İZMİR KÂTİP ÇELEBİ ÜNİVERSİTESİ
2010
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

A Geospatial Planning and Management System for Somalia's Local Water Resources (Shabelle River Hiiran Region)

Submitted to the Graduate School of Natural and Applied Sciences
in partial fulfilment of the requirements for the degree of

Doctor of Philosophy

in Urban Regeneration Department

by
Abdirahman Ahmed OMAR

ORCID ID 0000-0002-4276-0329

December, 2021

We are hereby clarifying that **Abdirahman Ahmed OMAR**, a PhD student in Izmir Katip Çelebi University Department of Urban Regeneration, submitted a thesis entitled **A Geospatial Planning and Management System for Somalia's Local Water Resources (Shabelle River Hiiran Region)**, which was reviewed and proven successfully and awarded the degree of Doctor of Philosophy by the members of the jury.

APPROVED BY:

Advisor:

Prof. Dr. Özşen ÇORUMLUOĞLU
İzmir Kâtip Çelebi University

Committee Members:

Prof. Dr. Mehmet Emin AYDIN
Necmettin Erbakan University

Prof. Dr. Çetin MEKİK
Bulent Ecevit University

Assoc. Prof. Dr. Sedat YALÇINKAYA
İzmir Kâtip Çelebi University

Assist Prof. Dr.Osman KIRTILOĞLU
İzmir Kâtip Çelebi University

Date of Defense: December 23, 2021

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I, **Abdirahman Ahmed OMAR,** declare that I carried out the thesis entitled **A Geospatial Planning and Management System for Somalia's Local Water Resources (Shabelle River, Hiiran Region)**. The literature has been properly recognized in the text, and a list of references has been provided. At this or any other institution, no part of the thesis has been previously presented for another degree or diploma.

I also certify that I have followed all academic principles honestly and integrity.

Date: 01.12.2021

A Geospatial Planning and Management System for Somalia's Local Water Resources (Shabelle River Hiiran Region)

Abstract

Somalia is a country located in the Horn of Africa with two perennial rivers, Juba and Shabelle. These two rivers can provide enough water for irrigation and other uses. Still, the lack of reliable data and an appropriate spatial management system has resulted in the misuse of these abundant resources. Limited water resources and tough competitions among various water demands create new challenges to the country's economic development. However, water resource management has to articulate and combine the necessary resources which can preserve the ecological quality of the environment and society.

People who live in arid and semi-arid countries like Somalia, where rainfall is highly variable and droughts or floods are unforeseeable are heavily impacted by water shortages and often have insecure livelihoods. The construction of water reservoirs such as earth dams near the Shabelle river to harvest rainwater from small watersheds and river runoff during high rainfall periods is one of the solutions available to overcome water shortages in Somalia in general and particularly in the Hiiran region. The success of rain water harvesting (RWH) systems depends heavily on their technical design and the identification of suitable sites.

Our main goal is to identify suitable sites for dams using an appropriate multi-criteria decision analysis in ArcGIS 10.3.1. We have used various bio-physical factors: slope, stream flow, land use land cover, soil texture, soil erosion, and stream order; however, to generate a thematic map, we used DEM with 5m resolution. The suitability map should be helpful to hydrologists, decision-makers, and planners to quickly identify areas with the highest potential for harvesting rain water.

We have used geospatial technologies that promise to improve hydrological forecasting, land use land cover, and water resource management during this research.

In this research, we used Erdas Imagine 2014 for image correction, water and vegetation analysis, and ArcGIS 10.3.1 to consolidate water-related data.

The study is divided into six chapters; however, chapters one, chapter two, and chapter three address a broad overview of the study area and the study's background, while chapter four assess the Shabelle River's regime flow and future water projects. In addition, chapter five describes multi-criteria decision analysis (MCDA) for the selection of suitable water storage sites in the Hiiran region, which employs a methodology based on four main steps; criteria selection, classification of criteria, data analysis, and the generation of appropriate thematic maps for water storage site identification.

Keywords: Surface Waterflow, Stream Flow, Riverbed, Geo-referenced Spatial Data, Remote Sensing, Somalia.

Somali Yerel Su Kaynaklari Için Konum Temelli Bir Planlama Ve Yönetim Sistemi (Shabelle Nehri Hiiran Bölgesi)

Öz

Somali, Afrika Boynuzu'nda yer alan ve Juba ve Shabelle nehirlerinin bulunduğu bir ülkedir. Bu iki nehir, sulama ve diğer kullanımlar için yeterli su sağlayabilir. Yine de, güvenilir veri ve uygun bir mekansal yönetim sistemi eksikliği, bu bol kaynakların kötü kullanılmasına neden olmuştur. Sınırlı su kaynakları ve çeşitli su talepleri arasındaki zorlu rekabetler, ülkenin ekonomik kalkınmasında yeni zorluklar yaratmaktadır. Bununla birlikte, su kaynakları yönetimi, çevrenin ve toplumun ekolojik kalitesini koruyabilecek gerekli kaynaklar birleştirmelidir.

Yağışların oldukça değişken olduğu ve kuraklık veya sellerin öngörülemez olduğu Somali gibi kurak ve yarı kurak ülkelerde yaşayan insanlar, su kıtlığından büyük ölçüde etkilenir ve genellikle geçim kaynakları güvencesizdir. Küçük havzalardan gelen yağmur suyunu ve yüksek yağışlı dönemlerde nehir akışını toplamak için Shabelle nehri yakınında toprak barajlar gibi su rezervuarlarının inşası, genel olarak Somali'de ve özellikle Hiiran bölgesinde su kıtlığının üstesinden gelmek için mevcut çözümlerden biridir. Yağmur suyu toplama (RWH) sistemlerinin başarısı, büyük ölçüde teknik tasarımlara ve uygun alanların belirlenmesine bağlıdır.

Ana hedefimiz, ArcGIS 10.3.1 kriterlerine uygun bir çok karar analizini kullanarak barajlar için uygun sahaları belirlemektir. Çeşitli biyo-fiziksel faktörleri kullandık: eğim, akarsu akışı, arazi kullanımı arazi örtüsü, toprak dokusu, toprak erozyonu ve akarsu düzeni; ve tematik bir harita oluşturmak için 5m çözünürlüklü DEM kullandık. Uygunluk haritası, hidrologlara, karar vericilere ve planlamacılara, yağmur suyu

hasadı için en yüksek potansiyele sahip alanları hızlı bir şekilde belirlemede yardımcı olmalıdır.

Bu araştırma sırasında hidrolojik tahmin, arazi kullanımı arazi örtüsü ve su kaynakları yönetimini iyileştirmeyi vaat eden jeo-uzamsal teknolojileri kullandık.

Bu araştırmada görüntü düzeltme, su ve bitki örtüsü analizi için Erdas Imagine 2014'ü ve suyla ilgili verileri birleştirmek için ArcGIS 10.3.1'i kullandık.

Çalışma altı bölüme ayrılmıştır; bununla birlikte, birinci, ikinci ve üçüncü bölümler, çalışma alanı ve çalışmanın arka planı hakkında geniş bir genel bakışı ele alırken, dördüncü bölüm Shabelle Nehri'nin rejim akışını ve gelecekteki su projelerini değerlendirmektedir. Ek olarak, beşinci bölüm, Hiiran bölgesindeki uygun su depolama alanlarının seçimi için dört ana adıma dayalı bir metodoloji kullanan çok kriterli karar analizini (MCDA) açıklar; kriter seçimi, kriterlerin sınıflandırılması, veri analizi ve üretim, su depolama yerinin belirlenmesi için uygun tematik haritalar

Anahtar kelimeler Yüzey Su Akışı, Akarsu Akışı, Nehir Yatağı, Jeo-referanslı Mekansal Veri, Uzaktan Algılama, Somali.

To my lovely family

Acknowledgment

First of all, my thesis advisor Prof. Dr. Özsen Çorumluoglu, and then members of Thesis Monitoring Committee (TMC) Assoc. Dr. Sedat Yalçinkaya and Assist. Dr. Osman Kirtiloğlu deserve my deepest gratitude and warm admiration for always offering helpful suggestions to improve my research.

I'd also like to express my gratitude to my co-advisors for their support and assistance throughout the process of writing my thesis.

I'd want to express my gratitude to Izmir Katip Çelebi University and the Turkish Government Scholarship for providing me with the opportunity to further my study.

I'd also want to thank FAO-SWALIM for their assistance in providing me with data when I needed it and for allowing me to use their resources.

My family deserves special thanks for their unwavering support and encouragement throughout my studies, as well as their continued support for my accomplishment.

Finally, I'd like to express my gratitude to Allah for providing me with the strength to complete my thesis.

Thank you to everyone who has given me an idea or contribution that has helped me with my thesis.

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List of Abbreviations

AHP	Analytic Hierarchy Process
BCM	Billion Cubic Mater
CDI	Combined Drought Index
CN	Curve Number
CV	Coefficient of Variation
DEM	Digital Elevation Model
DMT	Digital Terrain Model
ENSO	El Niño Southern Oscillation
EUSLE	Revised Universal Soil Loss Equation
FAO	Food and Agriculture Organization
FSAU	Food Security Analysis Unit
GIS	Geography Information System
GSIS	Geo-Spatial Information System
IDW	Inverse Distance Weighting
ITCZ	Inter-Tropical Convergence Zone
IWRM	Integrated Water Resource Management
LPCD	Litter Per Capita Per Day
LULC	Land Use Land Cover
MCDA	Multi-Criteria Decision Analysis
MCM	Million Cubic Meter
MNDWI	Modified Normalized Difference Water Index
MoWR	Minster of Water Resources
NDVI	Normalized Difference Vegetation Index
NGO	Non-Governmental and Organization
NIR	Near Infrared Range
OSR	Jowhar Off stream Storage
PDI	Precipitation Drought Index
PET	Potential Evapotranspiration
RS	Remote Sensing

RWH	Rain water Harvesting
SCS	Soil Conservation Service
SDR	Sediment Delivery Ratio
STD	Standard Deviation
SWALIM	Somali Water and Land Information Management
SWIR	Short-Waves Infrared Range
TDI	Temperature Drought Index
UN	United Nations
UNDP	United Nations Development Program
USLE	Universal Soil Loss Equation
VDI	Vegetation Drought Index
WHO	World Heath Organizations
WPDI	Weight Precipitation Drought Index
WTDI	Weight Temperature Drought Index
WVDI	Weight Vegetation Drought Index

Glossary of Somali Terms

Deyr	Rainy season October to November
Gu’	Major rainy season in Between April to June
Xagga	Dry and cool season in Between July to September
Jiilaal	Dry and hot season in Between December to March
Togg	A seasonal stream which is deep and narrow
Wadi	A seasonal stream which is wide and shallow
Warr	An artificial dam usually 2 – 4m deep

Chapter 1

Background of the Study

1.1 Introduction

Somalia is a slowly developing country; it is also recovering from long-termed conflicts and civil strife that hampered the development of every sector in the country. Consequently, water resource management in the country is fragile.

Water resource management, including water distribution, sanitation, and water drilling services, was formally organized by the Central Government of the country. Chaotic political situations, ongoing economic crises, unstable security, and transitioning from the Central Government to Federal Government which has not carefully planned constitutional infrastructure, worsened water resource management.

Local private entities were standing the role of the government. These local private entities only focused on water drilling and distributions in urban areas more than water resource management as a holistic approach, while the rural areas are between floods and droughts.

Due to the aridity of the climate, geological, geomorphological, and hydrogeological consequences, some parts in the country's northwest (Somaliland) and northeast (Puntland) have deteriorated water resources. The population of these regions mainly depends on groundwater. However, this system is insignificant due to the overstretched population in urban areas and increasing water demand from rural populations in long dry seasons. As a result, the inhabitant of this area suffers from inadequate water supply and have fewer opportunities to meet their water needs [1, 2, 3].

Over 90% of annual rainfall evaporates in dryland, and this evapotranspiration is an essential component in land-atmosphere interaction [4]. Sun radiations that result from the combined deforestation and global warming increase evapotranspiration, which creates a significant loss of surface water, which will turn the harshness of the environment to even more desolate and barren. Furthermore, the swampy and lushness of the alluvial in North-West regions change into a more devastating and irreversible environmental situation. At the same time, the economic development of the country will cripple and social fragmentation inevitable.

Despite the importance of groundwater for humans, livestock, and agriculture, there are no hydrogeological maps for groundwater management and exploration in these regions. Strangely enough, the state of knowledge about the quality and quantity of groundwater resources is limited. Moreover, information on hydrogeology to develop a strategic water resource management and facilitate drilling groundwater is either scattered or limited or, even in some cases, non-existent. It results in unguided water drilling projects that lead to a low success rate [1, 2, 3].

Although the groundwater is one of the most critical water sources for survival and sustainability of the population in these regions, acidity and alkalinity, salinity and dissolved solids – minerals made the quality of the water low and not suitable for drinking with only 40 – 50% of groundwater ideal for drinking. Furthermore, the majority of the water resources have excessive levels of salinity, approximately 70%, compared to the WHO standards for drinking water (1500µS/cm) [4].

The north part of the country has little surface runoff and rainfall, and most of the runoffs are lost through infiltration and evaporation. However, some streams in the mountainous regions flow throughout the year in some stretches.

Gulf of Aden Basin and Darror Basin are among the primary drainage basin in the Northern regions, as shown in Figure 1.1. In addition to this, there are some natural springs in the mountainous areas and shallow and deeper aquifers, which are significant water sources in this area. Small-scale dams (artificial dams, also known Warr in the Somali language) play an essential role in rainfall water catchments and harvesting.

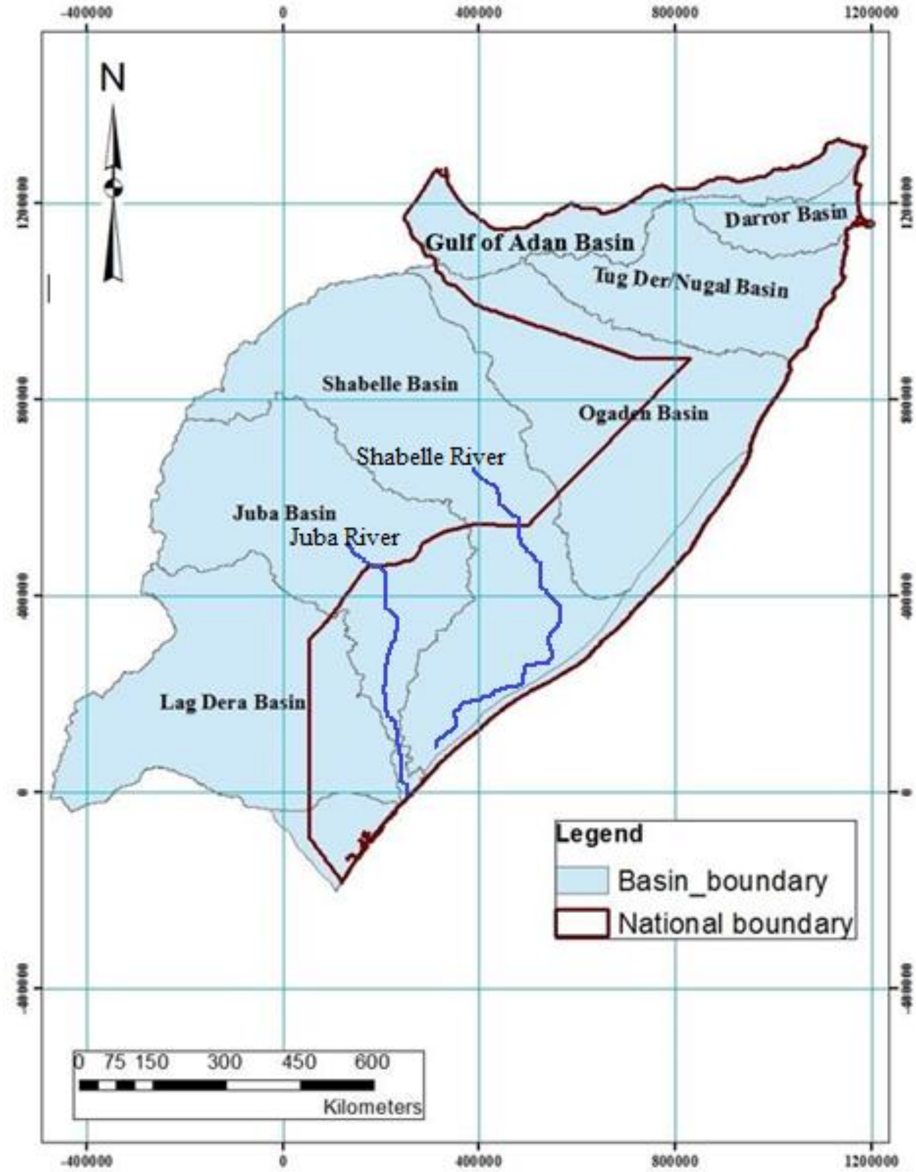

Figure 1.1. Major drainage basins in Somalia [1]

Somalia's surface water resources are limited mainly along the two perennial rivers located in the Southern regions; thus, the population of these regions has a higher opportunity of accessing surface water. Furthermore, the deterioration of the river regulation infrastructure and the flood control increases the vulnerability of the riparian community to the floods and progressively smaller peak floods which occur once every three to four years [4].

The climate of these regions falls under moisture semiarid and minor scales of forest to tropical climatic conditions with minimal other surface water resources such as dams [5]. Juba and Shabelle constitute a small percentage of Somalia's territory, while two-thirds of the rivers are outside the country. Juba river plays an essential geo-politics role for the East African countries. It demarcates the border of three neighbouring countries, the Kenya-Ethiopia border, Somalia-Kenya border, and Somalia-Ethiopia border [4, 5].

Juba River combines three main tributaries Wabi Gerstro, Wabi Dawa, and Ganale, all in Ethiopia territory Figure 1.2. The river covers about 1808km of 804km in lies in Ethiopia and 1004km lies in Somali.

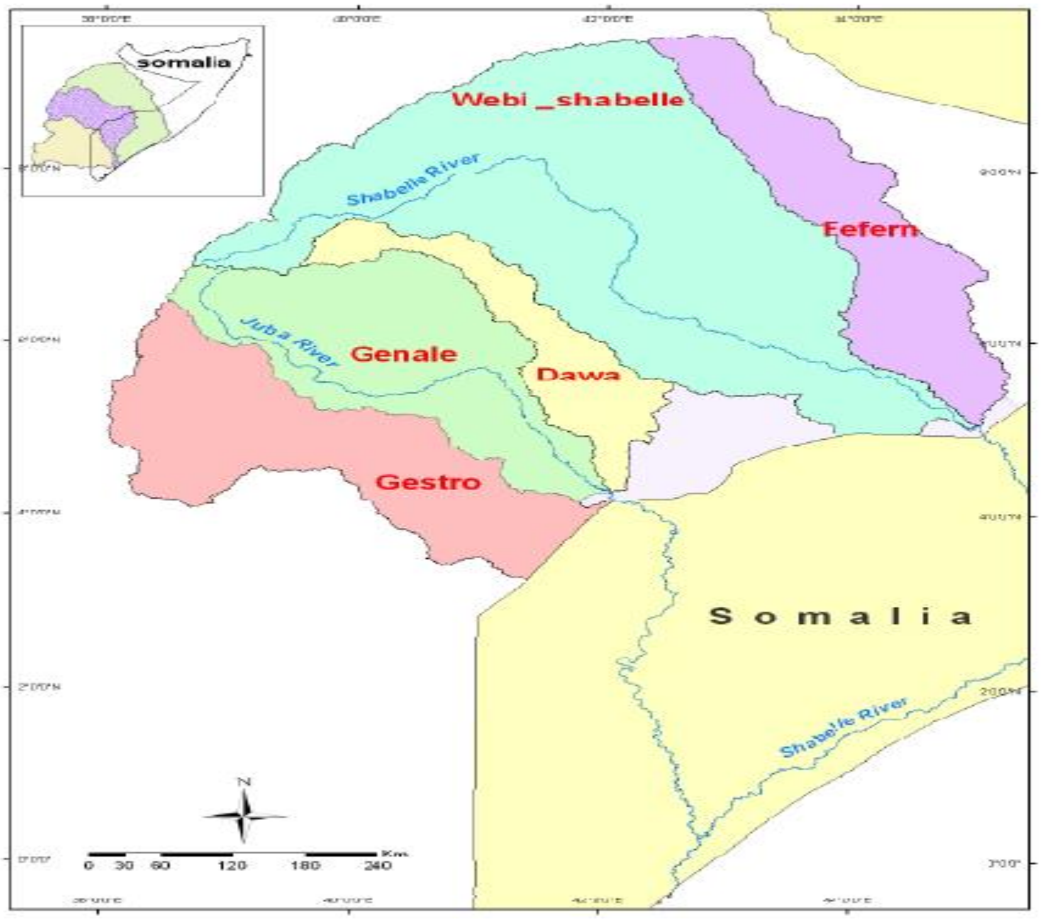

Figure 1.2. Sub-basins of the Juba and Shabelle rivers within Ethiopia [6]

Shabelle river, which is the main focus of this study, covers an area about $108300 km^2$ in Somalia [4, 5]. Two main tributaries in Ethiopia, Fafan and Wabi Shabelle, form the Shabelle River, as in Figure 1.3. Shabelle River covers a longer distance inside Somalia than the Juba River. Shabelle river moves to the south of the country parallel to the coastline from which a range of sound dunes separates it. The flow of the river discharges into the Juba River only during high rainfall periods.

This research examines the physical development of land and water resource management as a holistic approach using geospatial technology and ways to find suitable management of the river water to use both near and far future. Water resources management is a complex system that integrates several spatial features. Thus, to deal with such a multi-functional system, a powerful technological tool is needed to facilitate and provide some of the most comprehensive techniques for storing, manipulating, and analyzing geo-referenced spatial data. Remote Sense RS and GIS combination ensures more efficient natural resource use with time flexibility and scale. These technologies can handle both digital spatial features and the associated databases of attribute information for map features. Groundwater exploration using traditional means consumes a lot of time, energy, and money and requires skilled human resources. In contrast, RS and GIS technology have significant advantages of spatial, spectral, and temporal availability of data covering an inaccessible area within a short time [7].

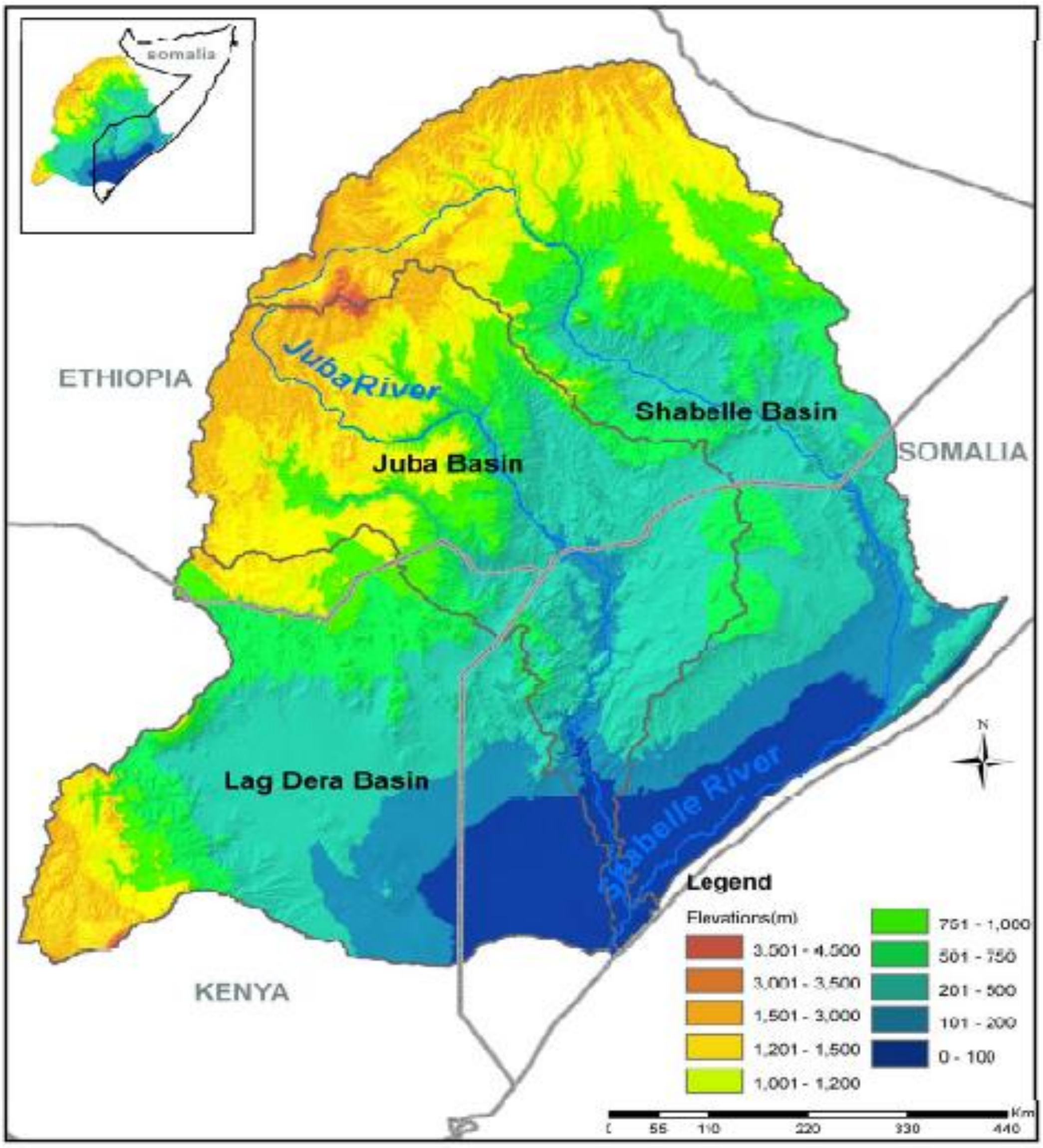

Figure 1.3. Elevation variations of the Juba and Shabelle river basins within Ethiopia and Somalia [6]

Gies, [8] Defines water scarcity as a threat to people's livelihoods due to a lack of access to safe and affordable water for drinking and food production. To overcome this threat and maximize food production, knowledge of water resources and related sectors are required. However, using RS and GIS technology will effectively facilitate required information on how much water is available and how much has been consumed for a different purpose. Therefore, it will lead us to know how availability will change under future scenarios. Ground-based water resources observations using various instruments such as rain gauges and weather radar give insufficient information. Space-based observations are the solution and are used as a promising alternative source. There are high-resolution satellite-based products that are recently functioning to provide an unprecedented opportunity for a hydrologist to monitor the spatial distribution [7].

GIS is a tool for displaying and processing multiple spatial data; one of them is the suitable site selection for the dam. Using GIS technology will be an attempt to select appropriate sites for checking dams for harvesting rain water and storing river flow when the stream flow is very high to avoid floods in Beledweyne. Beledwyene was selected based on many factors, such as the Shabelle river entrance point to Somalia, altitude, slope irrigation, and infrastructure facilities. There are also some other sites down to Baledwayne city which are suitable check dams for both rainfall harvesting and river flow storing when the streamflow is high, but the following factors made Beledwayne city more ideal than others

1 Population density: this city has more man-to-land ratio than any other city around the river course; hence this population has more pressure on the river flow for domestic use, livestock and irrigation practices.
2 It is the first city where the Shabelle river enters the Somali border and has the highest river discharge.
3 The available water in this area should be reasonably satisfactory if it is well planned

To identify a suitable site for a water store in the Hiiran region, we have used multi-criteria decision analysis (MCDA) to select appropriate sites for water storage. To perform MCDA, we have divided as follows

1 Criteria selection
2 Classification of criteria
3 Analysis and generation of suitable maps for site selections

This study assessed three main parameters to evaluate which area has the highest potential for dam selection to overcome agricultural and domestic water use demands. Topographic settings, soil erosion factors, and riverbed analysis were the main parameters that have been analyzed. After these assessments, three main areas were identified as a potential site selection in the Hiiran region. Also, we have compared these three areas and recommended which are has more suitable than the other two sites.

1.2 Problem Description and Justification of the Research

It is doubtless that improved water resource management can potentially contribute to the development of every sector in the ecosystem and social welfare for every society. Still, the dimension of enhanced water resource management is not precise yet [8]. Covering water resource management dimensions has become an elusive goal to date. In this context, this goal will be impractical to achieve in the least developed countries as long as water resource management data are missing or gathered throughout traditional data collection methods. In addition to this, Integrated Water Resource Management (IWRM) has become an essential key factor that directly contributes to minimizing water scarcity levels and maximizing sustainability. IWRM became more prominence after Rio and Dublin[1] conference in 1992. IWRM states as:

> "…a method of promoting the equitable development and management of water, land, and related resources in order to optimize economic and social welfare without jeopardizing the long-term viability of key eco-systems" [9].

IWRM is undoubtedly the most appropriate water resource management concept, but there is no single document regarding Somalia's implementation of this concept at a national level. The question that seeks an answer is how this finite and vulnerable water resource essential to sustain life, development, and the environment could make a holistic policy that decreases the vulnerability and increases the sustainability of this vital resource.

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[1] International conference on water and the environment was held in Rio De Janeiro (3rd most populated city in Brazil) and Dublin (capital city of the republic of Ireland) in 1992 and was agreed on water and sustainable development agenda and later was submitted to the United Nations department of Environment and Development (https://www.gwp.org/contentassets/05190d0c938f47d1b254d6606ec6bb04/dublin-rio-principles.pdf)

1.3 Research Significance

Highly dependent on natural resources for a livelihood without appropriate spatial management will lead to society lagging significantly behind the rest of human well-being and development indicators. However, Somalia's livelihood situation between floods followed by droughts is enough example of natural resource dependence without good planning and management. However, most of Somalia's surface water resource is in Juba and Shabelle rivers in the Southern part of the country with an insignificant number of artificial dams scattered to the country inadequately. To the best of my knowledge, there was almost no water resource management at a national level during the last two decades. As a result, surface water use became more traditional with very little scientific support [10].

Almost twenty-seven years ago, the country's political and economics had reshaped – from developing to deteriorating – this situation has also affected almost all of the hydro-meteorological data collection network and water resource infrastructure, resulting in water resource data being either lost, missing over many years, or are scattered. In contrast, some private agencies, whether local or international, gather and store data and install some stations to control surface water and collect data for a short period. Still, these stations could be insignificant during intensified rainfalls [10].

Most of the data concerning the irrigation schemes, water resource infrastructure, such as development projects like the Bardheere Dam Project, is either lost or missing [4, 5]. In addition to this, very little research is carried out concerning Somalia water resource management using a combination of techniques such as GIS and RS.

Sufficient quantity and quality of water for human needs are considered fundamental human rights. Access to safe water is said to be limited to only about 20.5% of the population around the Shabelle river, of which 53.1% live in urban areas [10].

The present per capita consumption is lower than the basic need standard of 20 LPCD (litter per capita per day).

Data on water used across the Shabelle river basin and socio-economic profile is not available. However, given water scarcity, 20 LPCD for rural and 50 LPCD in urban areas is considered the region's average water consumption (basic requirements).

Based on the current estimation of the population, which is 535685 in which 60% of the population is urban, the total water requirement for this region is estimated to be 2.0MCM (Million Cubic Meter) per day.

Water for livestock is crucial as the livelihood of the majority of the population depends on livestock. However, more than 2 million head of combined cattle, camel, and sheep/goats. If water demands of 20, 10, and 5 litres per day are assumed per camel, cattle, and sheep/goats, respectively, then a total daily water livestock requirement of 22987.5m^3 for the basin can be determined [10].

Since the Shabelle river originates from Ethiopia, the Ministry of Water Resources of Ethiopia has envisioned developmental master plans for irrigations approximately 190000ha inside Ethiopia territory. This plan will consume more than 80% of the Shabelle river stream; however, this plan will create a lousy river flow situation. However, such plans must consider beyond the territorial border, since it has natural concepts moreover, Rio – Dublin statement on water and sustainable development should also be considered.

