.0	0.0	0.0	4.9	14.7	12.3	7.9	11.6	16.5	14.0	5.8	0.2	
Max	0.0	0.0	0.1	39.2	40.5	34.5	31.2	20.2	28.4	26.8	26.0	1.0	
Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	1.3	0.0	0.0	0.0	

6. Summary of Flow Duration in Reservoir storage (m3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mean
1980	0	0	0	0	1.2	6.3	0	0	12.7	11.5	3.7	0.1	2.9
1981	0	0	0	28.2	111.6	141.1	96.8	56.8	78.5	130	156.1	136.2	78.3
1982	104.2	72	39.7	10.6	24.1	69.7	67.9	58.8	80.4	104.8	160.2	198.5	82.7
1983	175.2	128.1	78.5	37.5	29.2	45.4	70.3	65.7	107	152.9	189.2	173.4	104.3
1984	143.5	110.9	68.4	25.2	5.4	0.6	0.4	6.2	21.9	45.1	65.8	56.3	45.6
1985	34.2	13.1	3.6	3.9	38.4	84.2	86.5	80.9	101.2	122.7	125.2	111.6	67.4
1986	89.3	58.1	31.5	21.1	40.9	78.8	106.8	136.3	160.6	176.7	163.2	144.8	101
1987	99	57.9	27	11.3	15.2	79.6	155.6	192.5	188.3	169.7	170.4	149.5	110.1
1988	104.2	45.5	18.7	9.7	13.1	15.8	13	28.7	76.8	128.1	171.3	182.1	67.4
1989	158.9	127.2	94.1	73.1	90.3	118.7	141.5	158.7	171.5	189.4	208.8	205.9	145
Mean	90.9	61.3	36.1	22	37	64	73.9	78.5	99.9	123.1	141.4	135.8	
Max	175.2	128.1	94.1	73.1	111.6	141.1	155.6	192.5	188.3	189.4	208.8	205.9	
Min	0	0	0	0	1.2	0.6	0	0	12.7	11.5	3.7	0.1	

7. Summary of Flow Duration in Outlet canal (m3/s)

Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual Mean**
1980	0	0	0	0	1.4	9	0	0	2.4	5.2	0	0	1.5
1981	0	0	0	0	0	0	0	0	0	0	6.4	8.1	1.2
1982	10.8	10	8.9	3.6	0	0	0	0	0	0	0	0	2.7
1983	8.1	21.9	19.3	11.9	0	0	0	0	0	0	9.7	22.4	7.7
1984	19.9	17.9	19.8	16.6	8.7	0	0	0	0	0	13.9	8.6	8.7
1985	13.6	12.8	9.6	1.5	0	0	0	0	0	0	m	m	
1986	m	m	21.7	m	m	m	m	m	m	m	m	m	
1987	m	m	20.2	m	m	m	m	m	m	m	m	m	
1988	23.4	m	m	m	m	m	m	m	m	m	m	m	
1989	m	m	m	m	m	m	m	m	m	m	m	m	
Mean	10.8	10.4	12.4	5.6	1.7	1.5	0	0	0.4	0.9	6	7.8	
Max	23.4	21.9	21.7	16.6	8.7	9	0	0	2.4	5.2	13.9	22.4	
Min	0	0	0	0	0	0	0	0	0	0	0	0	

8. Summary of Flow Duration in of Sabuun barrage (m3/s)

Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual Mean**
1980	8.3	5.1	3.3	6.8	86.1	17	12.5	71.6	74.5	52.3	16	3.7	30.2
1981	1.5	0.5	37.8	124.7	128.1	68	23.2	94.6	141.7	143.5	67.1	19	71.1
1982	11.6	9	8.6	55.6	129.3	102.1	46.4	103.4	126.2	122.8	154.6	102.1	80.5
1983	47.5	24.4	17.3	28.5	114.7	150.2	79.4	148.4	152.5	147.1	141.8	63.8	93.3
1984	27	17.6	11.8	10.1	37.4	68.7	55.2	110.5	111.1	99.3	22.9	11.2	46.7
1985	7.8	5.3	3.8	72	156.3	105.2	45.7	125.8	104.3	73.9	34.7	11.1	61.9
1986	6.3	4.4	4.3	46.1	121.2	109.7	93.8	114.7	107.5	86	11.2	7.5	61.7
1987	4.3	3.5	2.8	76.4	118.8	148	60.4	28.1	62.9	90.3	11.1	m	
1988	m	m	m	m	m	m	m	m	m	m	m	m	
1989	14.2	12.2	13.4	108.7	142.5	63.8	m	m	m	m	m	m	
Mean	14.3	9.1	11.5	58.8	113.9	92.5	52.4	99.6	110.1	101.9	65.9	31.2	
Max	47.5	24.4	37.6	124.7	156.3	150.2	93.6	148.4	152.5	147.1	154.6	102.1	
Min	1.5	0.5	2.6	6.8	37.4	17	15.5	28.1	62.9	52.3	16	3.7	

Cross sections