Natural resource management, mainly those are in scarcity, needs more precise information to predict, manage and make reliable decisions that minimize their negative impact and maximize sustainability. Therefore, remote sense together with GIS offers excellent information about temporal and geo-referenced data.

In this study, we have used ArcGIS to capture, store, manipulate, analyze, manage, and present types of geographical data, particularly those related to water resource management. This generic tool allows us to create interactive queries and investigate spatial information, which is the focal point of our study. In contrast, observing a large area of land and extracting information about the environment, we need advanced technologies which can minimize the data gaps that we have experienced through the literature review and thus can simplify our data collecting procedure. Hence remote sense plays a crucial role in collecting a large scale of information within a short time. Furthermore, RS products give us comprehensive knowledge about spatial variation in land use, climatology, soil properties, and soil moisture conditions to improve water productivity. Therefore, the combination of these technologies is indispensable.

1.4 Research Objectives

This study analysis current water situations in the Hiiran region and how the available surface water could be utilized efficiently. In contrast, we have used multi-criteria decision analysis to investigate the suitable area for water harvesting.

The following are our significant Objectives:

1. To analyze available water and water demand in the Shabelle river basin
2. To assess the impact of the region's water scarcity, global warming, increasing solar radiation, and deforestation on the river basin.
3. To analyze the impact of rapid urbanization and population growth in the riparian area on the stream flow and river course
4. To analyze the suitable location for water harvesting

1.5 Research Questions

This research has been centred on the following questions:

1. What are the main drivers influencing practices in water resources management to reach a sustainable water level in the Shabelle river basin in Somalia?
2. How do local actors (domestic use, environmental use, agricultural demand) try to "Sustain" livelihoods and catchment management?
3. What are the environmental impacts related to the planned interventions at the catchment level, such as upstream developments and how these developments can mitigate any adverse effects that may arise from the intervention?
4. What field-level practices were promoted to manage water in the irrigation system, and how can their adaptation or rejection be explained?
5. Which approach has been used for Shabelle river basin planning and management?

1.6 Key Assumptions

This thesis assumes that surface water management is practically valuable if certain conditions are ensured. Therefore, this study's focus is to examine the practical value of the concept of IWRM and explore ways to improve its current application.

In general, the IWRM context has been accepted as the best one, and we need to explore how to apply it most optimally without going back to questioning whether IWRM is good to approach or not.

1.7 Scope and Limitations

The topographical features of the Shabelle river could be accurately derived from the aerial photographs and DTMs. Still, the availability of field data such as the discharge measurements and gauging data for key locations is vital for determining the hydraulic and hydrological characteristics of the rivers. While the staff gauge data are available in some stations in Shabelle River. The aerial photography was carried out during January, when the river flows were the lowest. The unavailability of an underwater profile could be a constraint for defining the cross-sections of the rivers for hydraulic calculations. On the other hand, more than 90% of the flows in the river are contributed by catchments outside the Somali territory, and the required rainfall, the river flows, and catchment characteristics data from these catchments are not available to undertake any basin-wide hydrological study of the river.

Detailed hydrological analysis of the river has been covered in the Water Resources of Somalia Report that was produced in SWALIM phase two. This report focuses on and summarizes the fundamental hydrological analysis related to flood hydrology and irrigation water availability. Somalia used to have a good data collection network for rainfall and river flow until the late 1980s. There are data gaps in a certain period (1988 – 2002).

SWALIM has since 2002 been trying to re-establish the data collection networks and even expand to new sites. The exercise is, however, time and resource-consuming. The majority of the pre-war stations have been re-established, and new stations, including telemetric automatic weather stations, have been established. Data collected during pre-war was reasonably good, but with some missing values for a few days, weeks, and occasionally months. The missing values can only be estimated through statistical methods and cannot be as correct as observed. In the post-war rainfall data collection, SWALIM has partnered with NGOs for data collection. Some gauge readers are employed directly by SWALIM, while other stations are managed by NGOs who read the gauge and send data to SWALIM.

Chapter 2

Literature Review and Research Methodology

2.1 General Approach of the Study

Floods followed by droughts, famine, water scarcity, power crisis, and other natural disasters are the main challenges that our country has been facing for centuries. Less than 5% of the export from agriculture, although 45% of Somalia’s land is classified as rangeland suitable for agriculture and grassing [10]. The development of the economy for the country depends on adequately utilizing the natural resource of the country. Dams have provided a substantial number of benefits to humankind. A dam is mainly a reservoir constructed over a water flow path (i.e., rivers or streams) for storing the water. Also, dams are beneficial for hydropower projects, an environment-friendly source of energy accompanied by the most negligible emission of greenhouse gases.

It is immensely needed to utilize these physical resources for sustainable developments like the construction of a small multipurpose dam that could cope with local power requirements and have the potential to fulfil the irrigation purpose. When it comes to the geographical information system (GIS) and the tools it contains, GIS might be the best attempt at selecting appropriate check dams for storing water rainwater and river streamflow when it is a full bank. In contrast, remote sensing has contributed to choosing the best site for water recharging or harvesting. Check dams were identified as one of the most important rainfall collection methods for agricultural and drainage purposes. GIS is a tool for processing and visualizing different spatial data sets, one of which is the dam's proper site selection. Using the GIS approach will be an attempt to select appropriate sites for checking dams for harvesting rainwater and storing river flow when the streamflow is very high to avoid floods in Beletweyne. This area was selected based on many factors, such as the Shabelle river entrance point to Somalia, altitude, slope, irrigation, and infrastructure facilities.

2.2 Theoretical Framework for Selecting a Suitable Site of Water Harvesting

The construction of a dam is a significant way for harvesting technique, and it provides multifarious service for sustainable agriculture and water shortage challenges. Some traditional methods are developed in many developing countries to construct small-scale artificial dams mainly built by clay. Some countries in Africa and Asia have all attempted to plan and develop ways to collect, store, and use rainwater for agricultural purposes [11]. The process of valuing, managing, and organizing rainwater harvesting becomes a severe concern for humans, especially in locations where precipitation is insufficient, and groundwater is scarce [12]. Water harvesting site selection is always challenging because it requires a proper balance of economic, environmental, social, and biological trade-offs. Traditional methods for dam site selections have many disadvantages such as time consuming, cost, labour and resources, while technological and technical methods, however, appeared as a powerful multidisciplinary science which provides easy data access, large area coverage and frequent temporal capabilities for many of its applications in hydrology, geoscience and agriculture [13]. Moreover, a detailed survey of all contributing watershed factors such as streams to flow, aspect, slope, soil properties, vegetation, water bodies, geology, and engineering inputs are essential to be considered [12].

Different researchers used different parameters for the selection and sustainability of dams, like topographic parameters (elevation, slope variability, and watershed analysis) [13].

Several studies have been undertaken in Pakistan, with the majority of them using factors such as infiltration rate, slope analysis, soil qualities, and land use land cover to choose a suitable dam site. [14]. Many pieces of research have been applied remote sensing and GIS to select a potential location for water harvesting structures. However, some of these researches have been adopted to generate check dams, gully plugs, percolation tanks, ponds derived from Landsat imaginary data, and some collateral data [15]. Most of these researchers were emphasized the importance of rainfall, soil properties, land use, land cover, drainage, and slope for the sustainability of site selection for water harvesting, the analysis of these parameters has been applied in many arid and semi-arid areas such as Australia [15]. Some researchers have reviewed several methodologies that have been applied in arid and semi-arid regions in the last three decades [16]. They compared and categorized four site selection methodologies and then identified three main criteria for water harvesting locations. They also underlined the main characteristics of the most common water harvesting techniques in arid and semi-arid regions. The methods range from those based on only biophysical criteria to more integrated approaches [15].

In Pakistan, many researchers have adopted the GIS system to select suitability for small dams, to assess potential sites in the river Kabul basin [14].

Geospatial technologies were used in Iraq to select a suitable site for rainfall water harvesting; furthermore, multicriteria analysis was performed to investigate the availability of ground information for the feasibility of the water harvesting site. All contributing factors such as drainage, urban areas, channels, roads, proximity to the river, slope, soil map, and agricultural area were studied before selecting a suitable site for the dam [16]. In Ghana, several pieces of research have been conducted and developed different criteria and techniques for harvesting rainwater site selection. The main parameters were runoff potential, soil quality, slope, land use land cover, stream order, and hydrology to determine suitable site selection.

A study for the site selection in the arid area has been conducted in Mali. This study proposed different sites for dam construction based upon utilizing the ASTER Global DEM to extract catchment areas. In addition to this, Landsat imagery for vegetation cover (NDVI), geological maps, climatological properties, and some urban data were used [17].

Dixon and Uddameri [7], it has been conducted a study dealing with the potential site selection for rainwater harvesting in the Bakhar watershed (India). This study has been identified using GIS and Remote Sensing to generate various thematic maps, such as land use, land cover, rainfall, soil erosion, and soil texture. Along with these layers, other parameters such as geology and drainage were used to derive suitable locations for harvesting structures.

In Korea, a study was conducted using Geo-spatial Information System (GSIS); although Korea has potential dam sites, the study underlines the importance of the following [18]:

1 Spatial analysis to create searching points.
2 Making criteria and assigning weights
3 Overlay analysis

Most of the researchers were underlined the importance of these parameters at the time of dam selection:

1 The density of the drainage should be low
2 The load of the sediment of the stream should be below so that the dam has more capacity to store water
3 The selected site should have good soil properties which have less infiltration and erosion and should have hard rock
4 High precipitation rate
5 The density of the tectonic lines should be below so that the internal water movement is less
6 Low level of evapotranspiration
7 Fewer effects on natural aquifers
8 High gravity forces to transport the water where it has been collected

Hiiran region needs the development of the livelihood and agricultural productivity; however, it is essential to capture rainwater and store and transfer the river stream flow when it is full bank to other storing locations for future uses. Even though the people of this region have already adopted some harvesting techniques for quite a long but it was low scale man-made dams mainly constructed by clay. However, identifying and evaluating the factors that could affect dam site selection in Hiiran catchment and hence proper planning of water resources is challenging.

To address these challenges, the criteria were defined qualitatively and quantitatively, and were based on a territorial study using satellite imagery in conjunction with climatological and hydrological data. This method is beneficial where there is very little territorial information is available [1, 2, 3].

This study identifies suitable sites for dam construction using model builder in ArcGIS 10.3.1 and ERDAS IMAGINE 2014. These models adopt a combination of many biophysical factors such as:

Slope, streamflow, watershed analysis, land use land cover, soil, and runoff depth.

In addition to this, climatology data was also adopted to generate more reliable thematic maps. Furthermore, USGS data was used for further analysis of topography such as NDVI and MNDWI.

2.3 Data Collection

This study involved the use of various datasets. The data required was governed by several criteria that affect dam site selection, including slope (Topography), Geology, Soil type, Catchment size, and Land Use Land Cover. The raw data also includes unprocessed satellite imagery from international civilian space programs such as Landsat and terrain (DTM); soils; climate (Rainfall, temperature, and potential evapotranspiration).

The digital elevation model DEM data was obtained from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), with a pixel size of 5m. It was processed and used to generate elevation (DTM) and slope. The processed DTM was used to delineate watershed and generation of stream network according to the process flow. The study area's land use land cover data, geology, and soil data were obtained from the FAO-SWALIM and ILRI GIS services website, consisting of different classes.

The quality of data used for modelling directly affects the output, so the collected data was screened and processed before being used.

The data used in this study were the key variables that determine the hydrological situations and generate runoff maps; however, these maps are the essential key for the design of a water harvesting plan.

Chapter 3

Description of the Study Area

3.1 General description of the study area

As illustrated in Figure 3.1, the Shabelle River enters Somalia near Beledwayne city in the Hiran area, and the basin covers three primary regions in Somalia. The river stream passes through numerous significant towns in the Hiran region, including Beledwayne, Bulo barde, and Jalalaqsi. The river then heads south, passing through two major regions: Middle Shabelle (Shebleelaha Dhexe) and South Shabelle (Shebleelaha Dhexe), but these two regions were excluded our study as in Figure 3.2. The landscape of these areas is characterized by low-lying flat terrain (undulating hills), plains of loose soil covered by bush and woody grasses interspersed with stony outcrops, while some areas steeply dissected mountains. Shabelle basin receives an average of 100 – 584mm of rain annually [4], and the mean annual temperature ranges between 25 – 45^{0}C. There are two main rainy seasons Gu (between April to June) and Dayr (October to December), each followed by a dry season. From December to March, there is a dry season called Jilaal, while in between June to September, sometimes it rains in the southern part of the Shabelle river basin and is called (Xagaa).

During the dry season, water demand in this area rises; nevertheless, the bulk of rural and pastoral people congregate near rivers where surface water is available; also, environmental water demand rises due to the aridity and high evapotranspiration rate.

Due to climate change, which is affecting rainfall patterns in the Ethiopian highlands and upstream developments that are primarily predicted to decrease and heavily restrict river flows, however, only streamflow cannot deliver enough water to meet sectoral water demand during dry season. To overcome these obstacles, rainfall must be harvested and the 2.4 BCM river outflow at Beledweyne must be regulated.

Rainwater harvesting for home or animal usage is being employed as a supplement to groundwater and river water.

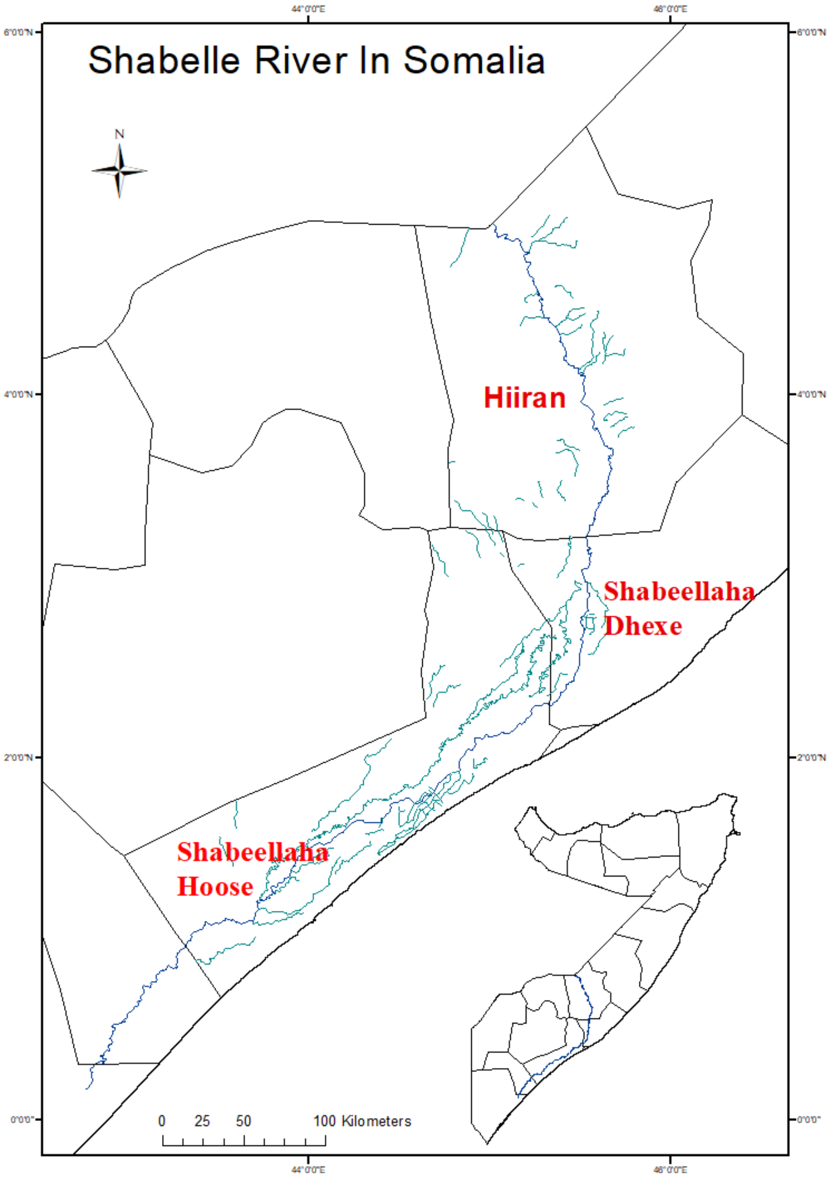

Figure 3.1 Shabelle river course in Somalia

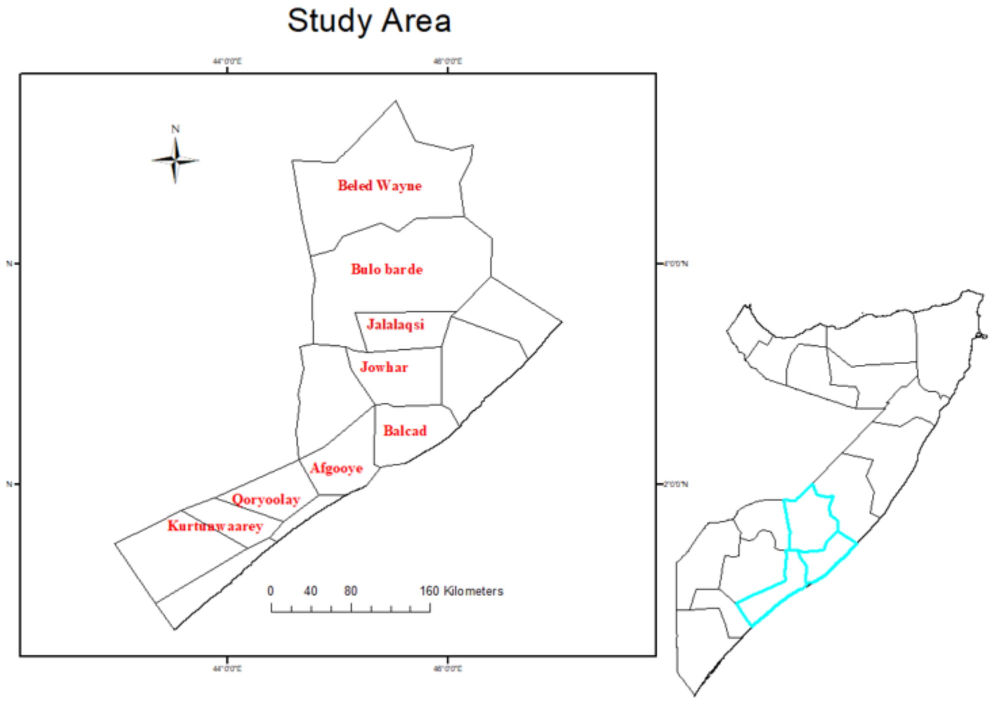

Figure 3.2 Shabelle river basin in Somalia

Afgooye and Kurtunwaarey area receive more mean annual rainfall than Beledwayne, although Beldewayne has more river flood frequency than any other city alongside the Shabelle river course [1, 3, 4]. Most of this rainfall in the Afgooye area is distributed throughout the year. January and February are, however, generally dry compared to the other months. It is observed that May and November are the wettest months in this area. Temperatures are high, and the same applies to potential evapotranspiration. Kurtunwaaray is a small-town southward of Afgooye; the river channel is shallow, making it possible to irrigate the adjacent land through flood irrigation.

3.2 Climate Settings

3.2.1 Climate

The climate of the Shabelle river basin in Somalia can be classified as semi-arid, making it extremely sensitive to climate change-induced drought and water scarcity risks [4].

3.2.2 Rainfall

Rainfall is low and unpredictable in the study area. Rainfall patterns vary greatly in both space and time across most of the country. There is also a significant seasonal and inter-annual variation in the amount of rainfall in the study area. In Somalia, the annual migrations of the ITCZ from north to south across Africa and back again produce four distinct seasons, with two distinct wet seasons alternating with two distinct dry seasons [4]. The four seasons are:

1 Jiilaal_dry season is from December to March. The northeast monsoon is in dominance, and conditions are generally dry and hot. The study area experiences some dry air and very hot conditions during this season.

2 Gu’ rainy season is from April to May. Relatively wet and hot conditions prevail, with Gu considered as the major rainy season.

3 Xagga dry season is from June to September. The South-west monsoon dominates, bringing relatively cool conditions, with showers along the coast but dry inland [5].

4 Deyr rainy season is from October to November. The low-pressure system (which sucks in moisture) known as the Arabian ridge intensifies over the Equator. The central part of the country receives moisture inflow from the Indian Ocean [4, 5]. The rainfall received at this time is less than that of the Gu rainy season. Rainfall varies considerably, with the Gu delivering about 60% of the total mean annual rainfall, which ranges from 300-500 mm in the Shabelle river basin in Somalia, as in Figure 3.3.

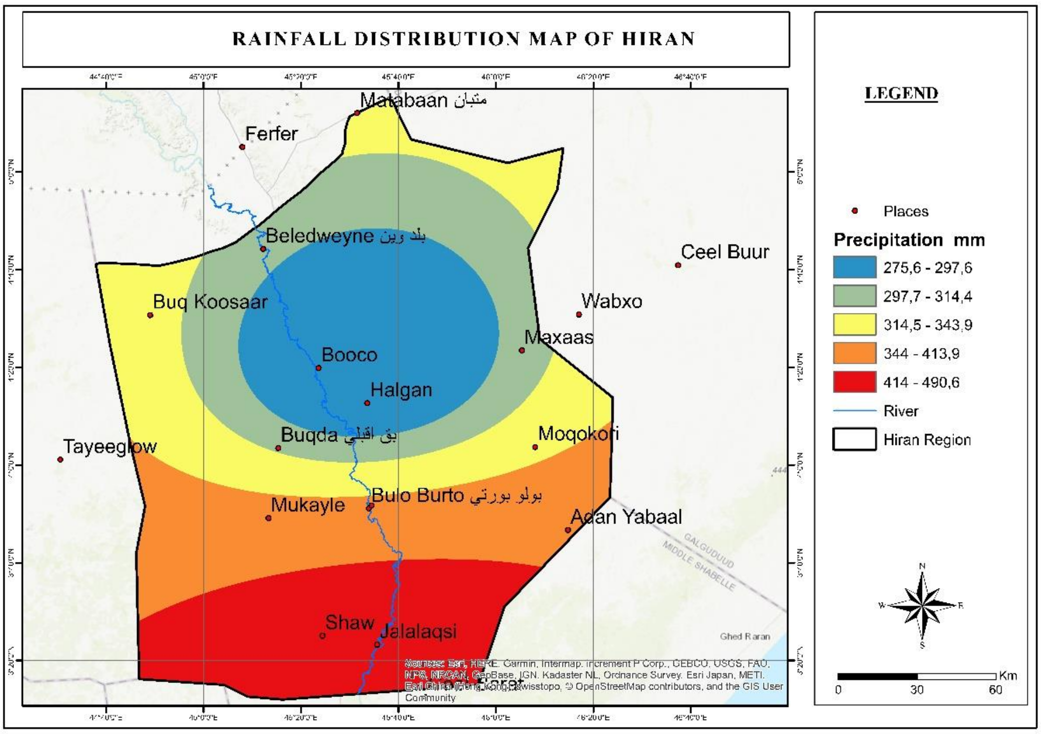

Figure 3.3 Rainfall distribution in Shabelle river basin
in Somalia [1]

During the Jilaal and Xagga seasons, as well as the beginnings of rainy seasons, particularly the Gu season, the temperature changes to a very hot and arid regime. Despite Deyr's moist nature, its annual rainfall percentage might be low [4]. Rainfall is suitable for rain-fed agriculture in the Gu and Xagga seasons. There is an exponential association between heights and Hagaa rainfall and an inverse-exponential correlation between elevation and Deyr rainfall when it comes to seasonal fluctuations in rainfall [5]. The El Nio Southern Oscillation (ENSO)1 has an impact on Somalia's climate variability. Inter-annual rainfall changes are closely linked to the ENSO, with heavier rain and flooding during El Nio years and droughts during La Nia years, both of which have serious consequences for human habitation and food security. Peak October/November/December rainfall during strong ENSO years (1972, 1977, and 1982) and drought episodes during La Nia years, according to the Somalia Rainfall Atlas (FAO, 1971-1990). (1971, 1974, 1975, 1984, and 1988). During the months of September, October, November, and December, these can be seen in pronounced peaks and dips [3].

Looking into the future (2031–2060 shortly, and 2071–2100 in the far future), the projected changes in rainfall relative to a reference period of 1981-2010 much of Somalia is expected to experience an increase in precipitation [4].

3.2.3 Potential Evapotranspiration (PET)

In the studied area, evapotranspiration is consistently high. PET (Potential Evapotranspiration) exceeds 2,000 mm/yr on a yearly basis. Annual rainfall (P) is substantially than below potential evapotranspiration (PET) throughout the year, resulting in a considerable moisture deficit for the majority of the year [5].

3.2.4 Temperature

The strength of seasonal winds and the altitude have an impact on air temperatures. Days are cool and cloudy throughout the region during the first dry season (Xagga). Days are hot or very hot and dry during the second dry season (Jilaal). Hottest months of earch year are March and April. Temperatures vary seasonally, with typical annual temperatures ranging from 23 to 30 degrees Celsius, with a maximum of 41 degrees Celsius in March and a minimum of 24 degrees Celsius in July. Figure 3.4 shows average monthly climatic data of Shabelle river basin.

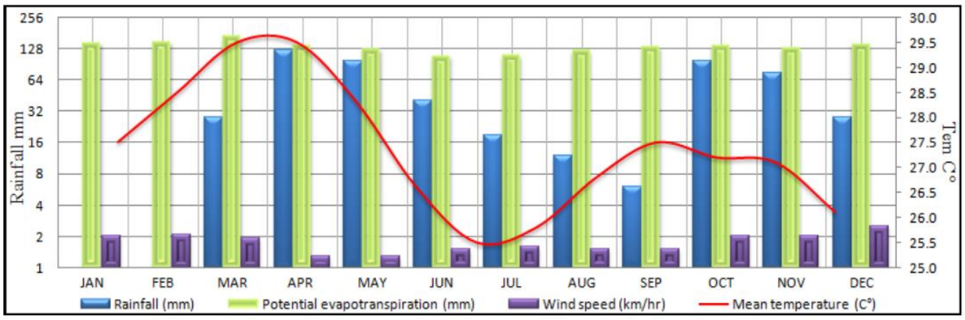

Figure 3.4 Average monthly climatic data of Shabelle river basin in Somalia (from 2003 – 2020) [5]

3.3 Development of the Hydrometric Network and Hydrological Assessment

To extract the development of the hydrometric network and hydrological assessment, we have used GIS and remote sensing technology, and we have developed a thematic evaluation map and locating the best dam site, and it has been used the similar study as in Al-tharthar basin north Iraq and Swat River in Pakistan [15, 16, 19]. The input data consists of DEM, satellite imagery, and runoff. Different software Erdas Imagine 2014, ArcGIS 10.3.1, and soil erosion model will be used to analyse the data. FAO SWALIM database was used to describe the characteristics of the catchment, and based on these characteristics, the suitable site for the dam was selected. Multi thematic layers were generated as an outcome of the study; these layers include land-use and land cover maps, DEM maps, slopes, etc.

Table 3.1 shows the combinations of Shabelle river catchment, precipitation, and annual river runoff

Table 3.1 Shabelle river catchment characteristics in Hiiran Region [1]

Location	Area (km^2)	Elevation ($m\ a.s.l.$)	Precipitation (m)	Annual Runoff Volume (BCM)	Max. river width (m)	Max. depth (m)	Max. flow ($m^3\ S^{-1}$)
Beletweyne	207000	182	300	2.4	44	7	500
Buloberde	231000	147	275	1.4	48	6	400
Jalalaqsi	255300	128	300	2.0	46	5	166

In 1980, a sizeable off-stream storage reservoir was constructed at Jowhar in the middle reaches of the Shabelle, south of Mahadey Weyne [5]. The Jowhar Offstream Storage Reservoir (OSR) was built to store excess river flow during the rainy season and release it for agriculture during the dry season. However, the supply route was also used as a flood relief channel when needed, diverting up to $40m^3/s$ of flow [20]. Several other gauging stations were associated with the Jowhar OSR and sediment and water quality monitoring programs. In contrast, riverbed and streamflow have changed due to erratic irrigation practices, global warming, deforestation, which resulted in significant water loss due to evapotranspiration, alternating rainfall in and out of Somalia, and upper stream development. As a result, Jowhar OSR has become less critical because most floods occur before the river reaches this city [1, 2, 3].

3.4 Geological Description of the study area

The geological description of the study areas is characterized as the complex metamorphic basement such as migmatites and granites; there are also observed some sedimentary rocks such as limestones, gypsiferous limestones, and sandstones. The Fluvial deposits are observed alongside the Shabelle river and mainly consist of sandy clay, gravel, and sand.

3.4.1 Landform

The Shabelle river basin has the following land features:

1. The river valleys traverse the general level, undulating morphology of the area towards the downstream.
2. Hilly topography in the Beletwayne region where the river enters to the Somali region cut by wadis (small valleys), and gently undulating vast plains toward the cost
3. A coastal dune complex, known as the Marka red dunes, separates some narrow coastal belts in some regions of the Shabelle alluvial plain.

3.4.2 Land Cover & Land Use

1 Land Cover

Natural vegetation dominates the research area's land cover. Crop fields (both rainfed and irrigated), Urban and Associated Areas (settlements/towns and airports), Dunes and Bare Lands, and Natural Waterbodies are some of the other cover types. Forests, bushlands, and grasslands make up the natural vegetation.

2 Land Use

Grazing and wood collecting for cooking charcoal and building are the primary land uses in the study region. Goats, sheep, cattle, and camels graze in the rangelands of the Shabelle catchments. The ownership of livestock is private, but grazing pastures are communal, making it difficult to control range use. Herders use rangelands as part of their transhumance initiatives. Forest, bushlands, and grasslands are examples of land cover linked with this land use.

The farmers in this valley are sedentary, combining crop production with animal husbandry. In the fashion of herding nomadic stock, they tend to keep lactation cattle, a few sheep, and goats close to their houses, while non-lactating animals are herded further away. Rainfed and irrigation farmers, on the other hand, raise a modest quantity of livestock, primarily cattle and small ruminants. Animal feed is mostly made from natural flora and crop leftovers, and animals are watered from rivers during the dry season [21]. Crop wastes are used as feed by non-browsing animals like cattle and sheep. During the wet season, several WARs (small man-made natural dams) provide water and act as an alternative to rivers. Groundwater is an important water resource for animals, as are hand-dug wells, wetlands, rivers, and boreholes.

3.4.3 Soil Properties

The climate of the area where the Shabelle river crosses in Somalia is characterized as semi-arid climate. This classification has been a little affected by the soil formation processes. This effect caused the soil in this region to commonly share some characteristics such as heavy texture (clay), low permeability, and poor drainage in some areas. It has been classified as Vertisols and Fluvisols mainly.

In the lower part of the Hiiran region, the surface soil erosion is shallow and stony soils with medium texture (loamy). It is further classified as Leptosols, Regosols, and Calcisols. While the dune complex soil, which is sandy and classified as Cambie Arenosols (Qc), which is slightly matured sandy soils, retains soil moisture better, suitable for agriculture under sprinkler irrigation is observed some areas in Hiiran and middle Shabelle region as the river goes near the coastal areas. Some other types of soil such as Calcaric Regosols (Rc) Calcaric Fluvisols (Jc) Chromic Vertisols (Vc)

Orthic Solonchaks (Zo) Haplic Yermosols (Yh) Calcic Yermosols (Yk) are observed in South of Somalia where the surface water is available. Table 3.2 shows soil properties from profile pits in the study area.

Table 3.2 Soil properties in the study areas [22]

	Old soil profiles				New soil profile			
	Topsoil (≤ 50cm)		Subsoil (> 50cm)		Topsoil (≤ 50cm)		Subsoil (> 50cm)	
Soil Type	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Sand (%)	28.79	15.90	26.71	16.21	41.04	19.53	40.95	20.03
Silty (%)	29.02	11.96	28.89	13.70	30.49	11.62	27.65	12.24
Clay (%)	42.51	15.30	44.32	15.14	28.48	12.74	31.40	16.29
N (%)	0.08	0.05	0.05	0.02	0.07	0.04	0.05	0.03
SOC (%)	0.94	0.57	0.56	0.30	2.80	1.53	2.64	1.19

Chapter 4

Assessment of Shabelle River Regime flow

4.1 Topography and Drainage Network of Shabelle River

The Shabelle River rises on the eastern flanks of the east Ethiopian highlands. The total catchment area of the Shabelle River at its confluence with the Juba River (Second river of Somalia) is about $297000 km^2$, two-thirds ($188700 km^2$) of the river lies in Ethiopia, and the rest ($108300 km^2$) is in Somalia. The basin's elevation varies from more than 3000m on the Eastern Ethiopian Plateau to about 20m above sea level in the southern part of Somalia where the river joins to Juba River inside Somali territory. Roughly 50% of the basin is below 500m elevation; however, the elevation of the study area is between 500m to 125m above sea level [4].

The river and its tributaries in the eastern Ethiopian highlands are deeply incised, and the slopes are steep. The total length of the river course from the source to the Somalia border is about 1290 Km, and it traverses to an additional distance of 1236 Km within Somalia before it meets the Juba River (approximately 600 km is in the study area). Its main tributaries in Ethiopia are the Fanfan (northern part of the basin) and the Webi Shabelle [5], as shown in Figure 4.1. The catchment areas of Webi Shabelle and Fanfan are $143278 km^2$ and $44867 km^2$ respectively [4]. The flows in the Fanfan tributary are intermittent and flow from its reach to the Shabelle River only during high rainfall periods. The drainage network in the Ethiopian catchment (especially in the western part) is dense to very dense except in the neighbouring region with Somalia [6].

The drainage network in the Somalia part of the basin is thin and non-existent. The small streams with small catchments are ephemeral types, where there is flow only during heavy rainfall.

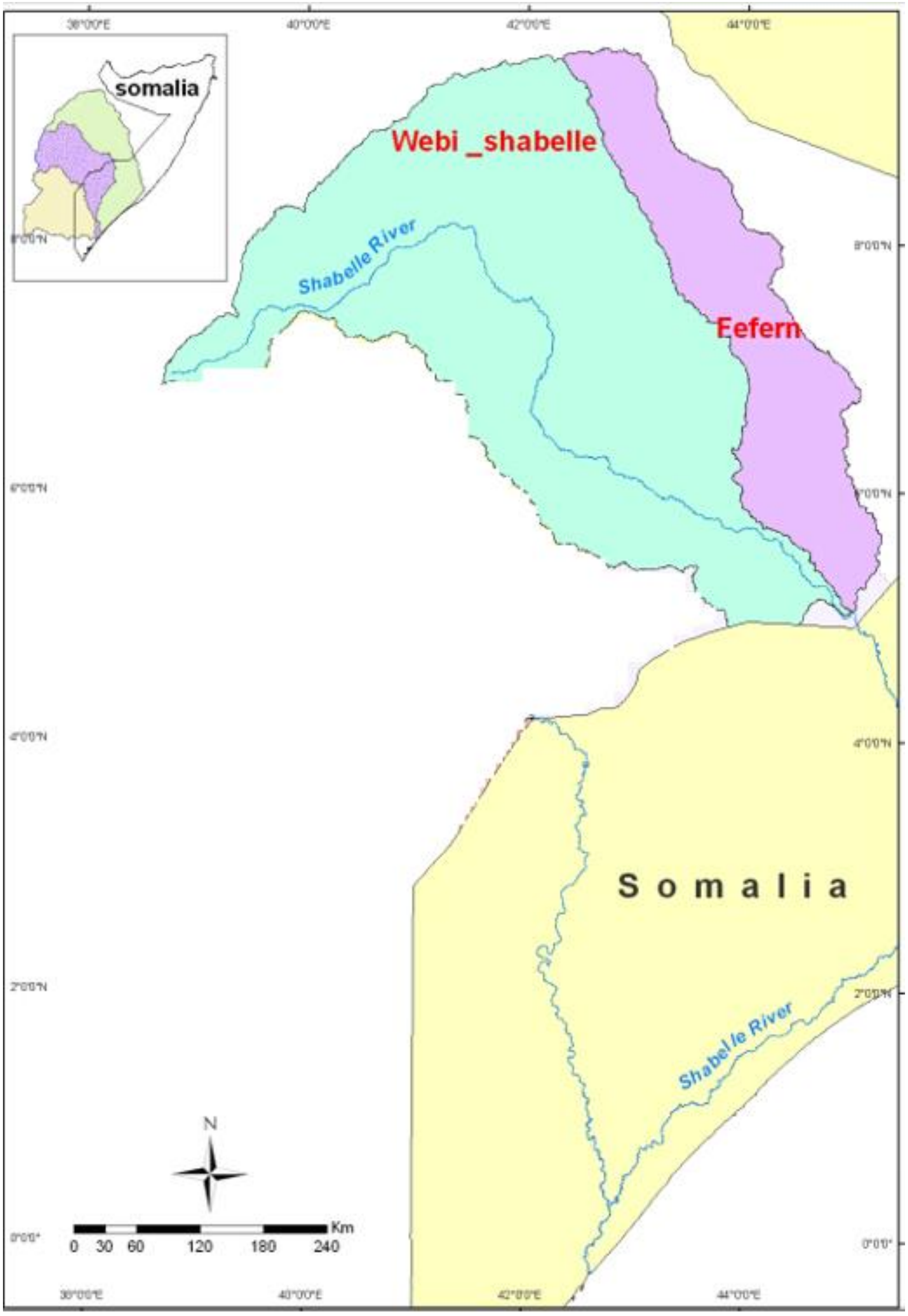

Figure 4.1 Tributaries of Shabelle river in the eastern Ethiopian Highlands [6]

4.2 Hydrological and Hydraulic Regime

The catchment outside Somalia contributes ninety percent of the flow in the Shabelle river within Somalia, however, the long-term mean annual flow volume in the Shabelle river at Beletweyne (catchment area of $193224\ km^2$) is 2.4BCM. the annual runoff to rainfall ratios or the runoff-coefficients is 2.1% at Beletweyne gauge station [4]. As the river flows downstream, the annual flow declines, but some streams near Jalalaqsi may add to the river flow; nevertheless, this contribution is insignificant. The decrease of the flow is mainly due to various factors such as not much contribution to flows from Somali catchment areas, frequent occurrence of bank full condition and spilling of floodwater 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 [23]. Table 4.1 explains the mean annual runoff volume and catchment area of the Shabelle river in Hiiran region.

Table 4.1 Annual runoff volume of Shabelle river in Hiiran region [2]

Gauge location	Catchment area (km^2)	Mean annual runoff (MCM)
Beledweyne	193224	2365
Bulobarde	207488	1410
Jalalaqsi	209865	2053

4.3 Available Surface Water in Hiiran Region

Available surface water in Hiiran region is a combination of rainfall harvesting and river streamflow, however, the aridity of the climate in this region has caused that there are not many effective rainfall harvesting practices in this region; meanwhile, the annual surface water yield in this region mainly depends on the amount of yearly rainfall in which the basin receives both inside of Somali territory or in the border of Ethiopia. The Shabelle River basin receives relatively low annual mean precipitation, approximately 425mm on the Ethiopian border compared to other basins in Ethiopia [4]. However, there are minimal streams which contribute to the river flow inside the

Somali border at Bulobarde. These streams have the typical hills torrents in arid areas. Figure 4.2 shows the average monthly discharge for four different stations in Hiiran region.

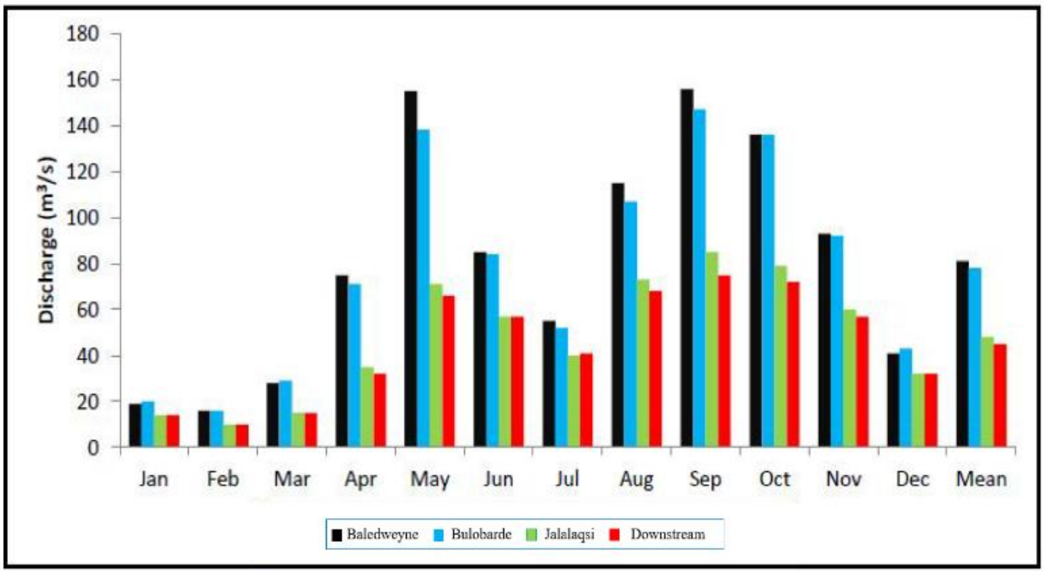

Figure 4.2 Average monthly discharge in Shabelle rive for selected station [2]

Based on the river discharge data, there are considerable flow variations within a year; it has been counted that the river has minimum flow in the first three months of the year. There is also a variation from one year to another. Approximately 50% of the river flow discharge is estimated to be more than 61m^3/s at Beledweyne stations through a year; however, due to extensive irrigation, infiltration, and evaporation, the river discharge decreases as the river goes downstream [2]. It shows that the water in the Shabelle River is diverted most extensively in the dry seasons. Table 2 shows the annual maximum/minimum Shabelle river discharge in the Hiiran region.

Table 4.2 Annual maximum & minimum Shabelle river discharge in Hiiran region [4]

Variation	Beledweyne	Bulobarde	Jalalaqsi
Maximum (m^3/s)	473.6	489.3	176
Minimum (m^3/s)	138.5	144.5	130.2

Based on Table 4.2, it has been noted that the river discharge increases its velocity at Bulobarde due to higher rainfall intensities as well as denser drainage networks near the Bulobarde area also, the riverbed gets narrow in some areas [10].

4.4 Access to Surface Water

The availability of surface water depends on the amount of rainfall and the river flow in the region; however, the accessibility of surface water depends on the infrastructure which will provide specific places and needs. The majority of the riparians use river water directly for local use, even though the quality of the water is questionable.

4.5 Water Demand in Hiiran Region

Available surface water in this region is mainly restricted by Shabelle river flow. However, water demands in the basin can be categorized as follows:

1 Agricultural Water Demand
2 Livestock Water Demand
3 Domestic Use Water Demand

To analyze above mentioned sectoral water demands, we have also to consider the possibility of available water quantity in the region.

These categories and aspects are essential conceptual viewpoints to explore the character, the dimension, and the location of water demands in the river basins.

Irrigation schemes did not get proper rehabilitation after El Nino Floods 1997 -1998; however, agriculture is still the main water consumer according to [24]. Moreover, agricultural development, population growth, and urbanization are important socio-economic trends in the region. Future projections about the local economy and demography are vital for the water demand assessment and will be explored in development scenarios.

4.6 Agricultural Water Demand

Irrigated agriculture accounts for the highest surface water consumption through a year, however nearly 70% of the agriculture is alongside the rivers and alluvial plain between the two rivers; for that reason, 60% of the national maize production is situated alongside the river or the areas near the river. Rainfed cultivation is mainly practised in the country, but it is active only during the rainy seasons. The Food Security Analysis Unit (FSAU) estimates that small-scale farmers may satisfy water-related food demands beyond the catchment boundaries [21]. River flow is the only surface water available in this region through a year; however, the river has been facing an enormous challenge in allocating, using, and protecting this limited water resource.

Concerning the extent and the location of agricultural water demands, information from several sources had to be combined to draw a differentiated picture, providing robust estimates.

Based on the analysis, irrigated agriculture in the southern part of the country was estimated at approximately 129774 ha, with most of the irrigation water coming from the river. However, the analysis doesn’t reveal whether the identified irrigation schemes are or ever were under simultaneous operation [21]. Since there is no available data on the exact groundwater availability, nor on recharge rates, demands, or abstractions in the Hiiran region, the analysis of water requirements for agriculture in the basin has to focus on abstractions along and from the river. The actual operation or operational status of the local irrigation schemes is questionable. However, most areas in the Hiiran catchment have been cultivated at least once during the last four years [25].

Since most agricultural production occurs near the river basin, under similar climatic conditions, and with identical cropping patterns, the value of (approx. 11000m^3/ha) at Beledwayne has been considered a reasonable estimate of crop water demands the Hiiran region.

Based on the given infrastructure information, the irrigated area alongside the Shabelle river is estimated as shown in Table 4.3.

Table 4.3 Areas under irrigation (ha) [25]

Location	Current (average)	Potential of existent schemes	Dry season	Wet season
Hiiran region	15000	40500	5100	24000

With information on the irrigated area and the crop water demand per hectare, quite a precise statement can be given on respective water demands in the Hiiran region Table 4.4 shows annual agricultural water demand in the Hiiran region.

Table 4.4 Annual agricultural water demand in Hiiran region (MCM) [21]

Location	Current (average)	Potential of existent schemes	Dry season	Wet season
Hiiran region	165	445	56	264

4.7 Types of Irrigation in the Region

Mainly the irrigation type alongside the river depends on the extraction of water from the river; however, the following system practised primarily in the Hiiran region

4.7.1 Controlled irrigation system

This system mainly practices extracting water from the river using channels with a width of 2.5m approximately controlled by barrages or a weir from the river, however, this type of irrigation can provide water throughout the year, more specifically whenever the river flow exists in the riverbed, even though further downstream may experience low flow during minimum rainfall. This irrigation system may require heavy equipment for maintenance. Also, there are many irrigating channels with a width less than 2m also controlled by barrages or weirs on the rivers even though the maintenance of such type requires less heavy equipment.

4.7.2 Uncontrolled irrigation system

This type of irrigation is mainly practiced during high river flow; the farmers extract water from the river using direct intake channels with no or limited control by barrages and weirs. However, this type of irrigation is supplementary irrigation of crops grown mainly under rainfed conditions.

4.7.3 Pumped irrigation system

The riparian farmers organized large irrigation schemes where large pumps supply the water and then distribute it through a channel network; however, the farmers associated pumps to access water directly from the river.

4.8 Future Agricultural Water Demand Projections

Given the country's 2.7% population increase (UN Data, 2020) and periodic food shortages (UNDP, 2021) [1], demand for agricultural products will continue to rise. Given the regional appropriateness of soils, if the constraints mentioned above persist in the future, the area for irrigation in the Hiiran region will increase by 15–20%; however, if the irrigation schemes are repaired, the proportion will climb up to 35%.

4.9 Livestock Water Demand

Water for livestock is an essential basis for subsistence and development of the Population in the region. However, the majority of the population in this region directly engages livestock production. Moreover, the estimated livestock population and water demand data has been taken from the minster of Livestock Forestry and Range of the Somali Federal Republic and FAO -SAWLIM database.

There is minimal regional livestock numbers data; however, the estimation is more than 2 million head of combined cattle, camel, and sheep/goats based on the minster of Livestock. Based on the minimum livestock water requirement of the Minister of Livestock for the Somali Federal Republic, if water demands of 20, 10, and 5 liters per day are assumed per camel, cattle, and sheep/goats respectively then a total daily water livestock requirement of 22987.5m^3 for the basin can be determined. This can be calculated through a year which amounts to approximately 8.4MCM as shown in Table 4.5.

Table 4.5 Livestock water demand in Hiiran region [21]

Region	Camel		Cattle		Sheep/goats		Total demand (m^3/day)
	Head	m^3/day	Head	m^3/day	Head	m^3/day	
Hiiran	550000	11000	198750	1987.5	2000000	10000	22987.5

There are also some other types of domestic animals that consume water daily; however, no data reveals the quantity of water consumed by this type of animal; for that reason, we didn't include our analysis.

Population growth will surely need a higher supply of livestock-related products. However, unpredictable droughts followed by floods resulted in the regional projections for livestock numbers, and its water demands cannot be forecasted.

4.10 Domestic Use Water Demand

The majority of the Somali population lives in the southern part of the country where surface water is available. However, domestic water demand includes all domestic-type water requirements in urban and rural areas. The majority of the urban population consumes underground water. It is estimated that 25 litter per day for rural and 50 litter per day for urban population and 60% of the population in this region is urban as minister of the national plan revealed [21]. Table 4.6 calculates domestic use water demand.

Table 4.6 Domestic use water demand (MCM)

Region	Urban population	Rural population	Total
Hiiran	321411	214274	535685
Yearly water Demand	5.9	2.0	7.9

However, 2.0MCM is expected to extract from the river yearly by considering that the urban population is mainly dependent on groundwater. Moreover, future domestic use water demand projection is complex to predict because of unknown rural and nomadic population growth. Total surface water demand is a combination of domestic, agricultural, and livestock water demand; however, Table 4.7 summarizes total surface water demand in the Hiiran region.

Table 4.7 Total surface water demand in Hiiran region (MCM)

Region	Livestock	Rural population	Agriculture	Total
Hiiran	2.7Mhead	214274	15000ha	
Yearly Water Demand	8.4	2.0	165	175.4

4.11 Impact of Climate Change on the Surface Water in Hiiran Region

Pastoral areas in Ethiopia and Somalia are expected to become drier due to lower rainfall; at the same time, drought and flood events are predicted to become more extreme and more frequent along the Shabelle river, especially in the Hiiran region [1]. Somali don’t have current any effective policy or plan for climate change adaptation; hence, the effects of climate change will damage society and the environment, and the consequences will last more than usual.

Climate changes in Ethiopia would therefore have a significant impact on water availability in Somalia. Moreover, alterations in temperature and precipitation in Somalia would also modify the regional agricultural water use in terms of irrigation requirements and crop water demands. Lower rainfalls imply a greater reliance on river or groundwater, and hence the climate change impacts on river flows are of central importance to the analysis of local water availability.

UNDP has conducted a study on climate changes and generated climate change projections in Somalia, but the raster units for which local transitions are indicated, are very coarse $(1.5^0 \times 1.5^0)$ and don't match the catchment boundaries nor the specific geomorphological runoff characteristics of the basin. Arnell (2020) has generated more precise predictions using HadCM Simulations with spatial resolutions of $(0.5^0 \times 0.5^0)$. he determined changes in precipitation of -5% to +15% at 2050 in the Shabelle river basin, associated with a change in a run-off between $(-10\ and + 45)\%$ in 2050 [26].

4.12 Droughts in Hiiran Region

Drought is a climate characteristic with unfavourable weather conditions that lead to scarcity of surface water, high temperature, and strong winds. It is the result of the following combinations

1 Precipitation component, which considers rainfall deficits and dryness persistence;
2 Vegetation component, which analyzes NDVI deficits and deficit persistence as a proxy for soil moisture deficiency.
3 Temperature component, which considers temperature excesses and continuation of high temperatures.

Combined drought index CDI can be calculated using precipitation drought index PDI, temperature drought index TDI and vegetation drought index VDI. The new index compares the present hydrometeorological conditions with the long-term average characteristics in the same interest period with the year.

The index for the various component in simple words can be expressed as

$$Drought\ Index = \frac{actual\ average\ for\ IP}{LTM\ forIP} * \sqrt{\frac{\frac{actual\ lenght\ of\ continuous\ deficit}{excess\ in\ the\ IP}}{\frac{LTMlenght\ of\ continuous\ deficit}{excess\ in\ the\ IP}}} \quad 4.1$$

Where IP is the interest period, LTM represents the long-term average, and deficit denotes rainfall or NDVI, whilst surplus denotes temperature. [27].

The value of the CDI measures the scale of the drought, however, if the computed drought index is

1 Equals to 1.00, then conditions in the actual time unit can be considered normal
2 Greater than 1.00, no droughts
3 Less than 1.00 droughts

Table 4.8 shows an initial classification of drought categories based on the CDI values.

Table 4.8 Classification of drought [27]

CDI Values	Drought Scale
> 1.0	No drought
1.0 - 0.8	Mild drought
0.8 – 0.6	Moderate drought
0.6 – 0.4	Severe drought
< 0.4	Extreme drought

This classification, however, can be modified based on socioeconomic data, geographical considerations, and personal experience. The impact of the drought depends on several factors such as crop type, climate zone, the vulnerability of the ecosystem, soil type, and groundwater, etc.

To calculate CDI in the Hiiran region, we need to calculate each of PDI, VDI, and the TDI for year i and time unit (dekad/month) m using the following formulas.

Dekad is a certain period of days e.g., 10 days

$$PDI_{i,m} = \frac{\frac{1}{IP}\sum_{j=0}^{IP-1} P^{*}_{i,(m-j)}}{\frac{1}{(n*IP)}\sum_{k=1}^{n}\left[\sum_{j=0}^{IP-1} P^{*}_{(m-j),k}\right]} * \sqrt{\left(\frac{RL_{m,i}^{(P^{*})}}{\frac{1}{n}\sum_{k=1}^{n} RL_{m,k}^{(P^{*})}}\right)} \qquad 4.2$$

$$VDI_{i,m} = \frac{\frac{1}{IP}\sum_{j=0}^{IP-1} PNDVI^{*}_{i,(m-j)}}{\frac{1}{(n*IP)}\sum_{k=1}^{n}\left[\sum_{j=0}^{IP-1} NDVI^{*}_{(m-j),k}\right]} * \sqrt{\left(\frac{RL_{m,i}^{(PNDVI^{*})}}{\frac{1}{n}\sum_{k=1}^{n} RL_{m,k}^{(NDVI^{*})}}\right)} \qquad 4.3$$

$$TDI_{i,m} = \frac{\frac{1}{IP}\sum_{j=0}^{IP-1} T^{*}_{i,(m-j)}}{\frac{1}{(n*IP)}\sum_{k=1}^{n}\left[\sum_{j=0}^{IP-1} T^{*}_{(m-j),k}\right]} * \sqrt{\left(\frac{RL^{(T^{*})}_{m,i}}{\frac{1}{n}\sum_{k=1}^{n} RL^{(T^{*})}_{m,k}}\right)} \qquad 4.4$$

where;

IP is the interest period (days or months), RL(P) (run length) is the maximum number successive dekads or months below long-term average rainfall in the IP

$RL^{(T)}$ is the maximum number of consecutive dekads or months above long-term average temperature

RL(NDVI) is the maximum number of successive dekads or months below long-term average NDIV in the IP

n is the number of years where relevant data are available

j is the summation running parameter covering the IP and

k is the summation parameter covering the years where relevant data are available [27].

The CDI is computed as the weighted average of the VDI, and the 2-dekad lagged PDI and TDI, furthermore, the lags on the PDI and TDI demonstrate that the effects of rainfall and temperature on vegetation are slightly delayed. In general, the present-day precipitation or temperature in a given area is likely to affect the area's vegetation in about two-dekad time. It is important to note that this lagging is not necessarily valid for time units of the order of 1 month. For a large time, units CDI will be calculated using the following:

$$CDI_{i,m} = WPDI * PDI_{i,m} + WTDI * TDI_{i,m} + WVDI * VDI_{i,m} \qquad 4.5$$

where w is the wights that are 50% for WPDI and WTDI = WVDI = 25%.

If either TDI or VDI data are missing, then WPDI is assigned a weight of 67%, while WTDI and WVDI are given 33% [27].

It's worth noting that the CDI doesn't take into account the physical properties of the vegetation or the soil. It makes no attempt to model either physical processes or water balance. It's a metric for determining how far current conditions differ from the reference level, which is the multi-year long-term average as defined by the time interval.Using FAO drought monitoring tools for Somalia, we have prepared Table 4.9, which classifies CDI, VID, TDI for Beledweyne, Bulobarde, and Jalalasi from 2003 up to 2020, as well as combined drought index map as shown in Figure 4.3, Figure 4.4, and Figure 4.5

Table 4.9 Values of drought indices of Beledweyne region [28]

Year	NDVI	PDI	TDI	VDI	CDI
2003	0.228361	0.975833	1.080000	1.300833	1.072500
2004	0.228306	0.557500	0.855833	0.562500	0.648333
2005	0.255444	0.940833	1.313333	1.759167	1.216667
2006	0.246028	0.989167	0.980000	1.045000	0.99750
2007	0.242194	1.350833	1.145000	1.563333	1.330833
2008	0.211917	0.765000	0.974167	0.488333	0.773333
2009	0.210361	0.709167	0.734167	0.448333	0.664167
2010	0.202833	0.943333	0.931667	0.363333	0.82500
2011	0.207667	0.745833	0.865000	0.362500	0.70500
2012	0.229583	1.301667	0.947500	0.510833	1.038333
2013	0.249444	1.313333	1.126667	1.4975	1.295000
2014	0.213722	1.010833	0.806667	0.491667	0.846667
2015	0.257778	1.133333	0.829167	1.004167	1.016667
2016	0.238722	0.598333	0.971667	1.616667	0.914167
2017	0.224667	0.533333	0.837500	0.652500	0.650833
2018	0.251417	1.473333	1.181667	1.281667	1.347500
2019	0.264025	1.216667	0.988333	1.102500	1.125000
2020	0.289133	3.170833	1.256667	2.753333	2.513333

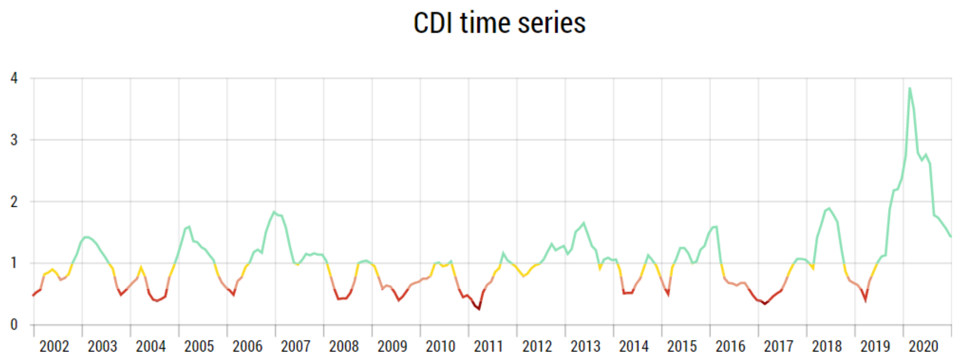

Figure 4.3 CDI in Beledweyne [28]

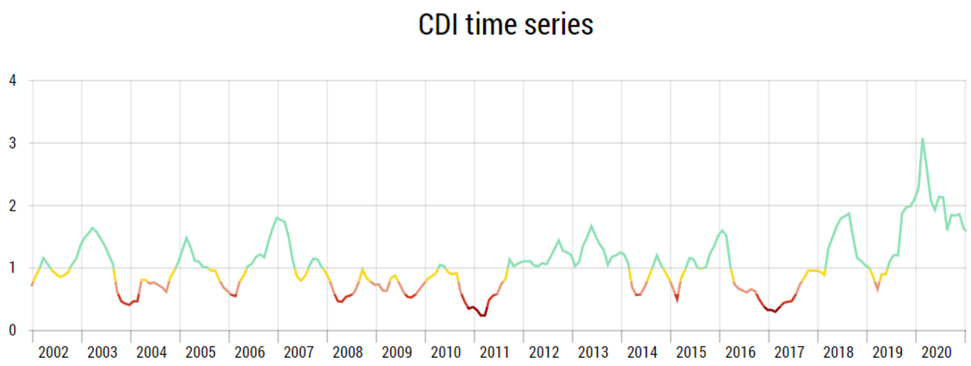

Figure 4.4 CDI in Bulobared [28]

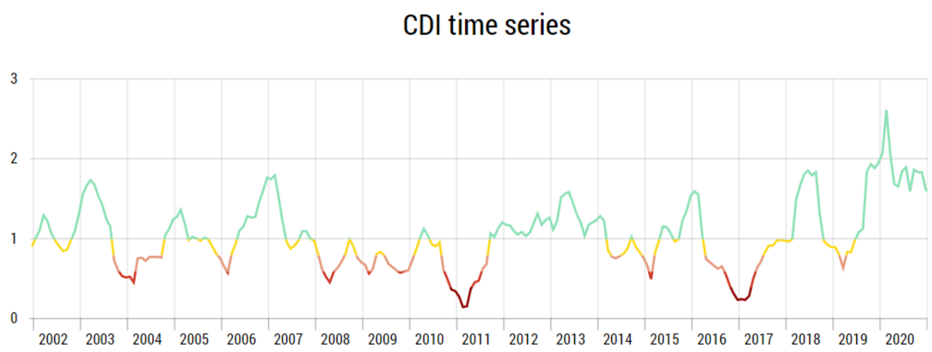

Figure 4.5 CDI in Jalalaqsi [28]

However, to calculate wider-ranging impact droughts we will use 9 months analysis as shown in Figure 4.6.

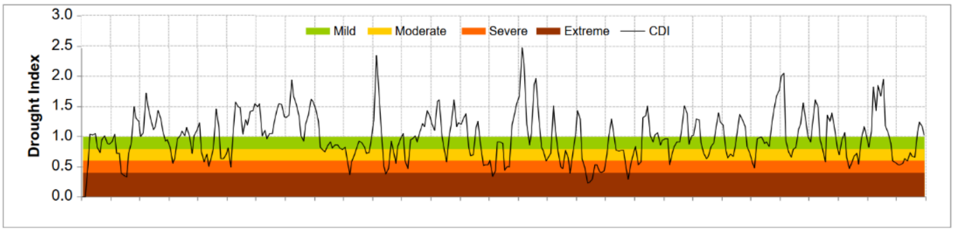

Figure 4.6 Hiiran CDI during 2003 – 2020 [28]

4.13 Floods in Hiiran Region

Floods can be forecasted with complete rainfall-runoff models or with only routing models. However, routing methods-based flood forecasting models are more straightforward and less data-intensive.

The basic data requirements for the various hydraulic flood routing techniques are generally the same; the differences are in the amount of detail. Usually, the data requirements are as follows:

1 Discharge hydrographs from upstream locations and lateral inflow and tributary flow for all points along the stream.
2 Channel geometry cross-section details and reach lengths
3 Stage discharge relationship
4 Channel roughness properties and slope
5 Initial and boundary conditions.

For the flood warning formulation, the data collected by the hydro-meteorological network are fed into the flood forecasting and updating models. The various flood forecasting centres around the world use different flood forecasting and updating models to formulate flood forecasting warnings. Some of the standard methods used for flood forecasting are:

1 Simple correlation based on stage discharge and rainfall data

2 Routing model, which is forecasting the location of upstream flow to downstream (e.g., Muskingum-Cunge method) the foundations of this method use the physical numerical principle to calculate the routing parameters such as Hydraulically wide, Triangular, and Inherently stable [29].

3 Rainfall-runoff model

However, the most convenient method for flood forecasting is to use a simple correlation method or rainfall-runoff model. In this study, we have used the FAO SWALIM database to compare recent years (2020 and 2021) river level and occurrence of high floods in the Hiiran region Figure 4.7 shows river level at Beledweyne, while Figure 4.8 and Figure 4.9 indicate the status of the river at Bulobarde and Jalalaqsi respectively.

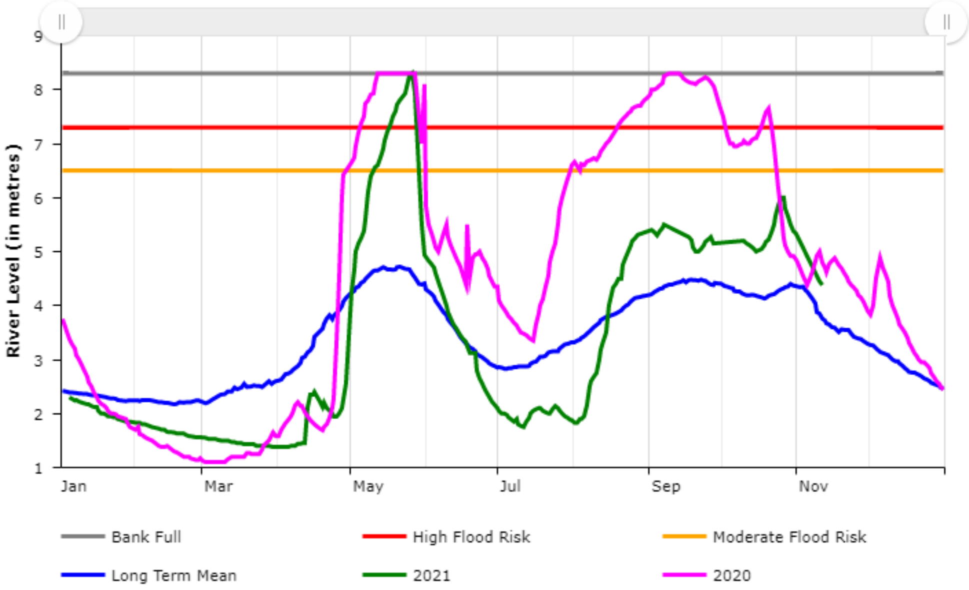

Figure 4.7 River level in Beledweyne [30]

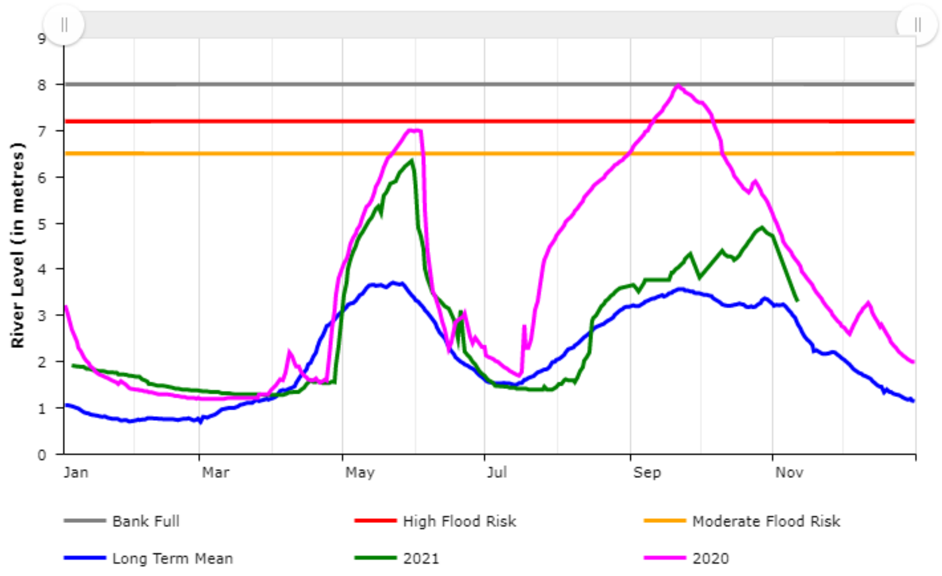

Figure 4.8 River level in Bulobarde [30]

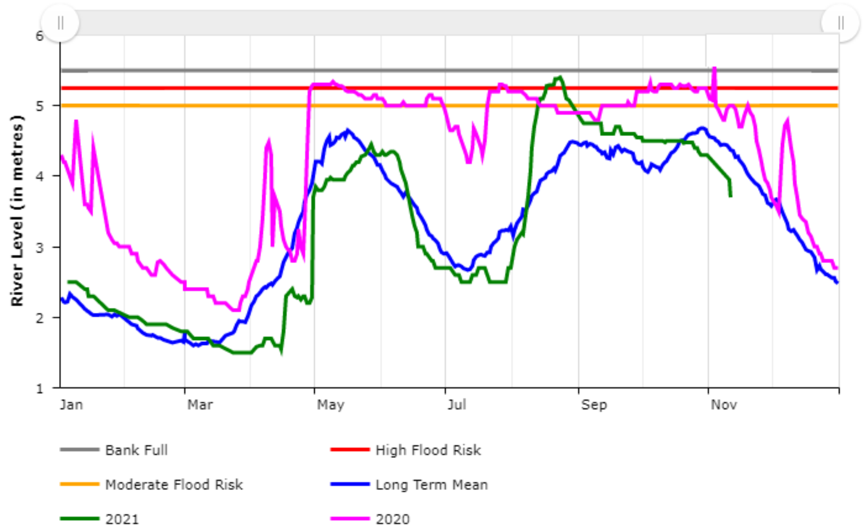

Figure 4.9 River level in Jalalaqsi [30]

These images compare the river's long-term mean of river level (2003 -2021) and moderate and high flood risk occurrence. It is clear that at Beledweyne, there was a high possibility of floods during Gu’ season (May and June 2020 and 2021), as well as between September and October in 2020 at Bulobarde, while Jalalaqsi also experienced as a scenario in May, June September, October, and November in 2020. Using geospatial technology and data from USGS we have created a flood vulnerability map of the Hiiran region, as shown in Figure 4.10. Using land use land cover classifications of Hiiran region, we have seen those areas in Beledweyne is very vulnerable to floods when the rainfall is moderate; however, Bulobarde and Jalalaqsi experience the same condition when the rain is average. However, the main reason behind this situation is that the weakness of the riverbank in this area. The highest floods occur in Jalalqasi, which is due to the fact that this location receives the most rainfall in the region.

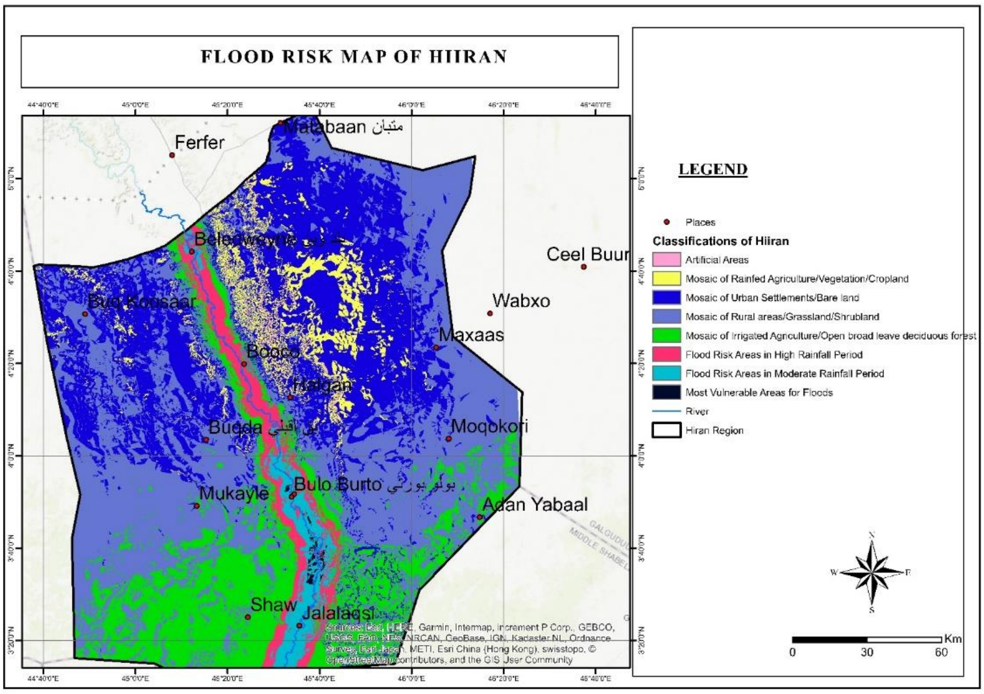

Figure 4.10 Flood risk map of Hiiran region

4.14 Impact of Upstream Developments on Shabelle River in Somalia

Shabelle River originates from Ethiopian highlands and directs towards the Ethiopia-Somali border. It traverses to an additional distance of $1236\,Km$ within Somalia. However, any development inside Ethiopia will directly impact Somalia unless there is an amicable agreement that underlines the rights of each country towards the yearly amounts of water they can get and uses to overcome their basic needs. In this study, we have focused only on upstream development and how the river flow will be after the implantations of the developmental irrigation projects in Ethiopia [4].

Ministry of Water Resources (MoWR) of Ethiopia envisioned developmental master plans for extending water allocation and utilizing water of the Shabelle river basin; however, the master plan proposes several dams for irrigations and hydropower generation in Ethiopia. This plan may cause a delay in river flows and alter prevailing stream patterns [21]. Also, the master plan proposes to divide the river basin into eight development zones, four in the Somali region in Ethiopia[2] and 4 in the Oromia region.

The plan irrigates approximately 190000ha. However, the most significant project for irrigation was envisioned area near the Somali border. If the proposal is fully implemented more than 80% of the Shabelle River stream will be utilized to upscale and will supply to Ethiopian agriculture, livestock, and domestic water needs [21]. Based on the reports from the Minister of Water Resource of Ethiopia, the annual flow of the Shabelle river will drastically decrease as shown in Table 4.10

[2] Eastern part of Ethiopia is a Somali region after British colony left the from Somalia, they have given part of Somali land to Ethiopia and they called reserved area and finally become part of Ethiopia territory, however, the inhabitants are Somalians.

Table 4.10 Annual Shabelle flow of Somali region in Ethiopia [21]

Year	Base (2005)	2010	2020	2035
Flows in m^3/s	123.33	83.15	80.90	23.84
Flows in BCM	3.9	2.6	2.5	0.75
Change to base		-32.6%	-34.4%	-80.7%

According to a report by Ethiopia's Ministry of Water Resources, river flow at the Somalia border was expected to be 2.5 BCM; however, the river flow gauge at Beledweyne border city is reporting less than 2.4 BCM of flow passing through this region annually, and river flow is expected to decrease due to climate change and population growth in the region. The decline in Ethiopian river flow will substantially reduce the amount of water available in Somalia.

According to the master plans of Ethiopia, the sectoral water demands in the Ethiopian Shabelle river basin are rapidly increasing, as shown in Table 4.11.

Table 4.11 Sectoral water demands development in Ethiopia for Shabelle river (MCM/yearly) [21]

Year	Irrigation	Livestock	Domestic	Total
2005	96	73	83	0.253
2055	2228	775	173	3176

Chapter 5

Water Storage Planning Based on Multi-criteria Decision Analysis in Hiiran Region Somalia

5.1 Introduction

The current study used multi-criteria decision analysis (MCDA) to find suitable agricultural water storage dam sites. The methodology of the study uses four main steps. Appropriate criteria selection, classification of criteria, data analysis and generation of suitable maps and site identification; each criterion were given an influence percentage and executed weighted overlay. The study employed numerous datasets, including a raster and a vector, to derive different information for site selection. ArcGIS 10.3.1 was used to create various hydrological characteristics and maps, while Google Earth was used for digitizing numerous features such as land use, land cover, riverbed analyses, and urban regions.

Geospatial techniques including ASTER Global DEM, rainfall data, discharge data, and Landsat 5 and 8 pictures of the Shabelle river were utilized to overcome water shortages, energy crises, and other natural calamities that impair the efficacy of agricultural ecosystems in general in the country.

This research aims to identify a suitable site for rainfall harvesting and relief canal when the river flow is high, as well as to derive a model builder in ArcMap 10.3.1. The model combined several parameters, such as slope and elevation, aspect, rainfall, river buffer, land use and land cover, and soil, to determine the site's suitability for harvesting rainfall and river flow.

The slope, drainage order, watershed analysis, flow direction, and flow accumulation were extracted using a digital elevation model, and inverse distance weighting (IDW) was used for the spatial interpolation of the rain data.

5.2 Decision criteria

This study focuses on four main categories for the identification of suitable sites for the water harvesting process

1. Appropriate criteria selection
2. Classification of criteria
3. Data Analysis and generation of suitable maps
4. Site identification

5.3 Appropriate Criteria Selection

According to FAO, there are six main criteria for the assessment of the site for soil and water conservation:

Soil, climate, topography, hydrology, agronomy, and socioeconomics [17].

Based on literature review and available data, five of these criteria were adapted to identify potential site selection.

Based on FOA recommendations, the following criteria were used:

1. Soil texture and soil erosion factors as a parameter for soil
2. Rainfall and runoff as a parameter for climate
3. Slope, elevation, and aspect as a parameter for topography
4. River buffer as a parameter for hydrology
5. Land use land cover as a parameter for agronomy

Socioeconomic was excluded while evapotranspiration was kept constant since all potential areas for the site selection have the same evapotranspiration [31].

5.4 Classification of Criteria

5.4.1 Soil Texture and Soil Erosion Soil texture

5.4.1.1 Soil Texture

Soil information is a crucial element for natural resources management and specifically for land use planning. In developing countries like Somalia, where there is no national spatial data infrastructure, soil data and information are very scarce. Conventional soil surveys were, and still are, the most widely used method of acquiring soil data at different scales for different purposes. Remote sensing and photogrammetric techniques provide spatially detailed digital data of the Earth's surface and considerably improve mapping land resources. However, in the case of soil resources, they are not particularly effective due to limitations in accessing information apart from soil cover.

Soil surveys in Somalia were mainly undertaken between 1961 and 1988, and information on previous national-level soil surveying and mapping initiatives are scarce [32]. However, Figure 5.1 shows the estimation of topsoil loss in tones/ha/yearly for Shabelle river basin in Somalia.

Soil quality is a critical and deciding factor in Somalia's agricultural output and natural ecosystems. Soil, on the other hand, is a finite and non-renewable resource. It's quickly degraded, and regenerating it is tough, time-consuming, and costly. Soil depletion and degradation are linked to the world's and Somalia's food crises.

Somalia has a variety of soil types, which are mostly determined by climate and parent rock. The organic content of the sandy calcareous soils typical of the Hiiran plains has increased in the highlands of eastern Beledweyne due to relatively high rainfall. This soil is suitable for rain-fed agriculture. Some areas below Bulobarde, has red calcareous soils which sustain vegetation that is good for camel grazing.

In the study area, eleven distinct Reference Soil Groups were evaluated. Leptosols, Regosols, Arenosols, Cambisols, Fluvisols, Calcisols, Solonetz, Solonchaks, Gypsisols, Luvisols, Vertisols, and Technosols are the different types of soils. Table

5.1 shows the occurrence of each reference group as a dominating class, as well as the relationships between reference groups.

Table 5.1 Areas of soil reference groups in Hiiran region [22]

Reference group	Area (km^2)	%
Vertisols	15667.17	17.82
Calcisols	9209.08	10.47
Regosols	6708.78	7.63
Leptosols	5427.92	6.17
Arenosols	4716.99	5.36
Fluvisols	2936.68	3.34
Solonetz	2861.93	3.26
Solonchaks	1150.82	1.31
Cambisols	527.03	0.60
Luvisols	228.14	0.26
Technosols	92.51	0.11
Associations at reference group	**Area (km^2)**	**%**
Vc- chromic vertisols	1322.40	0.93
Qc- cambic/ arenosols	2020.35	1.42
Rc- calcaric/regosols	8020.90	5.65
Yk- calcic yermosols	1059.92	0.74
Jc- calcaric fluvisols	858.13	0.61
Yh- haplic yermosols	569.95	0.40
Zo- orthic solonchaks	328.26	0.23

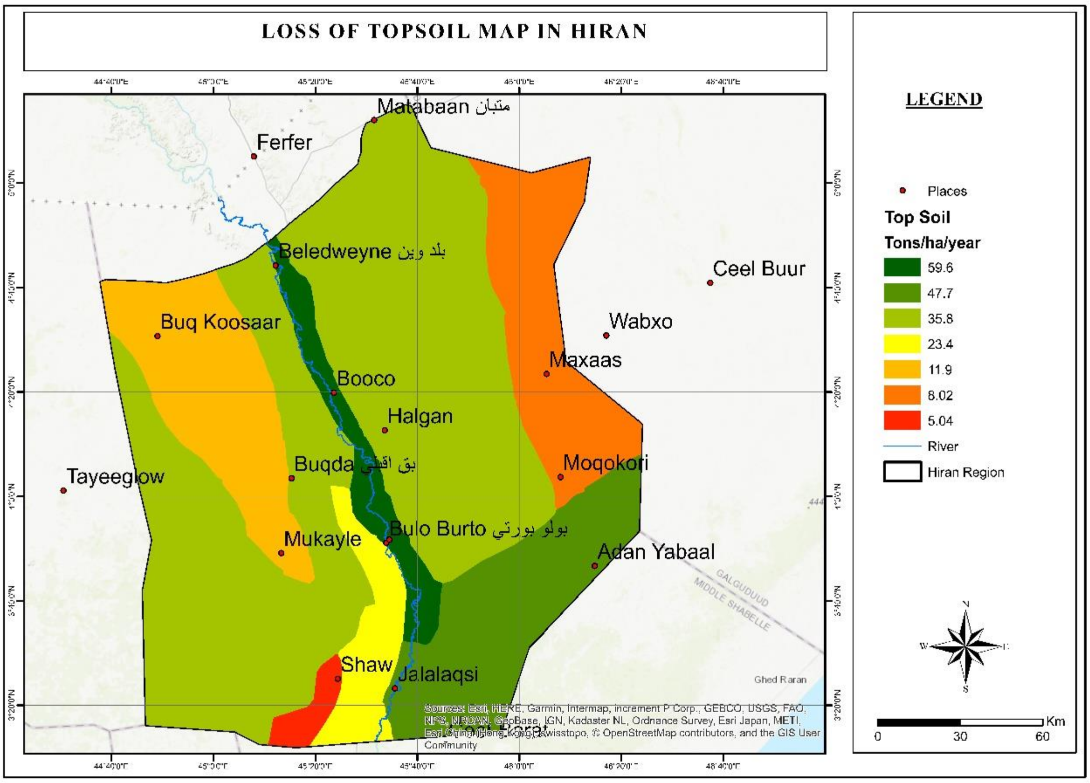

Figure 5.1 Loss of topsoil estimation in tons/ha/year of Shabelle river basin in Somalia

Table 5.1 shows soil classes in the study area; however, the map shows different layers of soil type; the majority of the land is flat and has a similar slope; for that reason, there is no major variant of soil type. Dominant soil types were classified are as follows

1 Calcaric

It accommodates soils in which there is a substantial secondary accumulation of lime; it also has a strong cemented or indurated layer starting within 100 cm of the soil [22]

2 Cambic

Cambisols combine soils with at least a nascent subsurface soil formation. Transformation of parent material is evident from structure formation and mostly brownish discolouration, increasing clay percentage, or carbonate removal

3 Regosols

Regosols are a taxonomic remnant group that includes all soils that fit into none of the other RSGs. Mineral soils with a weakly developed mollic or umbric horizon in unconsolidated materials are not extremely shallow or rich in gravels..

4 Vertisols

These soils are churning, heavy clay soils with a high proportion of swelling clays. These soils form deep, wide cracks from the surface downward when they dry out, which happens in most years.

5 Fluvisols

Fluvisols accommodate genetically young, azonal soils in alluvial deposits of Shabelle rivers and also in lateral river valleys, lacustrine and marine deposits [33].

6 Solonetz

These are soils with a dense, strongly structured, clayey subsurface horizon with a high proportion of adsorbed Na and Mg ions; Figure 5.2 shows soil classification in the Hiiran region.

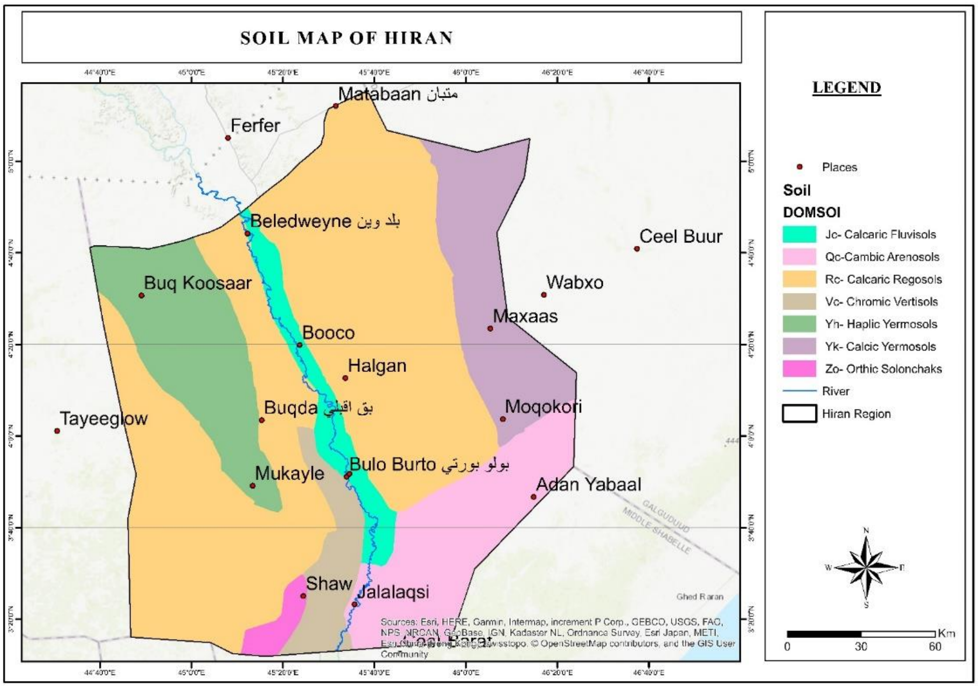

Figure 5.2 Soil map of Hiiran region

The soil texture affects the infiltration rate and surface runoff, while the textural soil class determines the percentage of sand, silt, and clay. However, medium and fine texture soils are suitable for water harvesting because of their high retention [33]; Figure 5.3 shows soil texture variety based on clay content. Good clay soil properties characterize the best dam site locations with high water holding capacity and low permeability. Table 5.2 shows soil texture properties.

Table 5.2 Soil texture properties [22]

Soil texture	Water-infiltration capacity	Water holding capacity	Nutrient-holding capacity	Aeration	Workability
Clay	Poor	Good	Good	Poor	Poor
Silt	Medium	Medium	Medium	Medium	Medium
Sand	Good	Poor	Poor	Good	Good
Loam	Medium	Medium	Medium	Medium	Medium

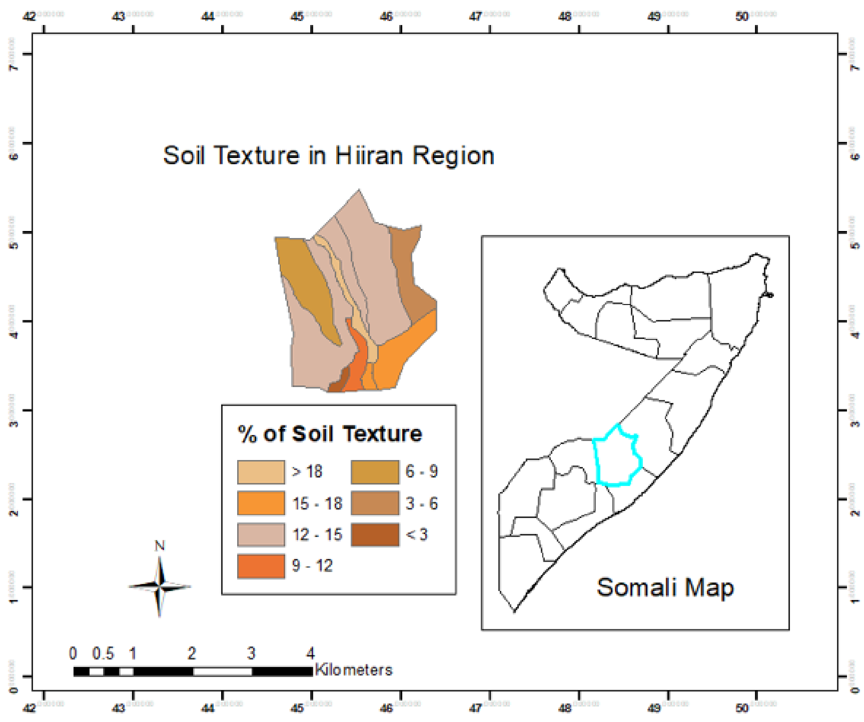

Figure 5.3 Soil texture based on clay content

5.4.1.2 Soil Erosion Factors

In semi-arid and arid areas with less or no protective plant cover, soil erodes more than those in humid climate soils. In the Horn of Africa up a stream of Shabelle river basin experiences the highest soil erosion rate, it was estimated the total annual soil loss in the Shabelle basin was estimated1.01 million tons in 2000, however in 2018 the estimation was increased up to 1.52 million tons, which results in approximately 75.85ton per ha yearly and 107.07 ton per ha annually respectively [34]. It is noted that the most extensive soil loss occurs in the croplands and bare land cover near to Ethiopia Somali border, where the Shabelle river enters Somalia. Furthermore, the soil erosion risk has also noted an increase of 18.28% by the total area in that region. Inside Somalia, the riparian areas experience a high soil erosion risk of approximately 15.89% because of the arid and semi-arid climate. However, areas near Baledweyne experience a total soil loss of $40t/ha$ yearly [22].

Different types of materials have been used for the calculation of soil loss within the Study Area. Those data are mainly, Rainfall data, Soil Data from FAO soil data classification, 5meter contour to delineate river flow accumulation, and Landsat 08 and Landsat 05 Images for land use land cover.

To generate the final map for soil erosion in the study area, we have studied soil erosion factors. We have used the Universal Soil Loss Equation (USLE) model with Geographic Information System (GIS). Remote Sensing (RS) have been used to quantify the soil loss in the study area. To calculate the quantity of soil loss in the study area, five key parameters were used: rainfall-runoff erosivity factor (R), soil erodibility factor (K), slope length and steepness (LS), cropping management component (C), and support practice factor (P). These layers have been prepared in Arc GIS 10.3.1 and RS platforms using various data sources and data preparation methods.

The USLE soil loss equation is:

$$\beta = R \times K \times LS \times CP \quad 5.1$$

Where β is the average annual soil loss, Figure 5.4 shows a Methodological flow chart to prepare a soil loss assessment map [35].

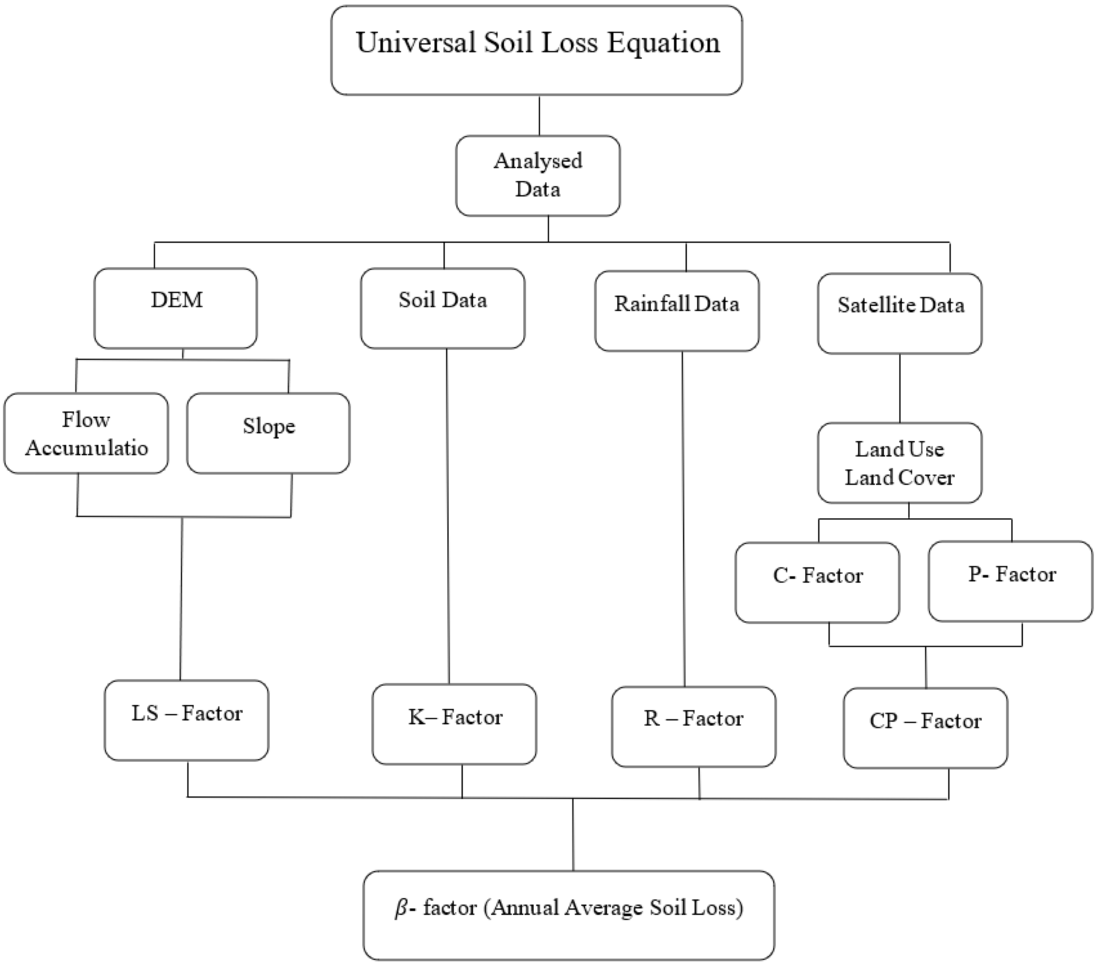

Figure 5.4 Methodological flow chart of the preparation of soil loss assessment map

1 Rainfall Erosivity (R) Factor

The rainfall erosivity factor (R) is a function of rainfall intensity and falling raindrops, and it is mainly used to describe soil erosion drivers. It is computed by multiplying the raindrop's kinetic energy by the 30-minute maximum rainfall intensity. In the USLE model and its revised version, rainfall erosivity is frequently described as the R-factor; RUSLE is useful for designing soil erosion management plans and erosion evaluation [35].

Numerous theoretical and empirical models describe soil erosion processes. The parameters of the processes, on the other hand, can be well-defined. For example, in the Universal Soil Loss Equation (USLE), rainfall intensity and land cover (C) are dynamic components, whereas the others are static. Calculating rainfall intensity and the erosion potential associated with it is a difficult issue. The rainfall erosivity factor (R) is calculated by adding the energy values of each rainfall event over a period of time. There are two methods for calculating rainfall intensity. One of them uses a minimum of 30-minute precipitation data to operate with high temporal resolution.

The other does not have such high temporal resolution data; instead, it uses substantially correlated parameters with R [36]. To determine intensity using more easily accessible precipitation data. The widespread use of the latter method demonstrates that no well approved and frequently used method for calculating rainfall intensity exists [35]. A weakness of the commonly used empirical formula is that it presupposes the existence of precipitation data series dating back to several decades, and the correlation was tested on plot-sized areas [36]. The erosion factor (R) is usually the average value of the data collected during several years. There are usually no data (which would be detailed enough) available to calculate the rainfall erosivity factor, so many alternative parameters were developed by using daily and annual precipitation data to substitute the value of the R factor. These parameters are typically such indices related to smaller areas, and they are used at the maximum of meso-level. They often show a good correlation with soil erosion as the R index [35].

There is a not only sure method of calculating the rainfall erosivity factor due to many active components and their plot-specific nature (although it would be important to estimate soil erosion, for example). Measuring soil erosion requires an extensive collection of both spatial and temporal data (e.g., 10-to-30-minute precipitation data and a sufficient number of rain gauges or pluviography). As they often were and are available, a lot of methods were developed to estimate this factor by employing easily obtainable data, as shown in Table 5.3

Table 5. 3 Compilation of alternative methods of calculating rainfall erosivity calculations [35]

Authors	Alternative methods of calculating rainfall erosivity.	Remarks
Fournier, 1960	$F = p2/P$, where p is mean monthly precipitation, and p is mean annual precipitation.	Fournier index
Arnoldus, 1980	$MFI = \sum_{i=1}^{12} p_i^2 / P$, where pi is mean monthly precipitation, and P is mean annual precipitation.	Modified fournier index
Onchev, 1985	$R = p/s_t$, where p is > 9.5 mm rainfall intensity, s_t is the time of a > 0.18mm/min rainstorm	Universal precipitation event index / Universal index for calculating rainfall Erosivity
Renard – freimund, 1994	$R = 0.07397\ f^{1.847}$ $R = 95.77 – 6.08\ f + 0.477\ f^2$	F<55mm F>=55mm
Fao – colotti, 2004	$R = a \times MFI + b$	A and b are two regionally defined Parameters
Deumlich et al., 2006	$R = -12.98 + 0.0783 \times P$ where p is annual precipitation.	Mean annual precipitation
Diodato – bellocchi, 2007	$R_m = b_0 \times [p_m f(m) + f(E, L)]^{b1}$	Rm is based on monthly precipitation
Sauerborn et al., 1999	$Rs = -33.2 + 2\ FIMs\ (r^2 = 0.64)$	Fournier index with summer months
Eltaif et al., 2010	$R = 4 \times 10 - 6 \times F3.5874$	Monthly precipitation data
Hernando – romana, 2015	$R = 0.15\ P$, where p is annual precipitation data $R = 2.51\ F$, where f is the fournier index $R = 1.05\ MFI$, where mfi is the modified fournier Index	>5-year-long simulation > 10-year-long simulation >10-year-long simulation
Herman h. 1985	$R = 0.55 \times MAP + 4.7$	Map mean annual precipitation

Several alternative indices were also connected to rainfall erosivity. Most of these indices had a strong correlation with the Fournier Index that uses monthly and annual mean precipitation data. Preparing soil erosion models requires such precipitation information that is very time-consuming and cost-intensive to obtain, and it is often without measurable benefits. The R-value often correlates well with other readily available rainfall data in the long run [35, 36, 37]. Of course, the result is usually also accurate: high erosivity rainfalls result in high R values. From the alternative calculations, the readily available monthly/annual precipitation data were investigated; a lot of researchers also used these data for extreme values, e.g., for >100 mm precipitation [34]. In our study, we used Herman H. 1985 because we had rainfall data that measured different gauges during the period 2003 – 2020.

Our study area is low laying watershed that experiences different spatial distribution and slope variation. This variation affects the river course in various aspects such as discharge flow, streamflow velocity, and riverbed. To calculate R-factor, we have analyzed different rainfall data available from rain gauge stations alongside the Shabelle river in the Hiiran region. We have used the inverse distance weighting (IDW) method for the interpolation in Table 5.4.

Table 5.4 Rainfall erosivity factor in Hiiran region 2003 – 2020 [34]

Years	Baledweyne R-factor	Bulobarde R-factor	Jalalaqsi R-factor
2003	14.69166667	18.61041667	19.31487500
2004	19.57291667	24.36250000	20.96991667
2005	16.61666667	22.08916667	18.52333333
2006	17.57916667	27.89166667	30.50416667
2007	28.41875000	30.55916667	22.02500000
2008	10.79583333	22.07083333	15.43325000
2009	22.25416667	13.14708333	18.10212500
2010	11.78125000	10.25958333	22.25416667
2011	19.18333333	18.63333333	23.65208333
2012	26.24166667	26.83291667	29.35833333
2013	16.18125000	25.59083333	27.29583333
2014	18.01458333	20.23750000	14.05000000
2015	36.46250000	30.11458333	30.11825000
2016	11.54750000	9.879166667	11.41504167
2017	9.466666667	9.30625000	18.18325000
2018	22.85000000	20.97083333	25.76683333
2019	27.05612500	31.66237500	34.67087500
2020	33.62037500	34.10300000	35.21445833

This study computed R by analyzing the rainfall data available from 3 rain-gauge stations in the Hiiran region alongside the Shabelle River. Spatial distribution of R Factors data in the study area is estimated using the inverse distance weighting (IDW) interpolation method. This IDW interpolation method considered 17 years of rainfall data for 3 rain gauge stations in and around the Shabelle river basin area.

To generate an R-factor map, we have used the average annual rainfall erosivity actor, and interval data was used to overlook the erosivity factor of the region, as shown in Figure 5.5

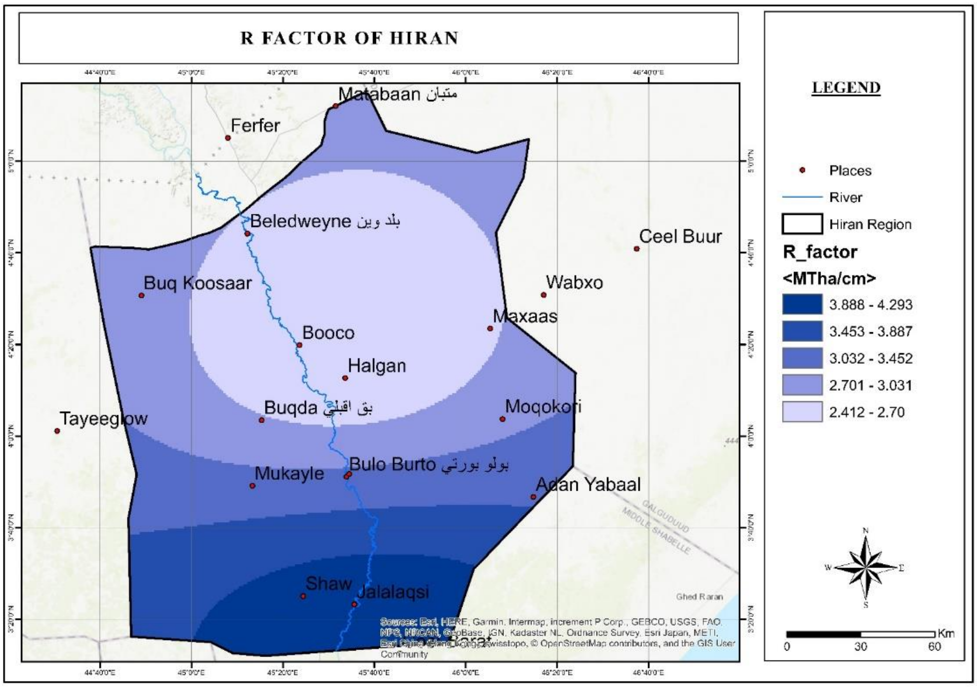

Figure 5.5 R-factor map of Hiiran region

2 Soil Erodibility Factor (K)

Soil erodibility is a crucial metric for determining a soil's erosion risk. However, it is generally understood that only a small portion of the sediment eroded inside a drainage basin will reach the catchment outflow and be represented as the sediment yield [35]. The Sediment Delivery Ratio (SDR) is a term that is frequently used to characterize the complete process of on-site erosion and downstream sediment production. The SDR is the proportion of sediment output at the catchment outlet to gross soil erosion in the drainage area as a whole.

The application of the USLE and SDR models to compute sediment yield geographically has been enabled by the development of Geographical Information Systems (GIS) technology in recent decades. Such estimations can be made by multiplying the USLE's gross erosion in a catchment cell I by the SDR estimated for the same cell I which represents each cell i's contribution to the catchment's sediment yield [36].

Three approaches were used to calculate the soil erodibility factor. The first study, conducted in field conditions with natural rainfall, associates soil loss with the rainfall erosivity index [33, 34]. Even though this is the conventional approach, it takes time to generate a reliable dataset and requires substantial fieldwork for sediment collecting. The second, which is also commonly utilized, is similar to the first, except that artificial rainfall is employed instead of natural rainfall [37]. The third method uses multiple regression models with independent soil variables associated with soil erodibility collected previously in normal processes are used in these methods. We shall apply the third approach with William's (1995) equations in this investigation.

$$K_{USLE} = f_{csand} \cdot f_{cl-si} \cdot f_{orgc} \cdot f_{hisand} \tag{5.2}$$

where:

f_{csand} is a factor, that represents low soil erodibility with high coarse-sand content and higher for soils with little sand;

f_{cl-si} indicates low soil erodibility factors for soils with high clay-to-silt ratios;

f_{hisand} is a factor that lowers K values for soil with very high sand contents.

f_{orgc} is a factor that reduces soil erodibility values in soils with high organic carbon content,

$$f_{csand} = \left(0.2 + 0.3 \cdot exp\ \left[-0.256 \cdot m_s \cdot \left(1 - \frac{m_{silt}}{100}\right)\right]\right) \tag{5.3}$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}}\right)^{0.3}$$

$$f_{hisand} = \left(1 - \frac{0.7 \cdot \left(1 - \frac{m_s}{100}\right)}{\left(1 - \frac{m_s}{100}\right) + exp\left[-5.51 + 22.9 \cdot \left(1 - \frac{m_s}{100}\right)\right]}\right) \tag{5.4}$$

$$f_{orgc} = \left(1 - \frac{0.25 \cdot orgC}{orgC + exp[3.72 - 2.95 \cdot orgC]}\right) \tag{5.5}$$

where;

m_s is the present sand fraction content (0.05-2.00 mm diameter) [%];

m_{silt} is the silty content (0.002-0.05 mm diameter) [%];

m_c is the clay content (<0.002 mm diameter) [%];

$orgC$ is the organic carbon (SOC) content [%] [34].

Because the topsoil cover of the watershed is directly affected by raindrop energy, it was represented by all fractions of soil, sand, clay, silt, and organic carbon. Applying Equation 5.2 and FAO soil classifications we have created Table 5.5

Table 5.5 % of Sand, Silt Clay, Organic Carbo, and K- Factor Values

Soil unit symbol	sand % topsoil	silt % topsoil	clay % topsoil	OC % topsoil	fcsand	Fcl-si	forgc	fhisan	K_factor
YK	63.5	17.9	18.7	0.26	0.20	0.81	1.00	0.99	0.16
I	58.9	16.2	24.9	0.97	0.20	0.76	0.93	0.99	0.14
Q	91.9	3.2	5	0.23	0.20	0.75	1.00	0.47	0.07
RC 1	82.2	6.9	10.9	0.33	0.20	0.75	0.99	0.70	0.10
RC 2	38.7	35.5	25.8	0.58	0.20	0.85	0.98	1.00	0.17
JC	39.6	39.9	20.6	0.65	0.20	0.88	0.98	1.00	0.17
YH	50.4	29	20.6	0.3	0.20	0.85	1.00	1.00	0.17
RC 2	38.7	35.5	25.8	0.58	0.20	0.85	0.98	1.00	0.17
VC	22.4	24.5	53	0.69	0.20	0.71	0.97	1.00	0.14
QA	92.6	3.6	3.7	0.87	0.20	0.81	0.95	0.46	0.07
ZO	43.2	24.6	32.4	0.4	0.20	0.78	0.99	1.00	0.15
NE	68.4	10.5	21.2	0.6	0.20	0.72	0.98	0.96	0.14
SO	57.6	13.5	29	0.39	0.20	0.71	0.99	1.00	0.14
SO 1	86.6	9.6	3.7	0.44	0.20	0.91	0.99	0.58	0.10

Using Table 5.5 results, we have generated a K-factor map as shown in Figure 5.6

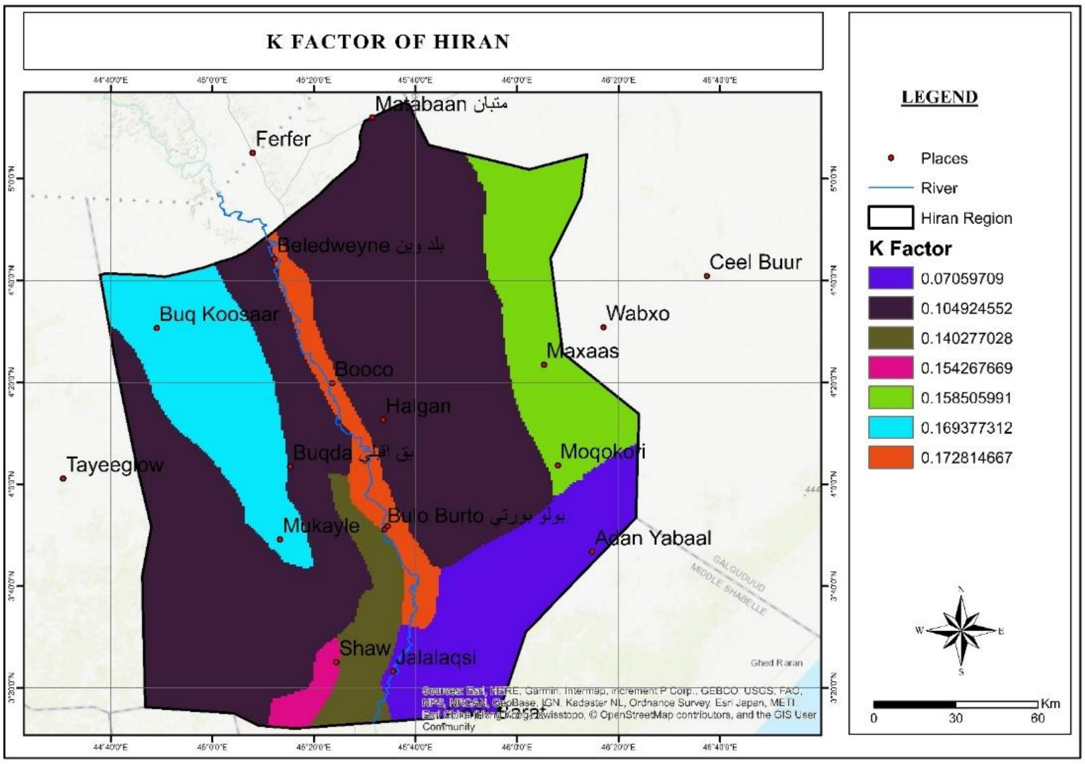

Figure 5.6 K-factor map in Hiiran region

K factor is rated ‘0.07’ to ‘0.17’, where ‘0.07’ indicates the vulnerability rate of soil erosion is less and ‘0.17’ indicates the highly vulnerable rate of soil erosion by water. We obtained these values using William's (1995) formula; however, most areas in Baledweyne, Booco, Halgan, and Buqda have fewer K – factor values even though Jalalaqsi was recorded as the lowest K – values area in this region. Areas with K- factor values of 0.14 have fine loamy typic dystrochrepts, coarse loamy typic Udorthents, fine loamy Hapludalfs, and Paleudults while areas with K – factor values of 0.10 have Fine loamy Typic Dystrochrepts, Fine loamy Oxyaquic Dystrochrepts, Coarse loamy Typic Udorthents. However, areas with 0.17 K – factor values have Fine loamy Aquic Dystrochrepts, Coarse loamy Fluventic Dystrochrepts soil type.

3 Topographic Erosivity Factor (LS)

The slope is an essential parameter in the generation of runoff and the amount of sedimentation. Thus, most researchers recommended that water harvesting areas have slopes lower than 10 degrees to avoid high erosion rates due to irregular runoff distribution.

Slopes also play an important role in the calculations of soil erosion; however, slope length factor (L) and slope steepness factor (S) generally reflects the effects of topography on erosion over any area. The increase of L and S results in a higher velocity of overland flow, which corresponds to a great erosion into the direction downstream. This erosion reduces soil productivity and transports the soil into riverbeds and reservoirs.

A digital elevation model with 5m resolution was used to generate the slope map. At the same time, flat areas and sinks were removed to maintain water flow continuity to the catchment areas using ArcGIS 10.3.1. When the slope length increases, the soil erosion by water also increases due to the more significant accumulation of surface runoff. Slope gradient and slope length factors were calculated from the flow accumulation and slope values. Finally, the Topographic Erosivity Factor (LS) map has been derived using the following formula in ArcGIS spatial analysis raster calculator function with the formula of Moore and Burch (1985) equation

$$LS = (slope\ lengh/22.13)^{0.4} * (0.01745 sin\theta/0.0896)^{1.4} * 14 \qquad 5.6$$

where Slope Length is Flow accumulation *Cell resolution (DEM) and θ is “Slope in Degree” [35].

To calculate LS factor using DEM in Arc Map following steps were done

1. Fill Sink was calculated
2. Flow direction using fill sink data was used as the input raster
3. Flow accumulation was done using flow direction as the raster input raster
4. The Slope of the watershed in degree was done using DEM data as the input layer (Arc Map → Spatial Analyst Tool → Surface → Slope)

5 The LS Factor formula was written as follows (Arc Map → Spatial Analyst Tools → Map Algebra → Raster Calculator as shown in Figure 5.7

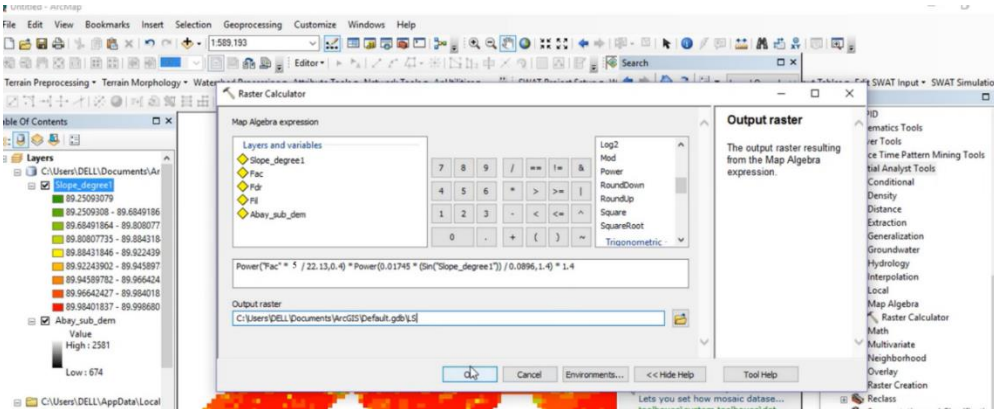

Figure 5.7 LS – factor process in Arc map 10.3.1

Slope steepness reflects the influence of slope gradient on erosion. In general, an increase in the L or S factor produces higher overland flow velocities and correspondingly more significant erosion [34]. Figure 5.8 shows Topographic Erosivity factor LS- Factor in the Hiiran region.

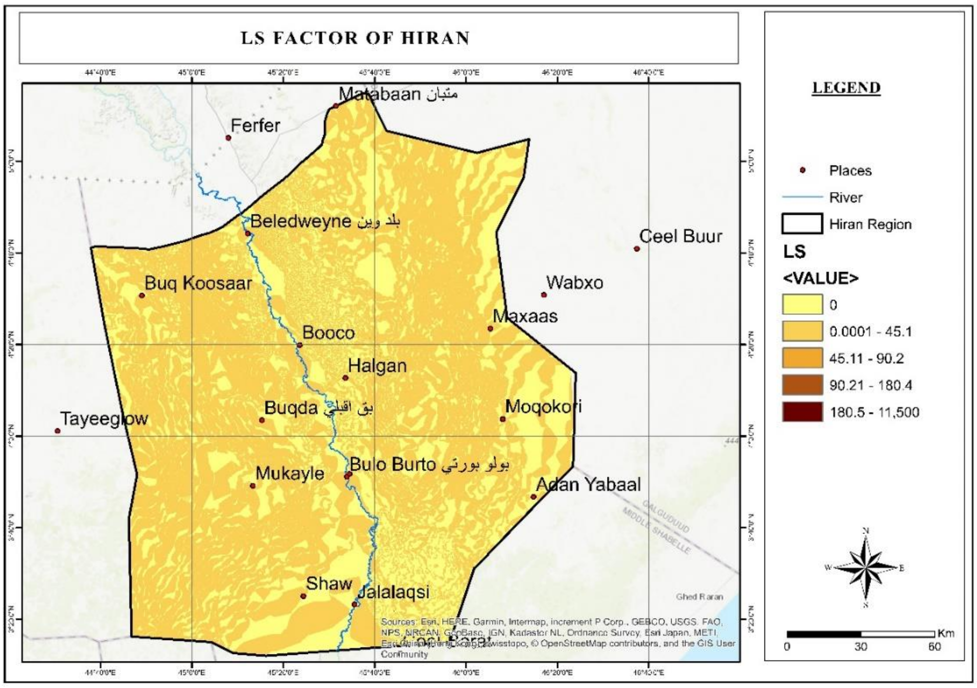

Figure 5.8 Topographic erosivity factor in Hiiran region

4 Crop Management Factor (C) and Conservation Supporting Practice Factor (P)

The crop management factor was estimated using USLE and RUSLE, which determine the degree of erosion by cropping pattern [34]. C factor map was prepared based on the land use land cover map of the study area. The land use land cover of the Shabelle river basin in the Hiiran region was classified into eleven major types of land use land cover classes. The satellite image was processed for extracting these eleven-land use-land cover classes using the supervised classification method and thereafter the land use-land cover map was reclassified based on their estimated C-factor value for the generation of the Crop management factor (C) map as shown in Figure 5.9 and P Factor map Figure 5.10

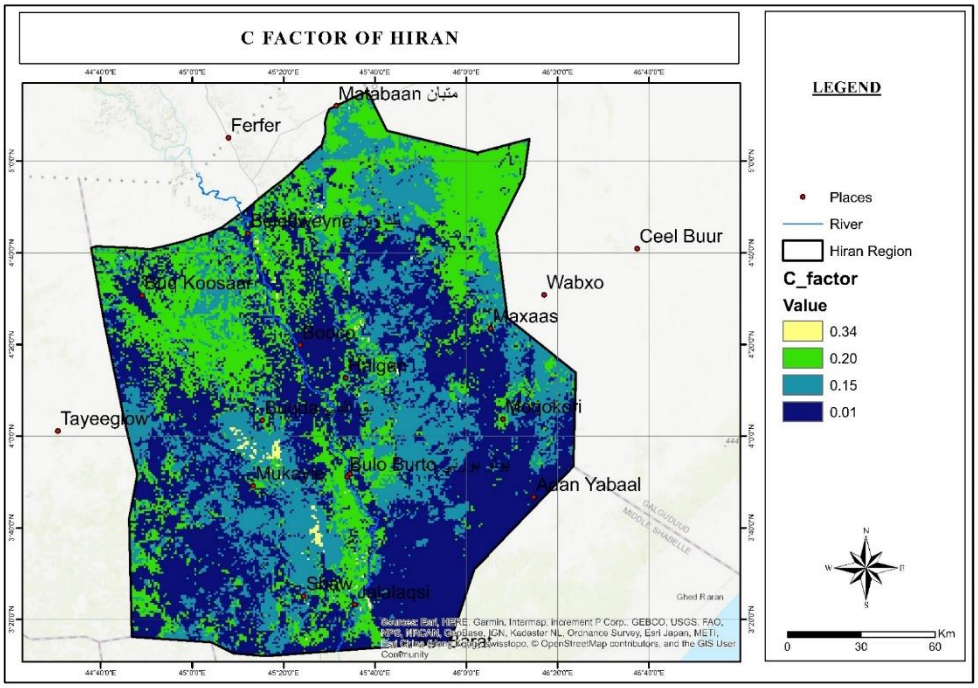

Figure 5.9 C factor map of Hiiran region

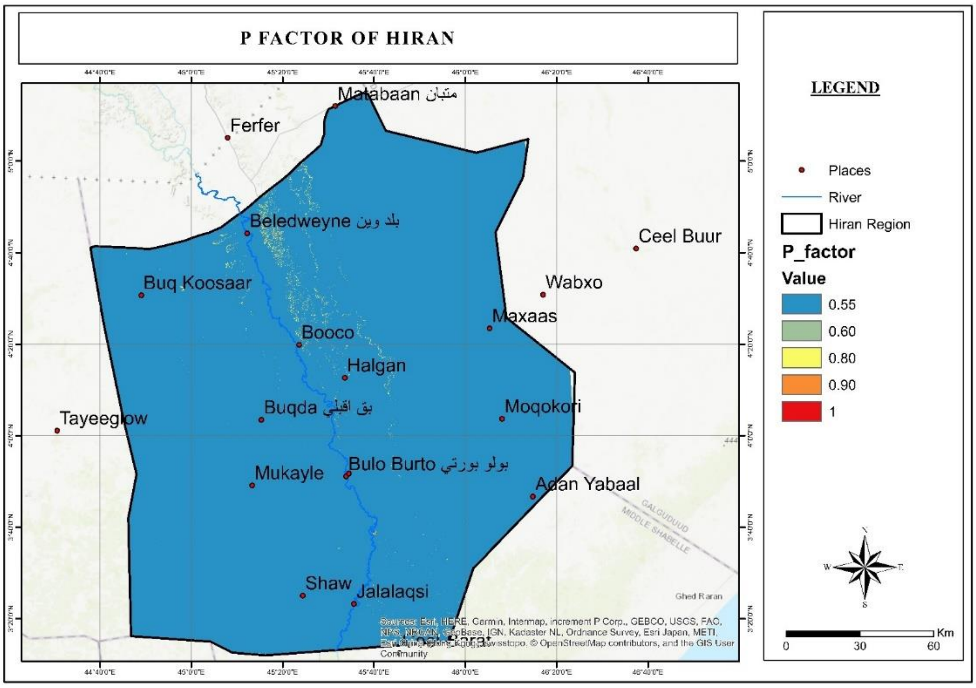

Figure 5.10 P – factor map in Hiiran region

In the study area majority of the area is under dense and degraded forest. CP factor is less significant when land use and the land cover area comprise the maximum percentage of natural vegetation and plantation crops. The CP factor values in the study area range from 0 to 1.

5 Average Annual Soil Loss (β factor)

The average annual soil erosion potential (β) has been computed by multiplying the developed raster data from each factor.

$$\beta = R \times K \times LS \times CP$$

The final β factor map displays the average annual soil loss potential of the Shabelle river basin in the Hiiran region, as shown in Figure 5.11

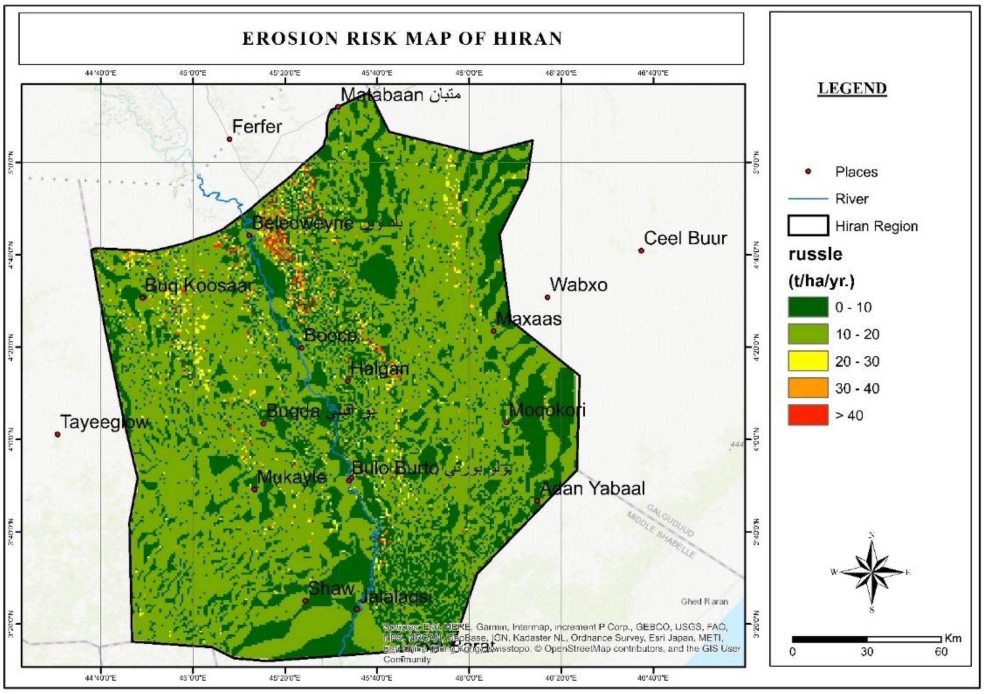

Figure 5.11 Average annual soil erosion map in
Hiiran region

From Figure 5.11, it has been noticed that the majority of the study area has average annual soil erosion in between ($0 - 20\ t/ha/yr$). However, there are some ears with high erosion, which mostly exceeds $40t\ /ha/yr$

5.4.2 Rainfall and Runoff

5.4.2.1 Rainfall

Somalia has an arid to semi-arid climate, influenced predominantly by the inter-Tropical Convergence Zone (ITCZ) and the Somali Jet. Orographic and coastal influences are also significant and cause a high degree of variability across the country. The ITCZ represents the boundary between the Hadley cells of the northern and southern hemispheres [5]. Convergence of the north-easterly and south-easterly trade winds creates a region of uplift and instability positioned approximately over the equator [38]. This zone moves north and south of the equator through the year according to the sun's relative position. The movement of the ITCZ dominates the equatorial climate. Regions close to the equator generally have two rainy seasons. However, the climate of the study area is tropical arid to dry, and sub-humid. In contrast, the rainfall in this area is relatively lowest varies from 100mm to 350mm; there are four main seasons with two rainy seasons alternating with two dry seasons:

- ✓ Jilal: January – March dry season with no significant precipitation
- ✓ Gu: April – June the main rainy season
- ✓ Xagaag: July – September light showers
- ✓ Dayr: October – December second rainy season

The demand for river water also depends on the availability of alternative water supplies such as rainwater. There is not much data available on amounts of rainwater substituting river water, nor any detailed maps illustrating and locating the current use of rainwater harvesting (RWH) techniques or the potential for these in the different parts of Somalia [39]. But rainfall values are known, and there seems considerable potential to expand rainwater use, substituting at least parts of the demand for water from the river, wells, and boreholes.

Rainfall is also a key determinant of growing seasons and the types of agriculture practised, directly influencing surface runoff, streamflow, and groundwater recharge. Rainfall variability from one year to the other is a prime concern for water utilization. The reliability of available water influences agricultural productivity as well as the design of water resources systems. Rainfall variation is relatively high in the case of

Somalia, including the study area. The coefficient of variation (CV) of annual rainfall is found to vary more for locations with lower rainfall as shown in Figure 5.12. The CVs of monthly rainfall is also greater during dry seasons compared to the two rainy seasons. Table 5.6 Table 5.7 and Table 5.8 show the amount of precipitation in Beledweyne, Bulobarde and Jalalaqsi, respectively.

Baledwayne city is always more vulnerable to destructive floods than the others cities, the reason is not only the weakness of the riverbed and river banks but is the fact that most of the people both urban and rural are coming near to the river to access more water during the dry season, however, when there is more rainfall in Ethiopia highlands the river stream comes with hight velocity to this city before the rainfall begins in Baledwayne city, and the river discharge can spread all areas near the river before the stream goes to the downstream. Figure 5.13 shows the rainfall map of the Hiiraan Region

Table 5.6 Precipitation of Beledweyne [40]

Year	Jan	Fe	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
2003	0.0	0.0	0.0	30.0	76.5	15.5	0.0	0.0	0.0	0.0	45.5	50.5
2004	0.0	0.0	0.0	76.0	24.0	0.0	0.0	0.0	0.0	52.0	172.5	0.0
2005	0.0	0.0	0.0	76.5	121.5	0.0	0.0	0.0	0.0	52.0	10.0	0.0
2006	0.0	0.0	0.0	59.5	10.0	23.0	0.0	0.0	27.0	60.0	86.0	15.5
2007	0.0	0.0	0.0	305.0	10.50	55.5	0.0	0.0	27.0	78.5	41.0	0.0
2008	0.0	0.0	0.0	16.0	26.0	8.0	0.0	0.0	8.0	75.0	0.0	0.0
2009	0.0	0.0	0.0	45.5	27.0	0.0	0.0	0.0	14.0	271.0	25.5	0.0
2010	0.0	5.0	11.5	64.5	42.5	0.0	0.0	0.0	26.5	4.50	0.0	0.0
2011	0.0	0.0	0.0	0.0	154.0	0.0	0.0	0.0	0.0	110.5	51.5	0.00
2012	0.0	0.0	0.0	24.5	13.0	0.0	0.0	0.0	205.5	185.0	42.0	0.00
2013	0.0	0.0	3.0	100.0	35.0	0.0	0.0	0.0	26.0	26.0	60.5	0.00
2014	0.0	0.0	0.0	0.00	86.50	0.00	0.00	6.00	0.00	134.0	64.00	0.00
2015	0.0	0.0	5.0	197.0	43.00	11.0	0.00	20.0	0.00	287.0	130.0	0.00
2016	0.0	9.9	0.0	37.50	44.50	0.00	0.00	0.00	0.00	52.50	0.00	5.00
2017	0.0	0.0	0.0	52.00	52.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2018	0.0	0.0	0.0	282.5	44.50	0.00	0.00	0.00	0.00	54.00	0.00	15.0
2019	0.0	0.0	0.0	18.97	92.73	5.92	12.9	9.30	2.57	205.6	133.9	5.87
2020	0.0	0.4	134.2	83.2	53.12	8.11	12.0	10.0	5.01	150.0	140.0	35.0

Table 5.7 Precipitation of Bulobarde [40]

Year	Jan	Fe	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
2003	0.0	0.0	0.0	147.0	77.5	9.0	8.0	0.0	0.0	0.0	14.5	47.5
2004	0.0	0.0	0.0	91.0	10.0	27.0	11.5	0.0	0.0	53.5	236.0	0.0
2005	0.0	0.0	3.5	113.4	160	0.0	0.0	0.0	0.0	81.0	21.5	0.0
2006	0.0	0.0	0.0	99.5	46.0	0.0	0.0	23.5	0.0	246.2	73.6	17.2
2007	0.0	0.0	0.0	307.8	63.0	39.0	0.0	0.0	11.0	111.4	32.0	0.0
2008	0.0	0.0	0.0	0.0	198	13.0	0.0	18.0	0.0	140.0	10.0	0.0
2009	0.0	0.0	0.0	92.8	69.0	8.5	8.5	0.0	5.5	0.0	0.0	0.0
2010	0.0	0.0	18.8	71.0	23.0	5.0	0.0	0.0	0.0	3.5	0.0	0.0
2011	0.0	0.0	0.0	0.0	130	0.0	0.0	0.0	0.0	108.5	65.5	0.0
2012	0.0	0.0	0.0	80.5	108	0.0	0.0	0.0	4.0	275.4	15.0	0.0
2013	0.0	0.0	80.0	140.0	5.0	0.0	0.0	0.0	0.0	198.8	32.0	0.0
2014	0.0	0.0	0.0	82.0	120	0.0	0.0	0.0	0.0	107.0	30.0	0.0
2015	0.0	0.0	27.5	113.0	68.0	0.0	0.0	0.0	0.0	249.0	97.0	0.0
2016	0.0	0.0	0.0	62.0	51.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2017	0.0	0.0	0.0	63.0	37.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2018	0.0	0.0	0.0	268.0	56.0	0.0	0.0	0.0	0.0	31.0	0.0	0.0
2019	0.0	0.0	1.1	28.3	116	15.3	37.1	9.4	0.7	213.1	156.1	11.5
2020	0.0	0.0	132	73.1	38.8	16.2	40.0	9.4	2.0	155.0	140.0	35.0

Table 5.8 Precipitation of Jalalaqsi [40]

Year	Jan	Fe	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
2003	0.0	10	5.2	164.4	14.5	14.0	0.0	8.7	17.2	17.9	40.6	0.0
2004	0.0	0.0	0.0	116.1	9.7	3.9	0.0	2.1	0.0	101.6	120.3	0.0
2005	0.0	0.0	0.0	90.4	42.6	0.0	0.0	13.0	21.4	58.2	76.0	0.0
2006	0.0	0.0	0.0	197.5	21.0	0.0	0.0	33.0	0.0	133.5	178.0	0.0
2007	0.0	0.0	53.5	305.0	0.0	19.5	0.0	0.0	0.0	0.0	0.0	0.0
2008	0.0	0.0	4.2	51.2	34.8	0.0	0.0	14.7	32.9	90.9	5.6	0.0
2009	0.0	6.0	0.0	112.2	23.0	1.8	0.0	4.2	15.8	99.5	12.7	0.0
2010	0.0	0.0	0.0	213.5	170	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2011	13	0.0	0.0	30.0	5.5	0.0	30.5	0.0	11.0	292.0	32.0	12.5
2012	13	0.0	0.0	141.5	174.	0.0	0.0	42.0	50.0	76.0	42.0	12.5
2013	13	0.0	30.0	206.0	0.0	0.0	0.0	0.0	0.0	146.0	98.5	12.5
2014	0.0	0.0	0.0	34.5	56.0	0.0	0.0	0.0	0.0	39.5	74.0	0.0
2015	0.0	0.0	1.5	178.6	20.3	7.1	0.0	56.0	13.0	175.3	96.4	0.0
2016	0.0	0.0	0.0	63.5	31.8	2.6	0.0	1.9	10.7	30.3	1.6	0.0
2017	0.0	0.0	4.6	63.8	39.3	4.9	0.0	22.0	23.3	52.6	83.5	0.0
2018	0.0	0.0	10.5	223.6	86.2	2.4	12.9	0.0	23.8	39.8	45.0	0.0
2019	0.0	0.0	0.0	30.9	119	21.0	23.8	9.4	1.4	252.7	186.2	0.0
2020	0.0	0.0	102	74.5	40.1	23.8	23.6	5.2	2.4	166.7	192.0	0.0

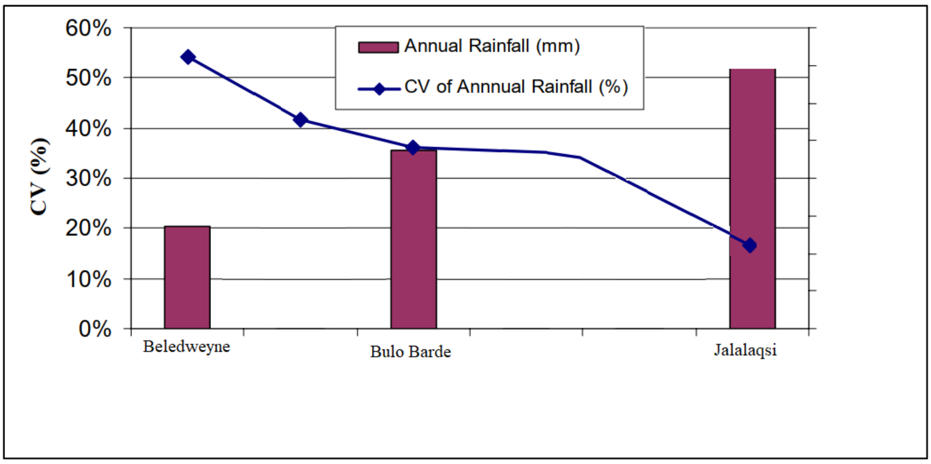

Figure: 5.12 CVs of monthly rainfall in Hiiran region [1]

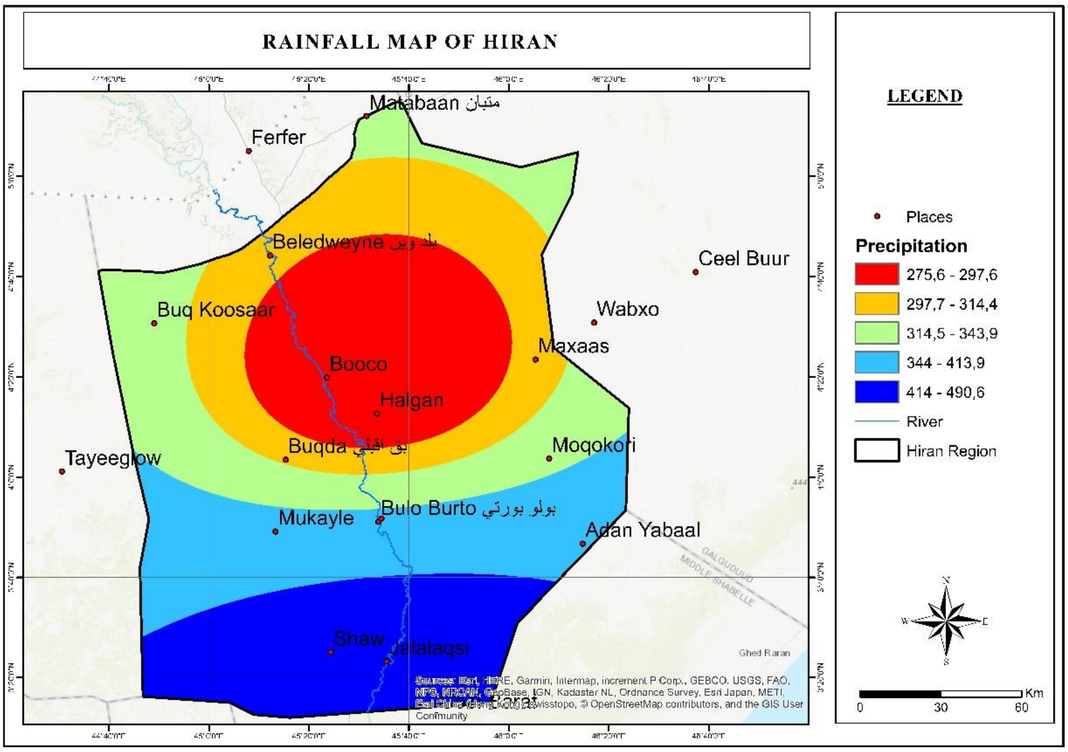

Figure 5.13 Rainfall map in Hiiran region

5.4.2.2 Runoff

Rainfall-runoff is the most common cause of river runoff, although the severity of the rainfall determines the river flow velocity. Rainwater harvesting is also a hydrological intervention that is best described using hydrological models that can indicate flow directions, runoff, and run-on area and identify impounding structure locations. The Soil Conservation Service SCS curve number approach is used to model runoff relationships for the basin. The SCS curve runoff model is primarily suitable for hydrological modelling utilizing remote sensing data in a GIS setting since it relies on land cover parameters that may be retrieved from remote sensing [39].

Runoff curve number equation estimates total runoff from total rainfall, and this relationship excludes time as a variable and rainfall intensity. Its stability is ensured by the fact that runoff depth (Q) is bounded between the maximum rainfall depth (P). This implies that as rainfall increases, the actual retention ($P - Q$) approaches a constant value, the maximum potential retention. The runoff estimation related runoff (Q) to precipitation (P) and the curve number (CN), which is in turn related to storage (S) [39]. CN is based on the following parameters; hydrologic soil group, land use and treatment classes, hydrologic surface conditions. Equation 5.7 known as the runoff curve number, gives the relationship between the parameters described in Equation 5.7 [39].

$$Q = \frac{(P - Ia)^2}{(P - Ia) + S} \qquad 5.7$$

where;

Q runoff depth (mm)

P rainfall (mm)

S Potential maximum retention after runoff starts (mm)

Ia Initial abstraction (mm)

Initial abstraction consists mainly of interception during early parts of the storm, and surface depression storage. Its determination is not accessible due to the variability of infiltration during the early part of the storm. It depends on the conditions of the watershed at the start of a storm, such as the land cover, surface conditions, and rainfall intensity. Thus, it is assumed to be a function of the maximum potential retention.

$$Ia = 0.2S$$

Potential maximum retention (S) can be calculated by the Curve Number below

$$\mathrm{Q} = \frac{25400}{\mathrm{CN}} - 254 \qquad 5.8$$

The soil conservation service (SCS) model depends on the Runoff Curve Number (CN). Curved Number is estimated via the effect of soil and land cover on the rainfall-runoff processes. The range of the Curve Number (CN) is between 1 (100 % rainfall infiltration) and 100; lower values of the Curve Number indicate lower runoff, while higher values of Curve Number refer to higher values of runoff [39]. Using this model with Arc Map, we have generated a river buffer map to analyze the impact of runoff during high rainfall.

5.4.3 River Buffer

Morphologically, the Shabelle River flows a flat valley due to the sediment loads deposit led the river bed to be elevated above the plain in the areas downstream of Buleburde; however, using rainfall and runoff data, we have generated a river buffer map using Arc GIS 10.3.1 as shown in Figure 5.14

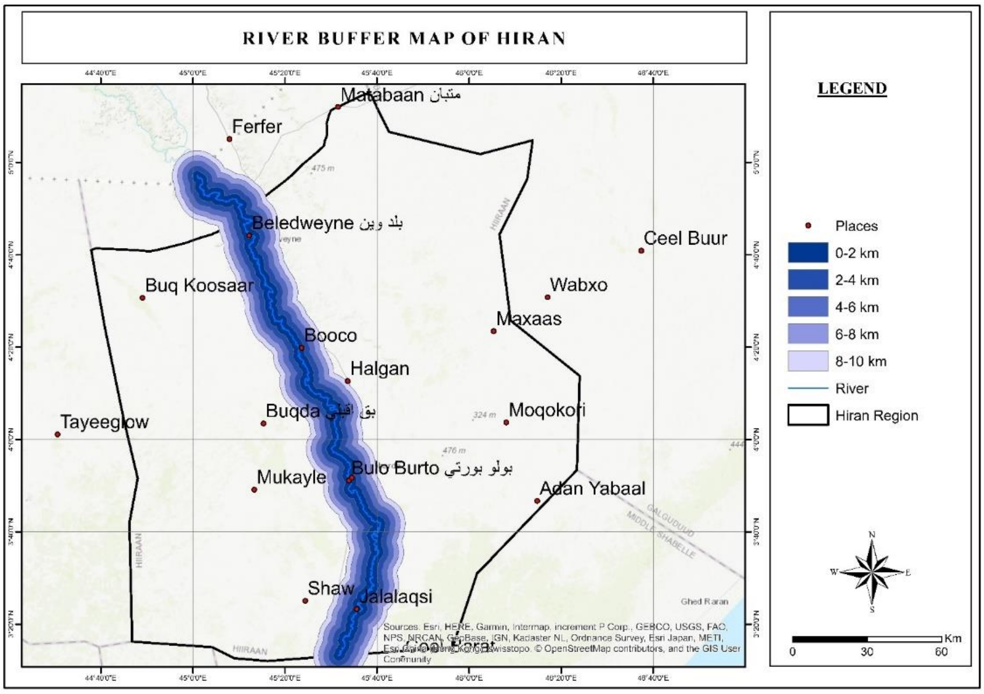

Figure 5.14 River buffer map of Hiiran region

5.4.4 Slope, Elevation, and Aspect

5.4.4.1 Slope and Elevation

The study areas range in elevation from 125 to 460 meters, with areas near the river having a lower elevation of 180 to 225 meters, except in the north-east part of Beledweyne, which has highland areas of more than 400 meters, as shown in Figure 5.15. However, the slope of the study areas is almost entirely flat, as shown in Figure 5.16.

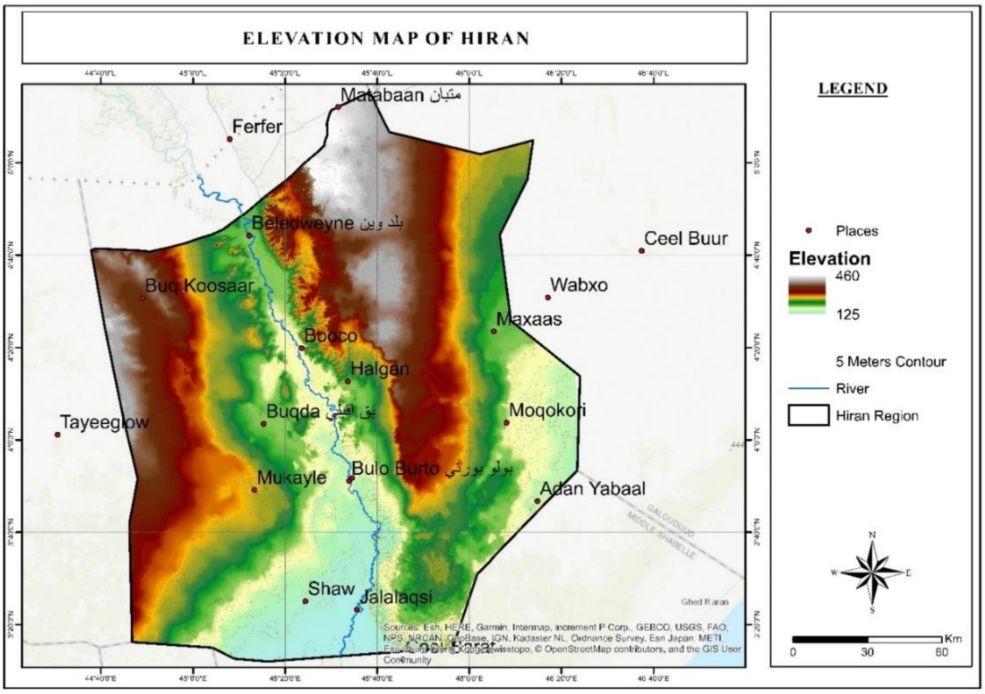

Figure 5.15 Elevation of Hiiran region

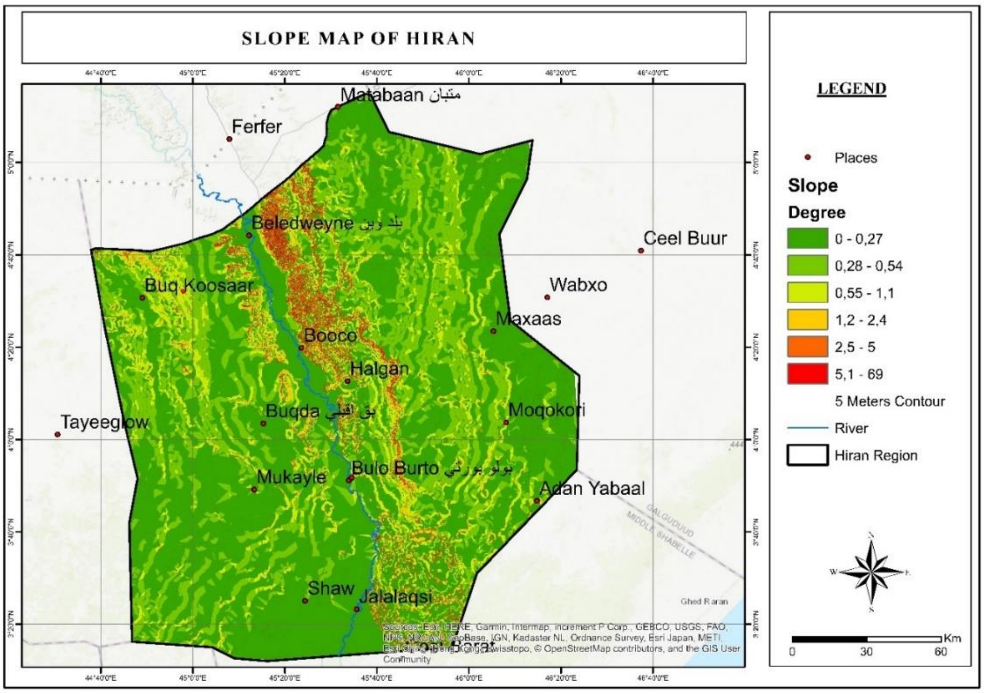

Figure 5.16 Slope map of Hiiran region

5.4.4.2 Aspect

Aspect layers were classified and created aspect map; however, the Shabelle river enters the country from the direction of the north-west of the Hiiran region and moves towards the south-east, till the river crosses the Hiiran region, as shown in Figure 5.17

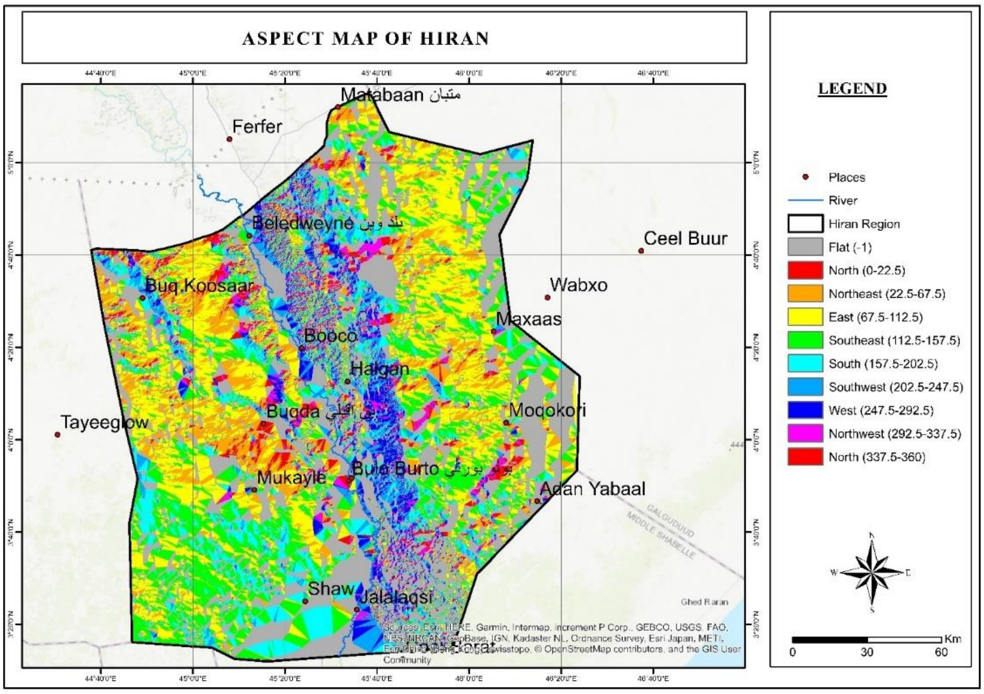

Figure 5.17 Aspect map of Hiiran region

5.4.5 Land Use Land Cover

Classifying LULC maps from satellite images necessitates a quality check on the acceptability of the results of the trained and assigned classes to each pixel in the image, i.e., an accuracy assessment. The area of interest has always been utilized to verify the LULC classification's accuracy [40]. Because of various factors, including classification methodologies and satellite data collecting methods, the categorized LULC maps may contain errors. To use the classified maps, the errors must be quantified through classification accuracy assessment and the information must be intended to describe reality. As a result, the conventional approach was used to measure classification accuracy [24]. Satellite images for the periods 2000, 2010, 2020 during the rainy and dry seasons were extracted from USGS and processed using Erdas

Imagine 2014. To get a clear image we have used the Reflectance Model. The Model works with the reflectance of surface objects using spectral remote sensing reflectance (R_{rs}) method. It is a semi-analytical model that simulates the spectral curves of remote sensing reflectance of objects based on the inherent optical properties. To run the model, we have used Landsat tool version 1.0.34 as shown in Figure 5.18 and Figure 5.19.

To extract water bodies and vegetation, we have used NDWI and NDVI formulas as shown in equation 5.1 then LULC map for 2000, 2010, and 2020 created as in Figure 5.20, Figure 5.21, and Figure 5.22, respectively. This information was combined to create a final map that will be used multi-criteria analysis for dam site selection map as in Figure 5.23 [41].

$$\mathrm{NDWI} = \frac{\mathrm{NIR} - \mathrm{SWIR}}{\mathrm{NIR} + \mathrm{SWIR}} \quad \text{and} \quad \mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}} \qquad 5.9$$

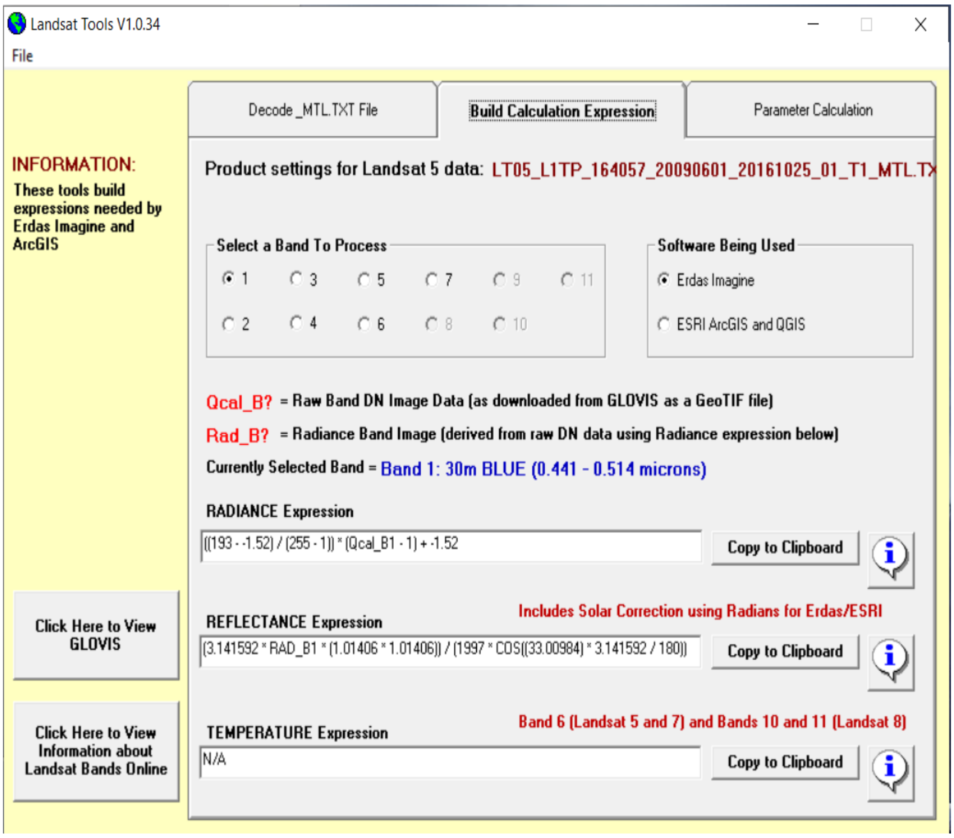

Figure 5.18 Landsat tool for the classification of Landsat 05 and Landsat 08 images

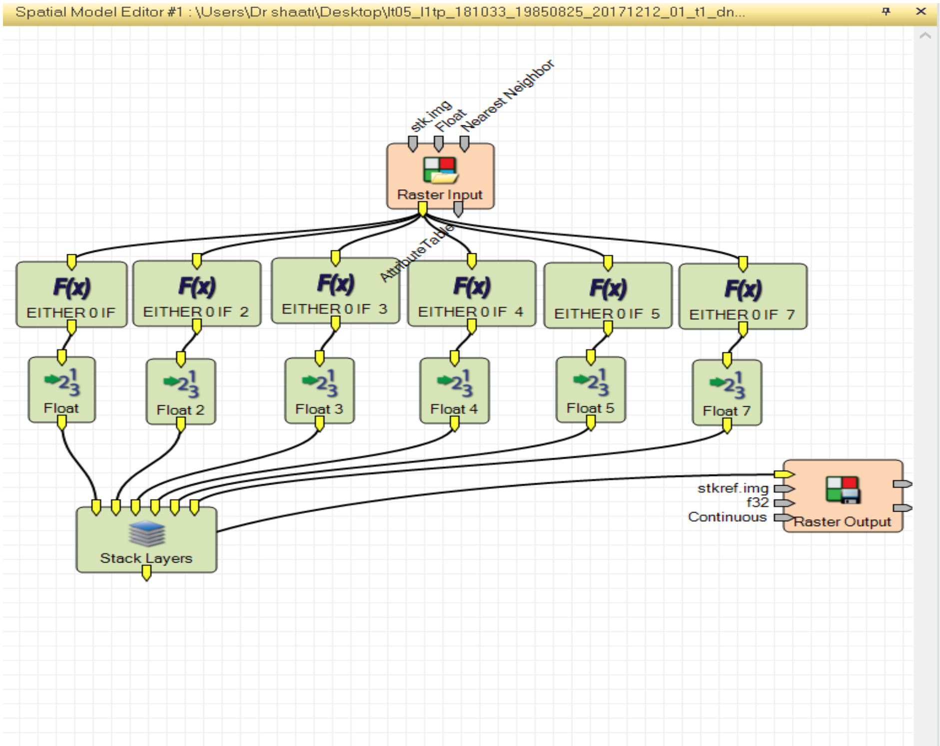

Figure 5.19 Erdas Imagine reflectance model

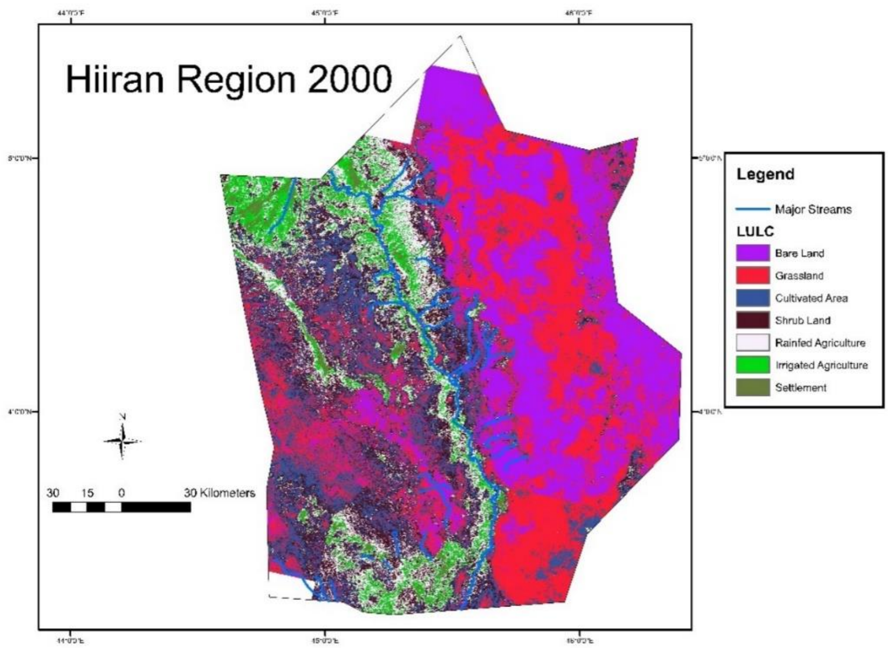

Figure 5.20 LULC of Hiiran region in 2000

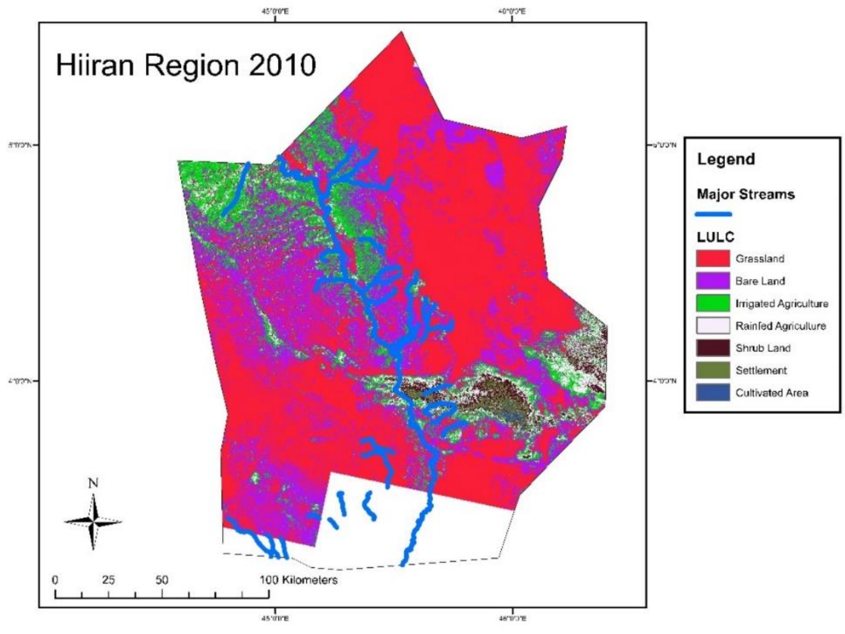

Figure 5.21 LULC of Hiiran region in 2010

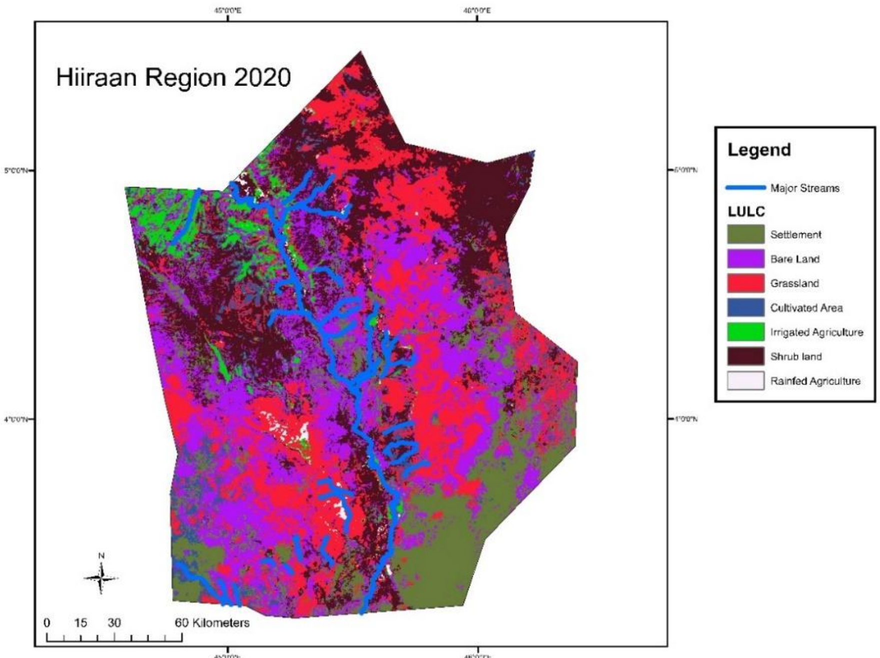

Figure 5.22 LULC of Hiiran region in 2020

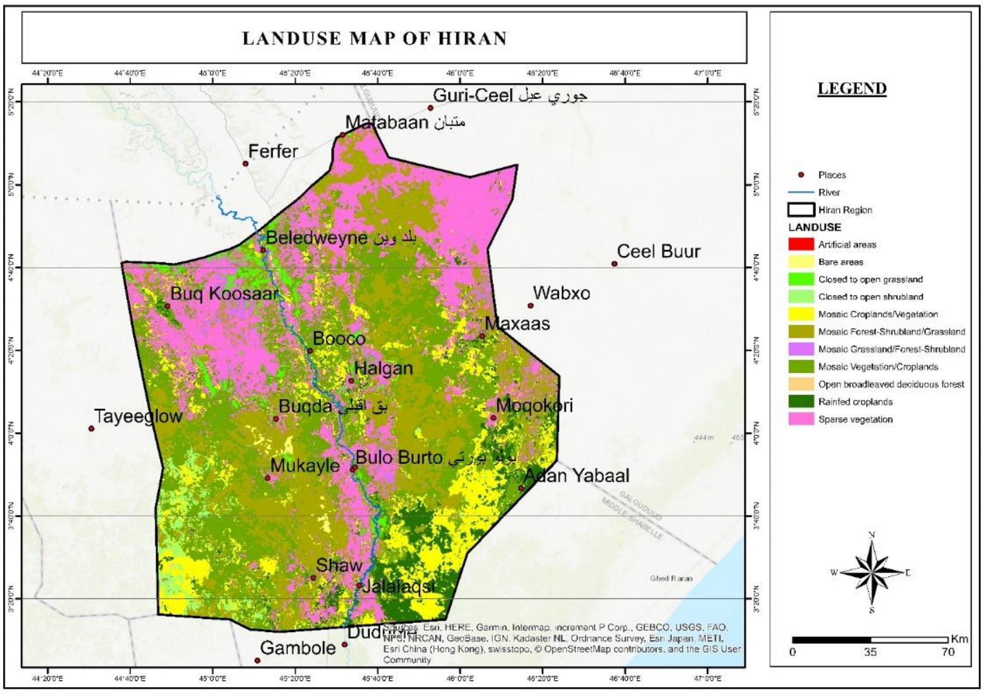

Figure 5.23 Land use land cover of Hiiran region

During high rainfall periods, some areas are very vulnerable to floods in the study area. Some areas in Beledweyne are very vulnerable to flood during high and moderated rainfall season; however downstream areas such as Bulo barde and near Jalalaqsi areas are also vulnerable to flood if the rain season starts. Figure 5.24 shows the map of flood risk areas with land cover types.

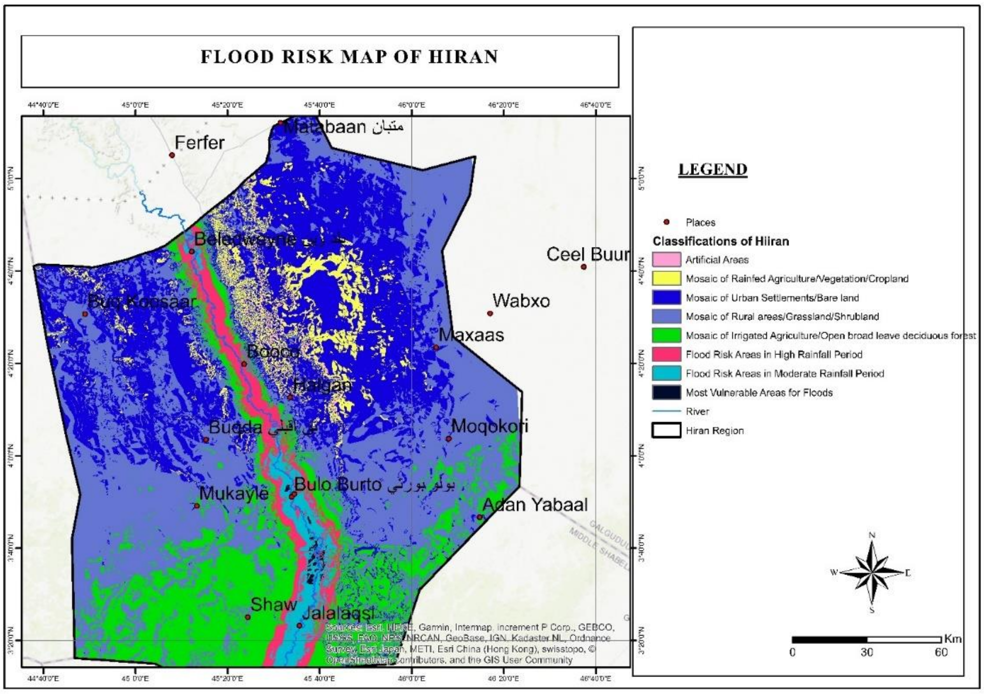

Figure 5.24 Map of flood risk areas with land cover

5.5 Analytic Hierarchy Process AHP

Making decisions in the real world sometimes can be complex because of the complexity of reality, however, one of the possible solutions is Multi-Criteria Decision Making (MCDM) which refers to making decisions in the presence of multiple criteria that usually conflict with each other [42]. There is no unified MCDM method that can be followed stepwise. Instead, a big variety of different techniques are proposed for MCDM. One of the most used ones is called Analytic Hierarchy Process (AHP). The procedure of AHP can be divided into three parts: identifying a hierarchy of objectives, criteria, and alternatives; pairwise comparison of criteria; and integration with the result from pairwise comparison as relative importance overall levels of hierarchy [13]. In this study, we have given each layer a certain weight and used a pairwise comparison matrix, as shown in Table 5.9

Table 5.9 Comparison pairwise matrix

Pairwise Matrix	Elevation	Slope	Aspect	Soil	Rainfall	LULC	River buffer	River discharge
Elevation	1	1/3	1/3	1/5	1/5	1/3	1/5	1/5
Slope	3	1	1/3	2	1/3	3	1/3	1/3
Aspect	3	1/3	1	1/3	1/5	1/3	1/7	1/7
Soil	5	1/2	3	1	1/2	3	1/5	1/7
Rainfall	5	3	5	2	1	2	1/3	1/7
LULC	3	1/3	3	1/3	1/2	1	1/5	1/7
River buffer	5	3	7	5	3	5	1	1/5
River discharge	5	3	7	5	1/5	5	5	1
Total	30	11.500	26.667	15.867	5.933	19.667	7.410	1.200

After giving each layer to a certain weight and performing the AHP method, we have calculated the Normalized matrix, which is dividing each cell the total of its column Table 5.10 shows a pairwise matrix

Table 5.10 Normalized matrix

Normalized Matrix	Elevation	Slope	Aspect	Soil	Rainfall	LULC	River buffer	River Discharge
Elevation	0.033	0.029	0.013	0.013	0.034	0.017	0.027	0.167
Slope	0.100	0.086	0.125	0.126	0.056	0.153	0.045	0.277
Aspect	0.100	0.029	0.037	0.021	0.034	0.017	0.019	0.119
Soil	0.167	0.043	0.113	0.063	0.084	0.153	0.027	0.119
Rainfall	0.167	0.260	0.188	0.126	0.169	0.102	0.045	0.119
LULC	0.100	0.029	0.113	0.021	0.084	0.051	0.027	0.119
River buffer	0.086	0.180	0.183	0.235	0.506	0.174	0.055	0.087
River discharge	0.086	0.220	0.223	0.275	0.024	0.214	0.605	0.793

The total of each row represents the weight of each layer, as shown in Table 5.11.

Table 5.11 Weighted matrix

	Elevation	Slope	Aspect	Soil	Rainfall	LULC	River buffer	River discharge
% Weighted Criteria	4.15	10.70	4.71	9.61	14.69	6.80	18.84	30.51

We created an MCDA map with a drainage network, as shown in Figure 5.25. The map suggests three potential suitable areas for dam construction based on the drainage network, amount of precipitation, soil type, and soil erosion level; however, the comparison of the three potential areas will be discussed in chapter six.

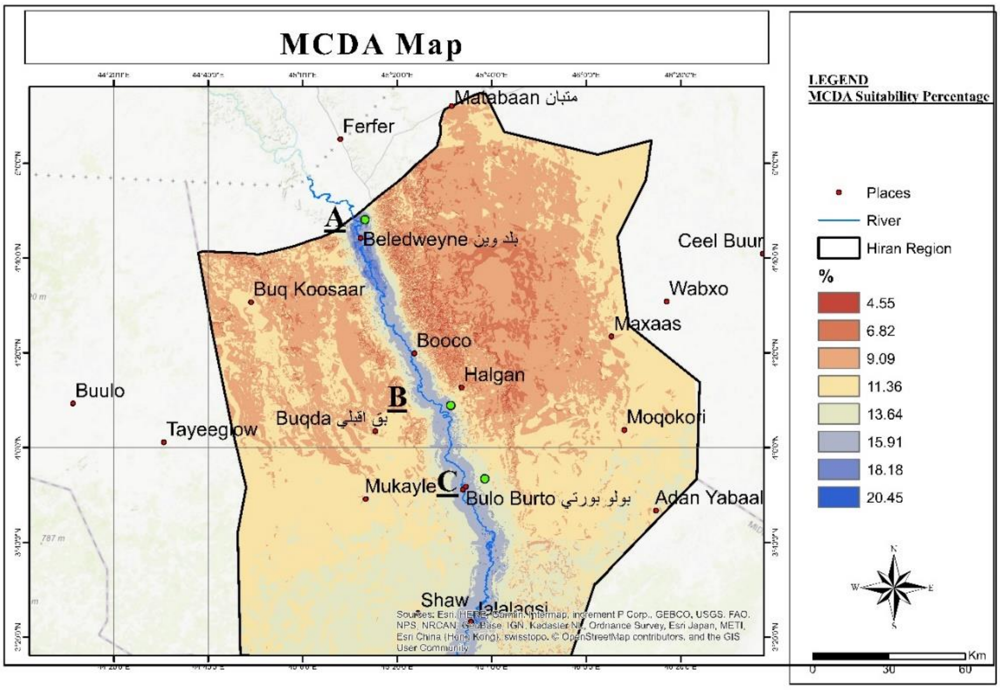

Figure 5.25 MCDA map of Hiiran region

Chapter 6

Analysis and Results

6.1 Analysis

We have assessed three main parameters to evaluate which area had the best chance of being chosen as a dam site to meet the region's agricultural and other water demands. The study was divided into three sections: topographic settings, soil erosion factors, and riverbed analysis. However, we concentrated primarily on river flow analysis, flood risk zones, and the ideal placement for a dam site. For the feasibility of these sites, the study used multi-criteria analysis with GIS technologies in addition to ground information.

6.1.1 Temporal Analysis of the Riverbed and Water Level

Three consecutive years, the Shabelle river in the Hiiran region has some dry sections. The first part dried in February and March 2016, then again in February and March 2017, and finally in early December 2017 to mid-March 2018 [43]. The failure of rainy seasons in Ethiopia's highlands and inside Somalia was the main cause of the river's drying bed; yet, this failure prompted people living near the river to move closer to it and break the river's banks to get water for their animals and agricultural areas. However, rainfall data shows that poor rainfall during the Dayr seasons of 2015, 2016, and 2017 combined with increased water demands for agricultural and domestic purposes resulted in a considerable reduction in river flow. In the Hiiran region, massive sedimentation on the riverbed has resulted in decreased water quantity and quality along the river. According to some reports, the river's flow has been reduced due to riverine activities in Ethiopia, where the river originates.

SWALIM has provided an analysis of the temporal river level status in selected regions in the Hiiran region utilizing observed river level data and very high-resolution satellite images obtained on different dates [44]. The visual measurement of the water level was carried out on multi-temporal images between January 2017 and January 2018. Despite the fact that the images were obtained during dry season, the best suited cloud-free images used were panchromatic black and white images acquired by the global view 1 satellite. Panchromatic photos are more difficult to understand, although water is usually represented by a dark grey color, whereas a light grey tint represents bare land. Figure 6.1 shows a comparison of a GeoEye image from February 2018 and a World view 2 image from February 2012, both depicting an area about 2.5 km south of Baledwayne. It can be seen that the active cropped area (Green) is much more prominent in 2018 than it was in 2012, owing to a change in agricultural practice in this region [45]. In 2012, the region was mainly covered by seasonal herbaceous crops (which were not active in February). However, in 2018, the area seemed to be covered by permanent tree corps (active in February) that required year-round irrigation. Irrigated crops have a negative impact on the riverbed because they drain a lot of water when raindrops are few, and river run-off is low, which has an effect on the river's downstream flow.

Figure 6.1 Shabelle river in Baledwayne [46]

Figure 6.2 shows that several river breakages occurred most recently, which was the result of the last rainfall in the region. It is still open and has no signs of intervention/rehabilitation on the latest analyzed images. However, in some portions of the river embankment where water overflows have occurred less than one-year, overflows generally take place along shallow parts of the embankment, which could be submerged for several hundred meters during the flood.

In the riverbank, there are also flood potential areas. The main causes are vegetation removal, embankment erosion, water spillage, or other signs representing a potential embankment weakness that have been identified [46].

There are also some fixed breakage points using either heavy machinery or sandbags. However, no floods have been detected recently, so that area may be considered closed.

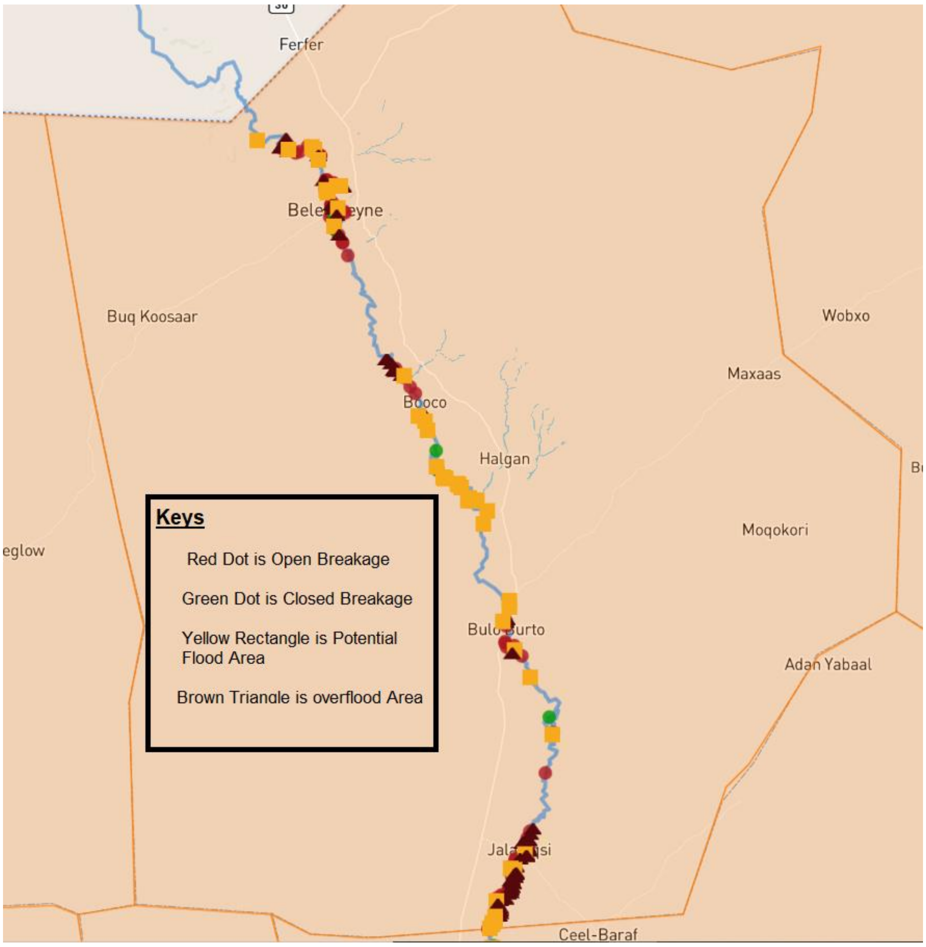

Figure 6.2 Shabelle river breakage in Hiiran region [46]

To analyze the riverbed, it is important to assess the level of water through a year. Figure 6.3, Figure 6.4 and Figure 6.5 show the river level at Baledweyne, Bulobarde, and Jalalaqsi respectively. In these Figures, we have compared long-term mean river level (2003 – 2020), High flood risk, moderate flood risk, and as well as most recent river level (2021).

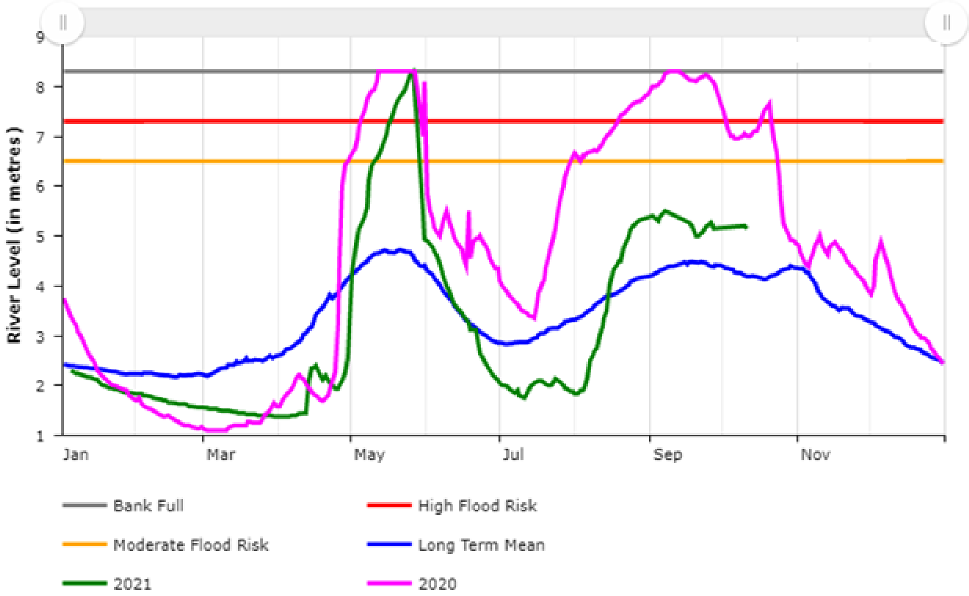

Figure 6.3 Shabelle river water level at Baledweyne station

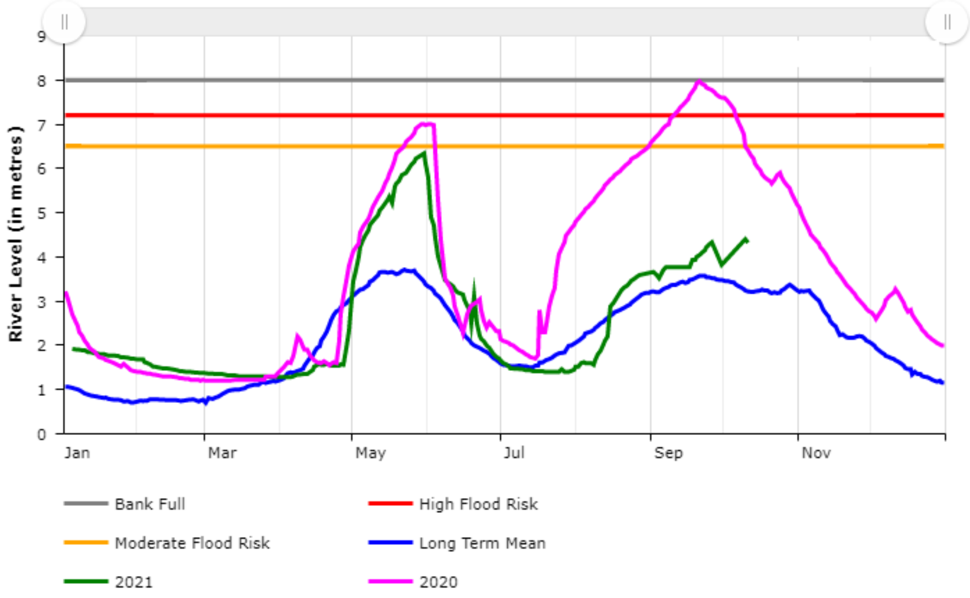

Figure 6.4 Shabelle river water level at Bulobarde station

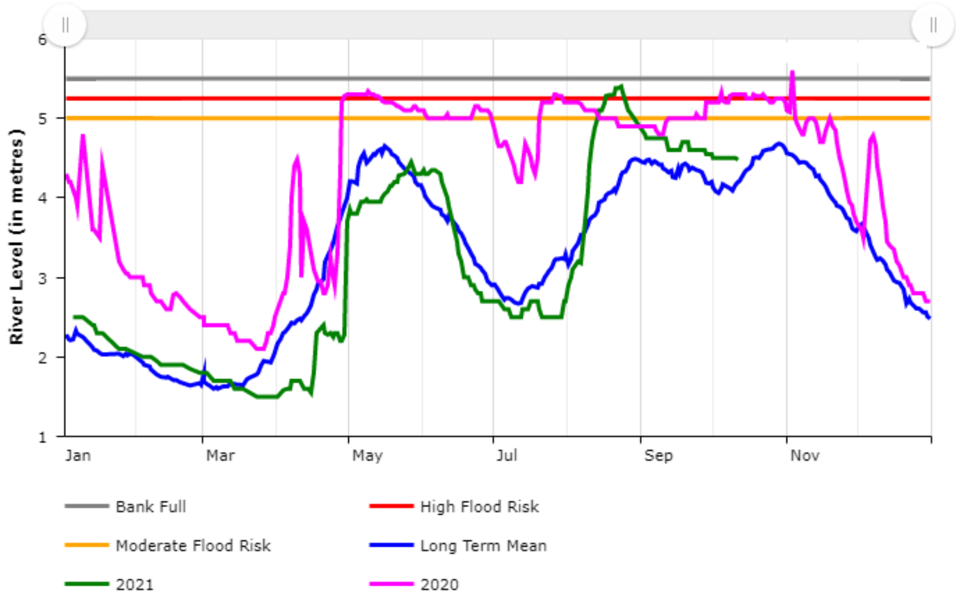

Figure 6.5 Shabelle river water level at Jalalaqsi station

As shown in Figure 6.4, the long term mean river level is far from high flood risk. However, some years have surpluses the high flood risk line; most recently, in 2020, there were some months recorded to have more river levels. However, the main reason is the rainfall in Somalia and how the rain was hit in Ethiopia highlands, where the river originated.

6.1.2 Topographic Settings

All contributing factors such as Aspect, Elevation, Slope, Soil, LULC, Rainfall, and River buffer were studied and generated a map of each layer before selecting the final site for small dam construction.

6.1.2.1 Aspect

Before the aspect map was created, the aspect layers were categorised and assigned weights; however, flat areas were given the highest weights, as seen in Table 6.1.

The river enters the country from the southwest and flows south-east. The south direction received 32% of the overall weights, while flat areas received 36%. These data were utilized to generate the classification aspect layer of the Hiiran region, as shown in Figure 6.6.

Table 6.1 Aspect classifications with weights

Aspect	Points
Flat	9
North (N, Ne, Nw)	3
East, West (E, W)	5
South (S, SE, SW)	8

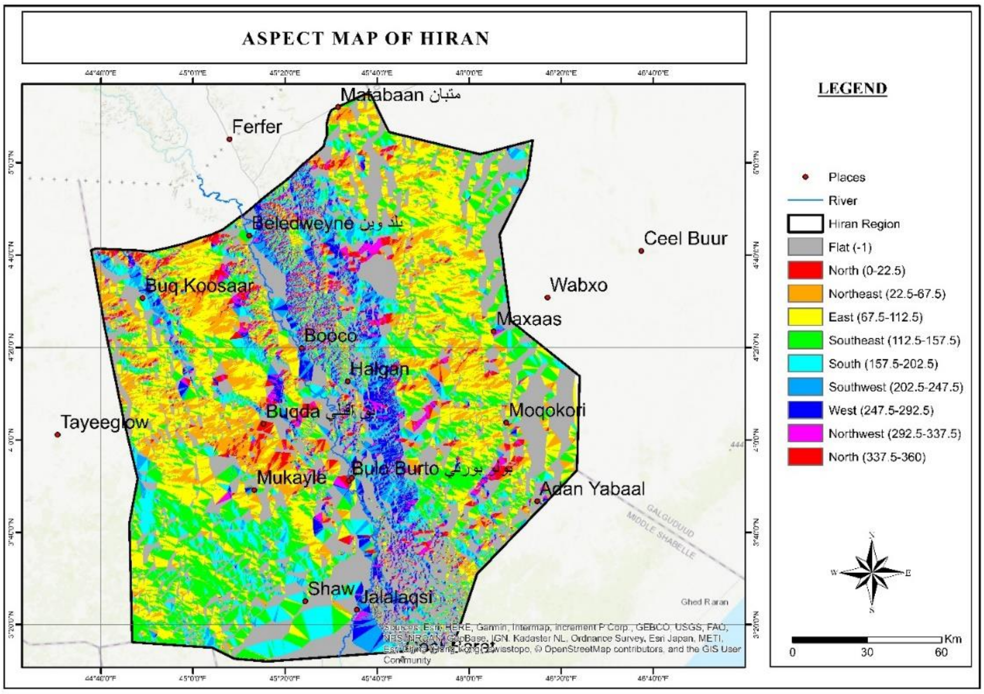

Figure 6.6 Aspect classification of Hiiraan region

6.1.2.2 Elevation and Slope

One of the most important considerations when selecting a dam construction site is elevation. Higher elevation means a steeper slope, which puts additional pressure on the dam's foundation. We have assigned weights to each elevation measurement scale in order to build an elevation map; nonetheless, these points are useful to generate a map for dam site selection. Table 6.2 shows the weighted elevation classes.

Lower elevations were given the highest weights, indicating that they are best suited for dam construction, whereas higher elevations were deemed undesirable for dam site selection, as is shown in Figure 6.7.

Table 6.2 Elevation classes in meters with weights

Elevation (m)	Points
125 – 200	9
200 – 250	8
250 – 300	7
300 – 350	6
350 – 400	4
400 – 460	2

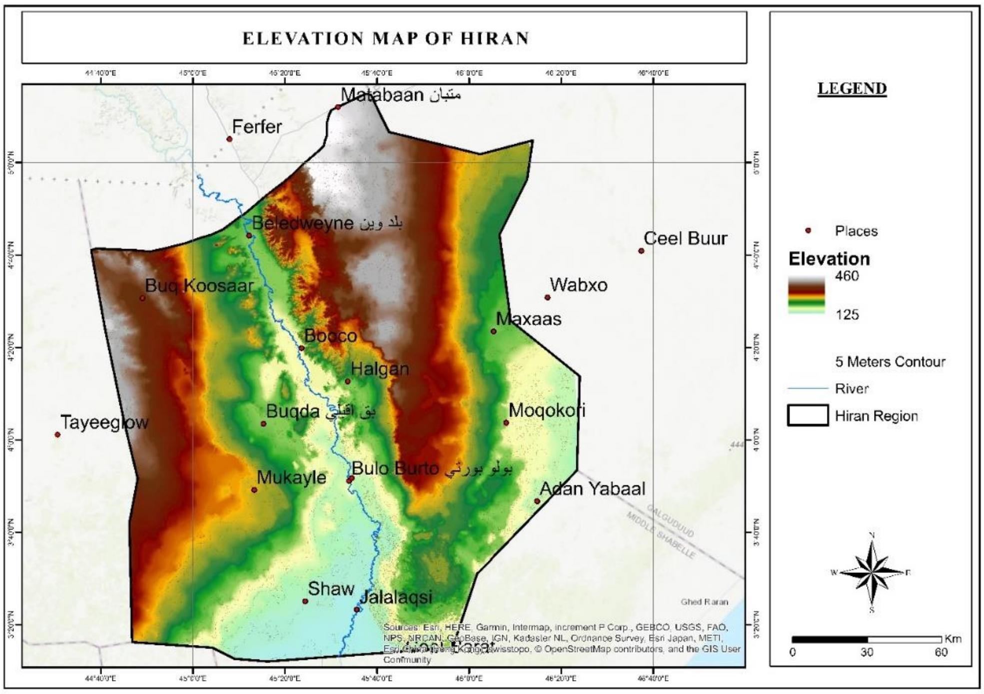

Figure 6.7 Elevation map of Hiiran region

The slope of the study area is mainly flat with small areas of hilly in the northeast part of the region. The slope map was classified and given different weights as shown in Table 6.3.

The slope above 3 degrees was considered to be unsuitable to highly unsuitable for dam construction because it ranges from steeply sloping to very steeply sloping which can create negative forces acting against the walls of the dam and making the site very vulnerable to landslide and slope failure.

Table 6.3 Slope of hiiran region with weights

Slope (Degree)	Point
0 – 0.27	9
0.28 – 0.54	8
0.55 – 1.1	6
1.2 – 2.4	4
2.5 - 5	2
5.1 - 69	0

Based on Table 6.3, (0 – 0.27) degrees were considered to be a highly suitable while (0.28 – 0.54) and (0.55 – 1.1) degrees were supposed to be suitable and low suitable, respectively. Figure 6.6 shows the slope of the Hiiran region; however, the map details that there are some high slopes in Baledweyne and Booco areas; while the slope goes flat as the river goes downstream, the majority of the region has a flat slope.

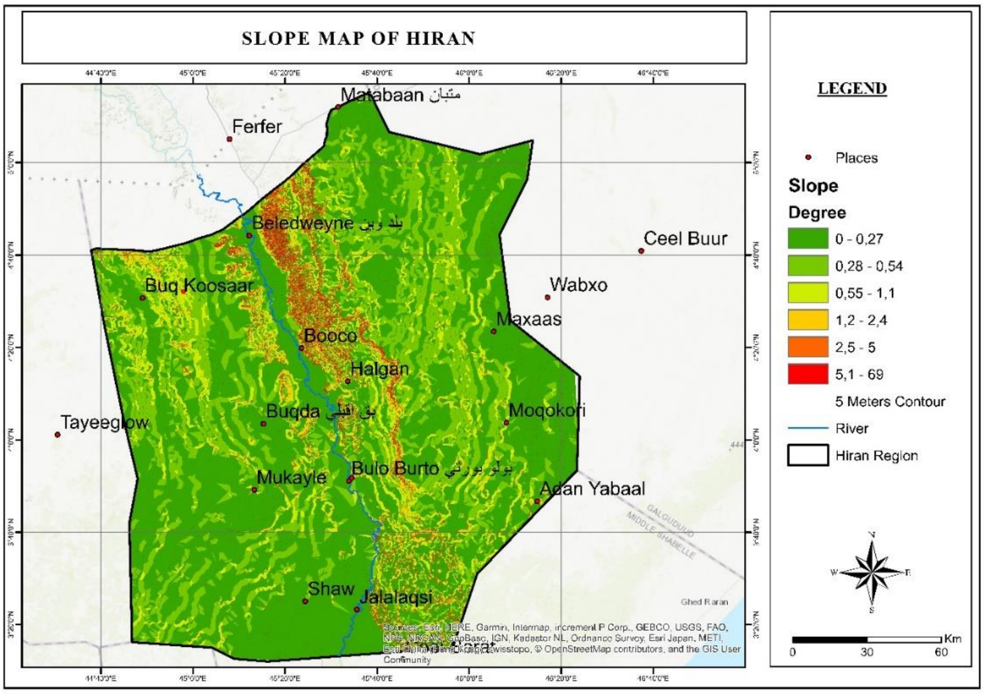

Figure 6.8 Slope classes of hiiran region

Some Hilly parts are in the northeast part of Baledwayne; these highland areas contribute small streams to the river during the rainy season. However, the study indicates that if these streams were captured before they joined the river, this action will minimize the risk of floods in the rainy season.

6.1.2.3 Soil Map

According to the available data, soil properties and soil texture were analyzed and given to a certain weight based on FAO soil classifications [47]. Jc – Calcaric Fluvisol has given the highest weight 9 points while Rc – Calcaric Regosols were given 5-point; Table 6.4 shows all layers with their weights. Areas with Jc Calcaric soil texture possessed the highest suitability for dam construction. However, this area can provide cementation and inhabitation for the infiltration of water into the soil; this can provide the highest water holding capacity Fig. 6.9 shows the soil texture map.

Table 6.4 Soil texture with their weights

Soil Type	Point
Jc- Calcaric Fluvisols	9
Qc-Cambic Arenosols	3
Rc- Calcaric Regosols	5
Vc- Chromic Vertisols	3
Yh- Haplic Yermosols	2
Yk- Calcic Yermosols	2
Zo- Orthic Solonchaks	0

Figure 6.9 shows that most of the areas near the riverbed have Jc – Calcaric Fluvisol soil type, which is suitable for water holding and cementation; however, this soil property will reduce as the river goes downwards before Jalalaqsi.

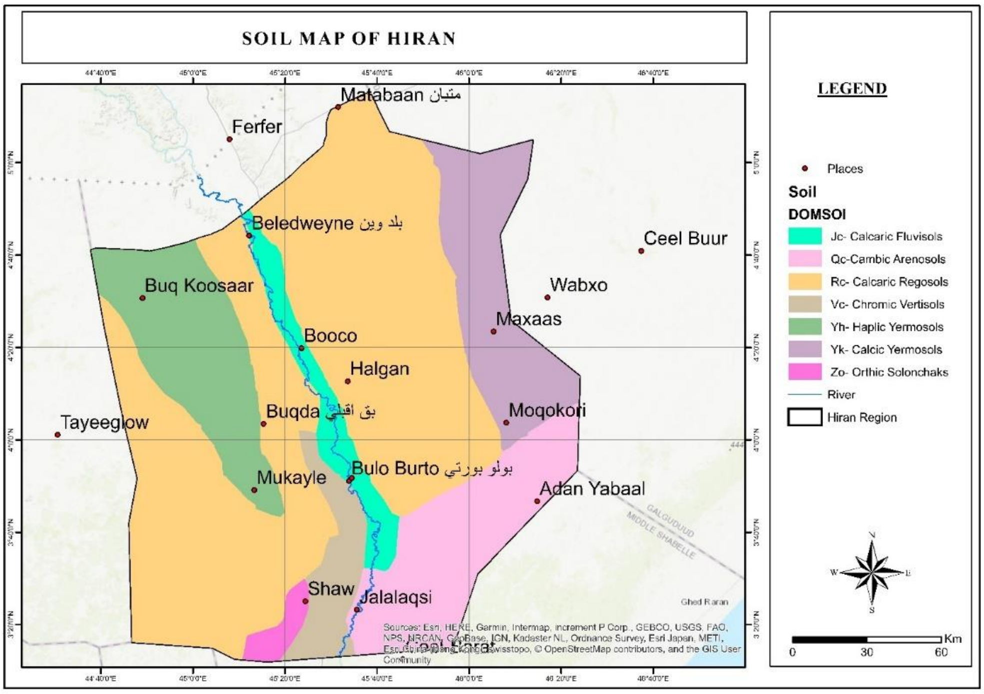

Figure 6.9 Soil map of Hiiran region

Based on the literature review Calcaric Fluvisol was given the highest weight 9 points, then all other layers were given to a certain weight to generate a weighted overlay map for each layer, however, the potential site selection was identified based on the soil texture (the percentage of sand, silt, and clay) i.e., clay > silty > Sand.

6.1.2.4 Land Use Land Cover

According to the data collection and analysis in the Hiiran region, 11 layers were analyzed. However, Artificial Areas were given the highest weight because of the amount of rainfall it receives during the rainy season.

Artificial Area is an area with a mixture of short trees such as the Salvadora Persica tree and other drought tolerance trees. It has water-holding soil and less infiltration; however, it receives maximum rainfall during the rainy season [48]. Table 6.5 shows all layers with their weights.

Table 6.5 Land use land cover of Hiiran region

Land Use Land Cover Types	Point
Rainfed Croplands	3
Mosaic Croplands/Vegetation	3
Mosaic Vegetation/Croplands	1
Open Broadleaved Deciduous Forest	1
Mosaic Forest-shrubland/Grassland	2
Mosaic Grassland/forest-Shrubland	2
Closed to Open Shrubland	4
Closed to Open Grassland	4
Sparse Vegetation	7
Artificial Areas	9
Bare Areas	7

It is unsuitable for constructing the dam where daily activities occur, such as settlements, agricultural areas, cropland, or vegetation areas. In contrast, selecting suitable dam site areas that are very far away is not recommended, such as a forest. However, artificial areas and bare areas, as shown in Figure 6.10, are the most appropriate areas for site selection.

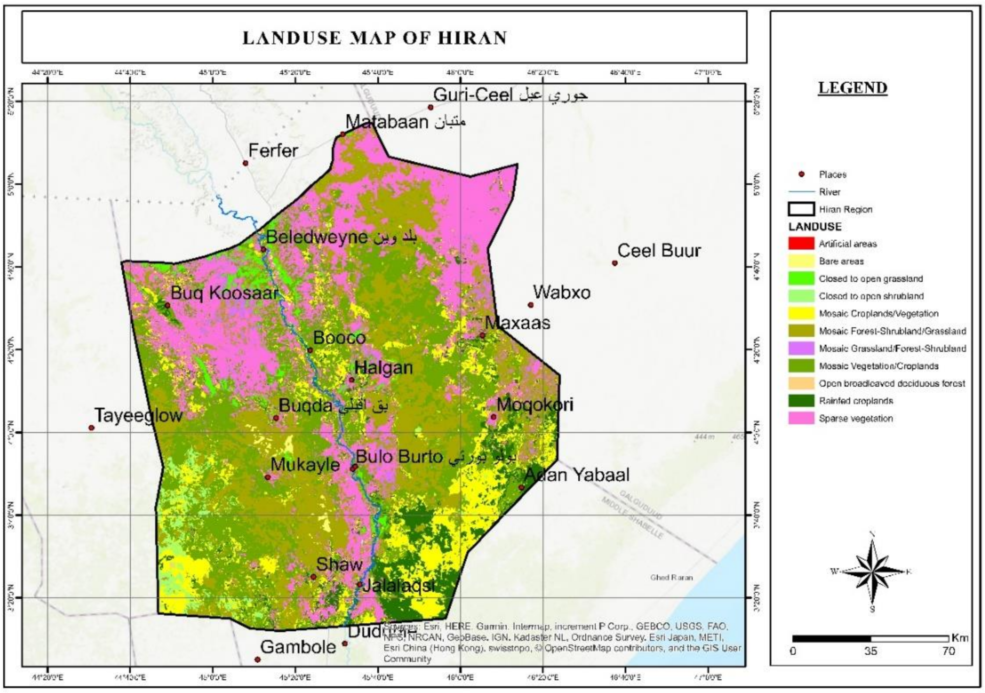

Figure 6.10 Land use land cover of Hiiran region

6.1.2.5 Temporal Rainfall

The climate of the Shabelle river basin is tropical arid to dry and sub-humid. However, the rainfall in this region varies from 100mm to 350mm; there are four main seasons with two rainy seasons alternating with two dry seasons:

1. Jilal: January – March dry season with no significant precipitation
2. Gu: April – June the main rainy season
3. Xagaag: July – September light showers
4. Dayr: October – December second rainy season

Rainfall information for 18 years (2003 – 2020) for three stations is shown in Figure 6.11, Figure 6.12, and Figure 6.13. The temporal rainfall in this period for the months (April – June) and (October – December) usually are monsoon rainfall in the study area. Beledwayne city receives lower rainfall than other neighbouring cities such as Bulobarde and Jalalaqsi. However, the results depict that the amount of rain was the highest in April, September, and October, and it was recorded that the peak of the rainfall was in April 2007 and 2018 and October 2009, 2012, 2015 and 2019 during this period several destructive floods were observed [49].

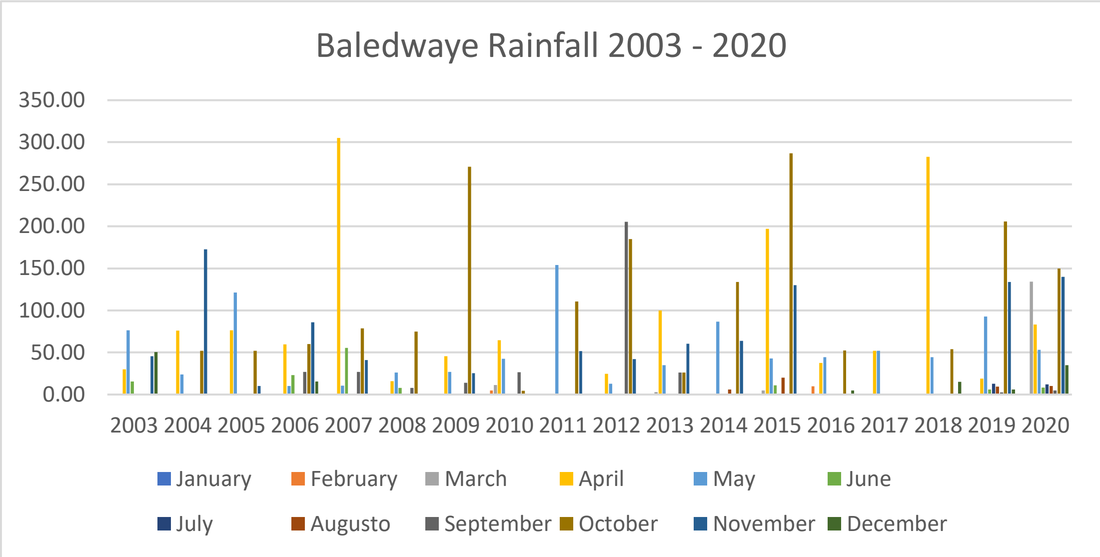

Figure 6.11 Baledweyne temporal rainfall

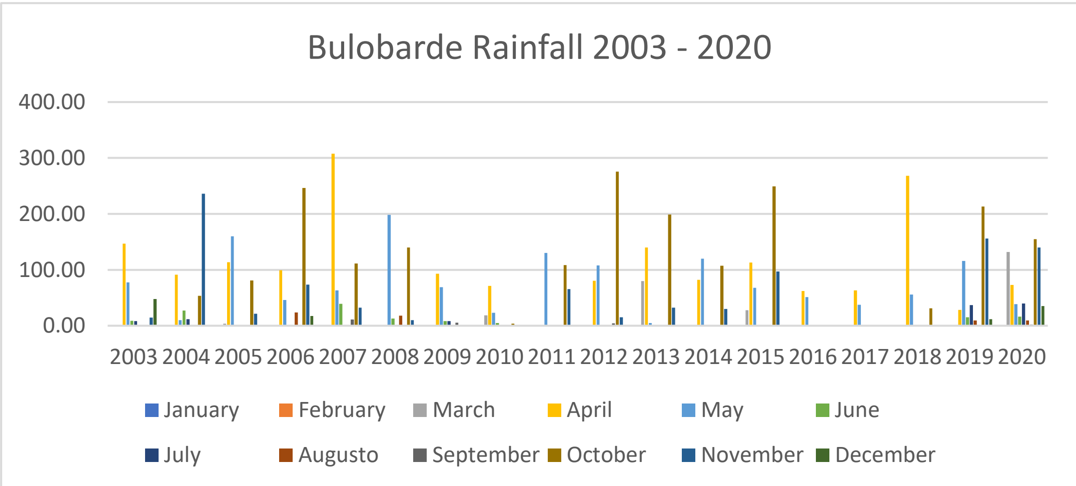

Figure 6.12 Bulobarde temporal rainfall

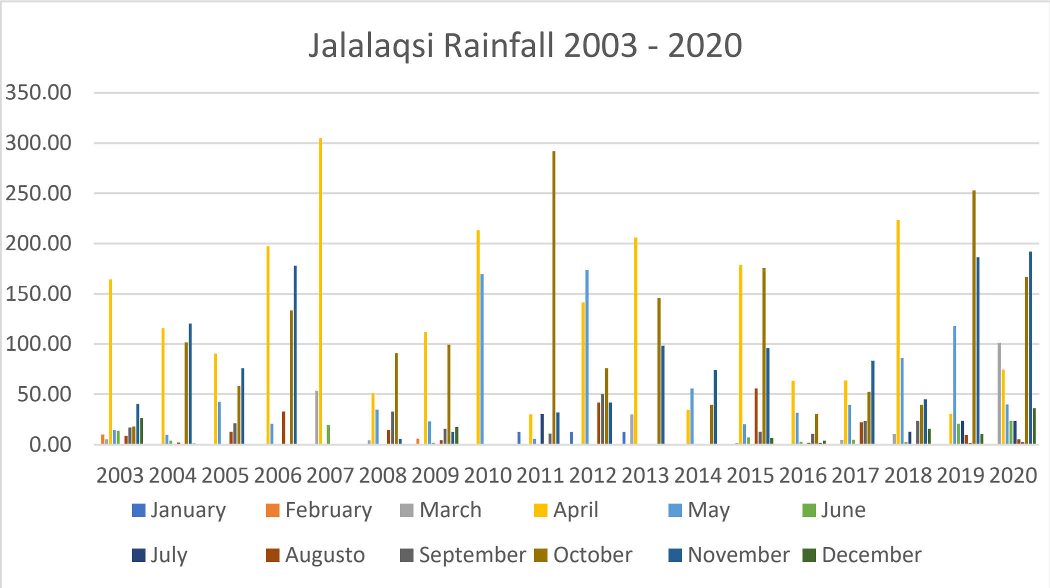

Figure. 6.13 Jalalaqsi temporal rainfall

Figure 6.11 shows that Beledwayne receives the highest raindrops, approximately 300mm, during early April 2007.

In 2003, 2004, 2005, 2006, 2008, 2010, 2016, and 2017 Hiiran region received minimum rainfall; however, pastoral people of this region were converging to the river banks to access water for livestock, while farmers were breaking the river banks to access more water for their farms. This action will create a more vulnerable situation around this area [50].

The reason for this is the weakness of the riverbed and river banks and the fact that most people, both urban and rural, come close to the river to access more water during the dry season. However, when there is more rainfall in Ethiopia's highlands, the river stream comes with a high velocity to this city before the rainfall begins in Baledwayne city, and the river discharge increases [51, 52, 53].

AHP was used to generate a rainfall map of the Hiiran region; however, Figure 6.14 shows that Beledweyne city receives slightly more rainfall than Booco and Halgan; however, Baledweyne receives less rainfall Buloburde and Jalalaqsi. Table 6.6 shows rainfall amounts in millimeters with their weights. Inverse Distance Weighting was used to generate a rainfall map using ArcMap.

Table 6.6 Rainfall amounts with weights

Rainfall	Point
275.6 - 297.6 mm	2
297.7 - 314.4 mm	4
314.5 - 343.9 mm	6
344 - 413.9 mm	8
414 - 490.6 mm	9

Rainfall quantities in Hiiran regions were given a certain weight. As a result, many areas near Jalalaqsi were estimated to receive the most rainfall, ranging from 414 to 490.6mm, and we assigned 9 points as indicated in Table 6.6. However, we have created a rainfall thematic map as shown in Figure 6.16.

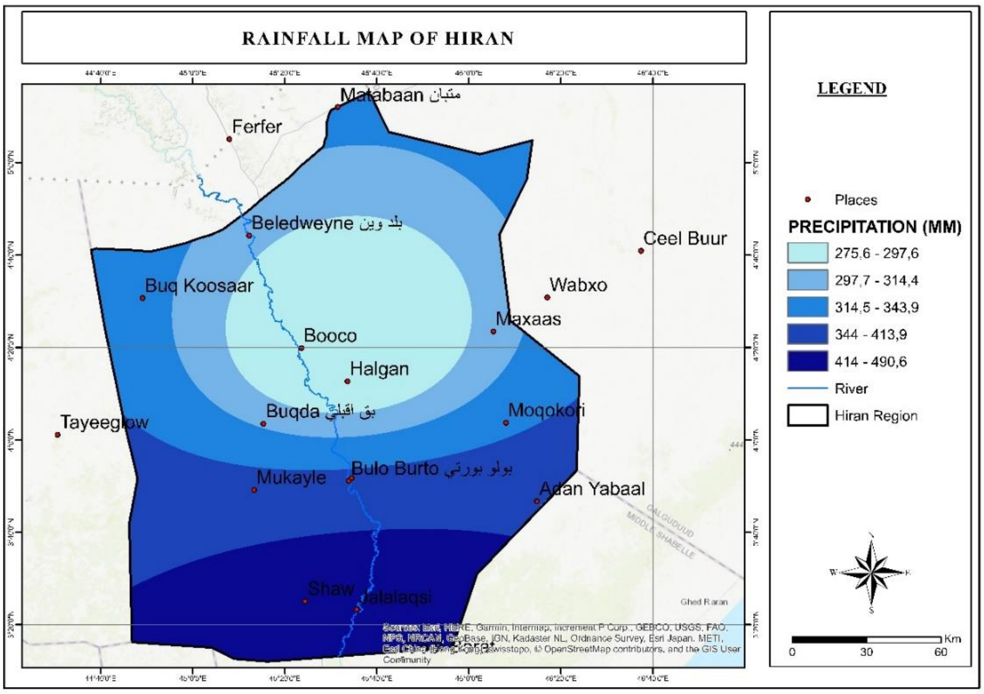

Figure 6.14 Rainfall map of Hiiraan region

6.1.2.6 River Buffer

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 Buleburde. However, a river buffer map was generated based on the river's proximity, and then we have used six measurement scales. The distance between 0 – 8km was labelled the highest weight from 9 points up to 4 points while the distance more than 10km did not consider and were given to zero as shown in Table 6.7

Table 6.7 River buffer with weights

River buffer (km)	Points
0 -4	9
2 – 4	8
4 – 6	6
6 – 8	4
8 – 10	2
10+	0

A river buffer with a large number of stream links near the selected dam sites would provide an ample amount of water to the dam site. A river buffer map was generated, as shown in Figure 6.15.

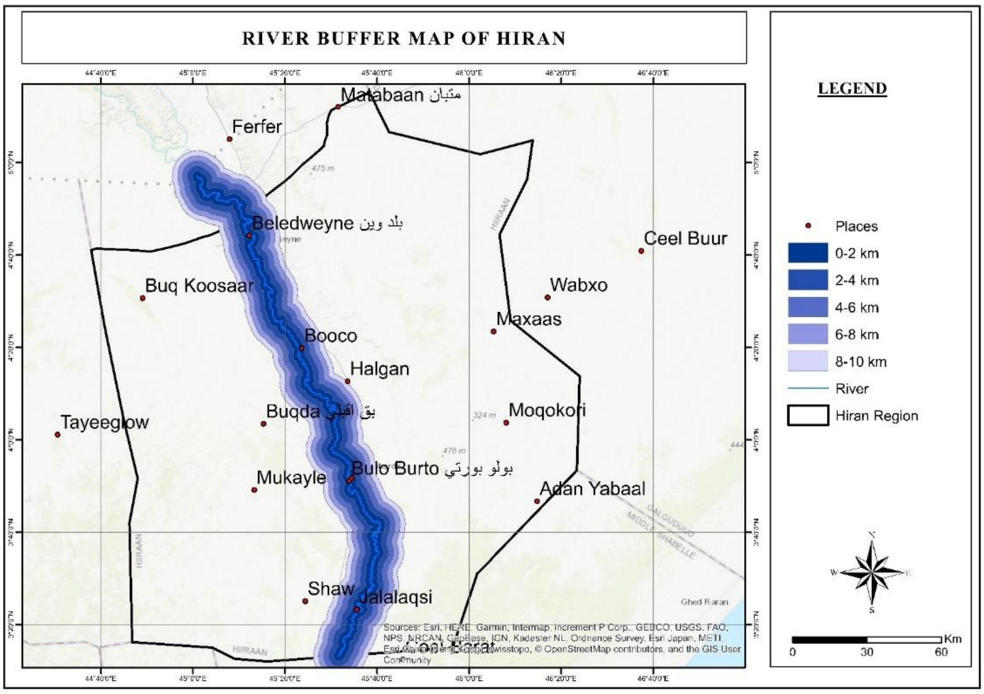

Figure 6.15 River buffer map of Hiiran region

6.1.2.7 River Discharge

Highest discharge of Shabelle river was observed in Beledweyne region approximately 2.4BCM, however, due to low rainfall inside Somali territory the discharge decereases as the river goes down at Booco the discharge is 2.2BCM, while in Jalalaqsi it is 1.3BMC.

The discharge of Beledweyne was given the highest weight 9 point while Booco areas was given 6 points, however, Jalalaqsi was given the lowest point as shown in Table 6.8. Figure 6.16 shows river discharge in BCM (billion cubic meter).

Table 6.8 River discharge with weights

Stations	River Discharge BCM	Point
Beledweyen	2.4	9
Booco	2.2	6
Halgan	2.01	5
Buqda	1.8	4
Bulobarde	1.5	3
Jalalaqsi	1.3	2

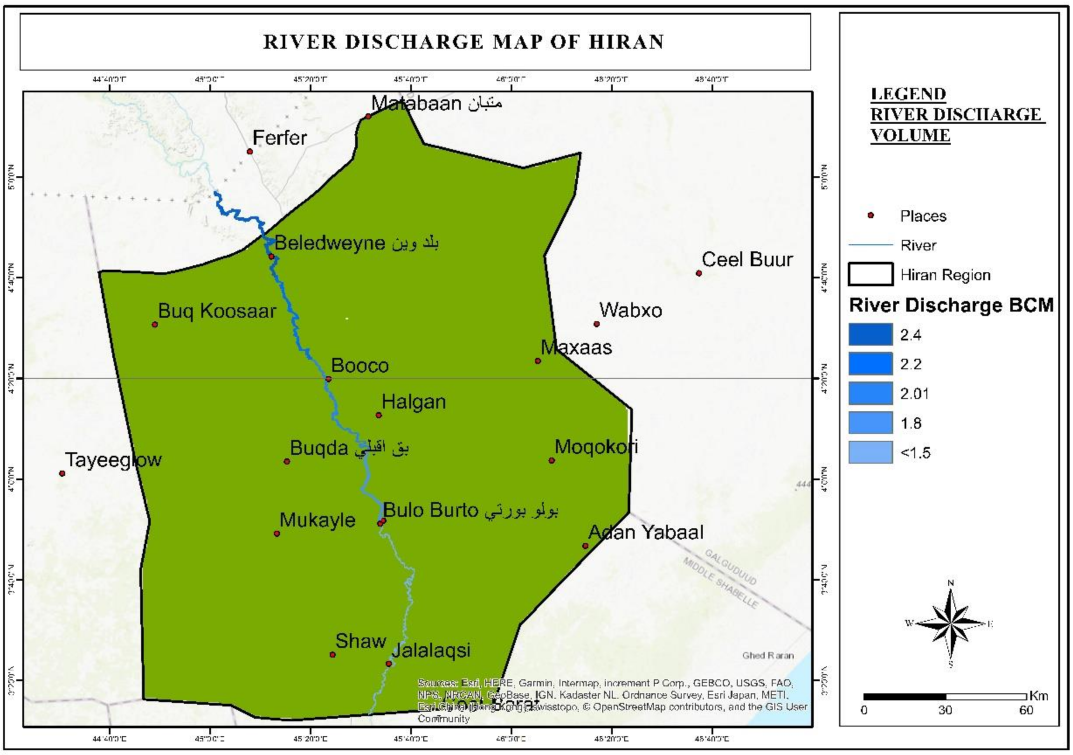

Figure 6.16 River discharge map of Hiiran region

6.1.3 Soil Erosion Analysis

In arid, semi-arid, and humid tropical climates like the Hiiran region, soil erosion is the most serious environmental hazard. To analyze soil erosion, we have assessed soil erosion factors, and we've used the universal soil loss equation USLE

6.1.3.1 R-factor

To calculate rainfall erosivity factor R-factor, we have used Equation 6.1

$$\mathrm{R} = 0.55 \times \mathrm{MAP} + 4.7 \qquad 6.1$$

The annual average rainfall erosivity factor R for the years 2003 – 2020 was found to be in the range of (9.467 – 35.21 $Mjhacm^{-1}$) as shown in Table 6.8.

Table 6.9 Rainfall erosivity factor in Hiiran region 2003 – 2020

Years	Baledweyne R-factor	Bulobarde R-factor	Jalalaqsi R-factor
2003	14.69166667	18.61041667	19.31487500
2004	19.57291667	24.36250000	20.96991667
2005	16.61666667	22.08916667	18.52333333
2006	17.57916667	27.89166667	30.50416667
2007	28.41875000	30.55916667	22.02500000
2008	10.79583333	22.07083333	15.43325000
2009	22.25416667	13.14708333	18.10212500
2010	11.78125000	10.25958333	22.25416667
2011	19.18333333	18.63333333	23.65208333
2012	26.24166667	26.83291667	29.35833333
2013	16.18125000	25.59083333	27.29583333
2014	18.01458333	20.23750000	14.05000000
2015	36.46250000	30.11458333	30.11825000
2016	11.54750000	9.879166667	11.41504167
2017	9.466666667	9.30625000	18.18325000
2018	22.85000000	20.97083333	25.76683333
2019	27.05612500	31.66237500	34.67087500
2020	33.62037500	34.10300000	35.21445833

From Table 6.8, it is clear that Baledweyne has a minimum R-factor; however, it is observed that the highest R-factor was recorded in Jalalaqsi during 2020.

To generate an R-factor map, we have used the average annual rainfall erosivity actor, and interval data was used to overlook the erosivity factor of the region as shown in Figure 6.17 to calculate average annual rainfall erosivity we have used intervals of the precipitation years as shown in Table 6.10.

Table 6.10 Interval of precipitation years with R-factor intervals

Interval Years	R-factor values (Mjhacm^{-1})
2003 - 2006	9 – 14
2006 – 2009	15 – 21
2009 – 2012	22 – 28
2012 – 2015	29 – 35
2016 - 2020	>35

To interpolate rainfall in the Hiran region, we have used IDW. As shown in Figure 6.17 Baledwayne, Booco, Halgan, and Buqada have minimum R-factors, and it reflects that it will have the highest weight when it was generating R-factor map. However, Bulabarde has a small amount of rainfall compared with Jalalaqsi, as shown in Table 6.11.

Table 6.11 R-factor layers with weights

R-factor (Mjhacm^{-1})	Points
2.412 - 2.70	9
2.701 - 3.031	8
3.032 - 3.452	5
3.453 - 3.887	3
3.888 - 4.293	2

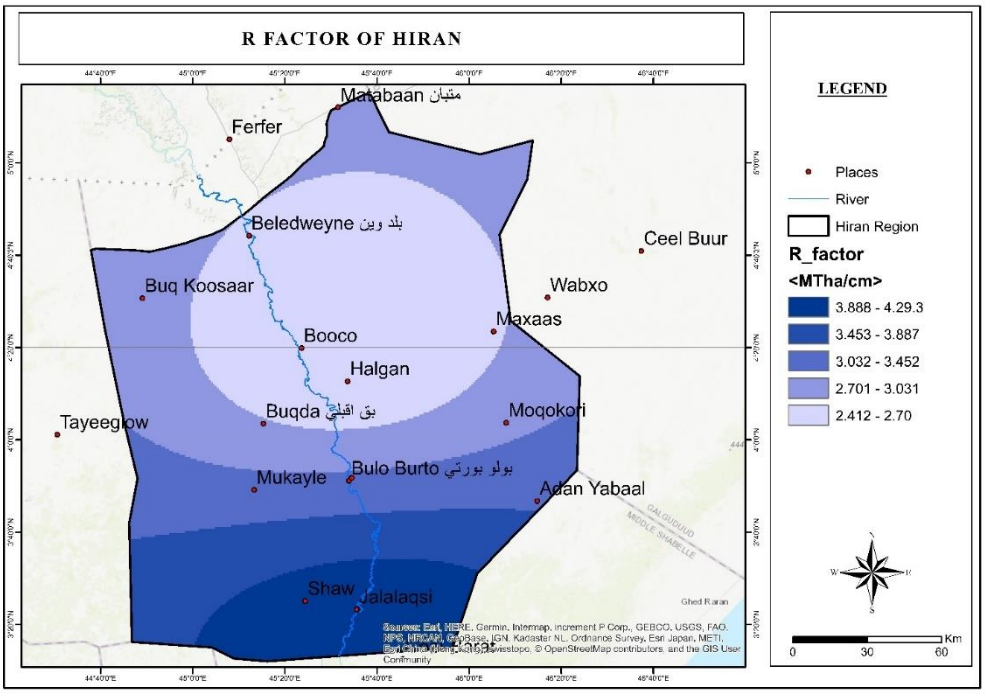

Figure 6.17 R-factor map of Hiiran region

6.1.3.2 K-factor

The K-factor is an important criterion for assessing soil erosion risk. K – values are notably high in low relief areas such as alluvial plains, inter-hilly valleys, and flood plain areas, ranging from 0.154 to 0.178. The soil texture of flood plains alongside the Shabelle River in the Baledweyne is mainly loamy sand to sand, soil erodibility is relatively high. The soil had a loamy texture in nature, and the organic matter level was low, making it more prone to erosion. The K – values are often reduced in high relief locations such as structural and denudation hills, ranging from 0.07 to 0.14. The map of K – factor is shown in Figure 6.18.

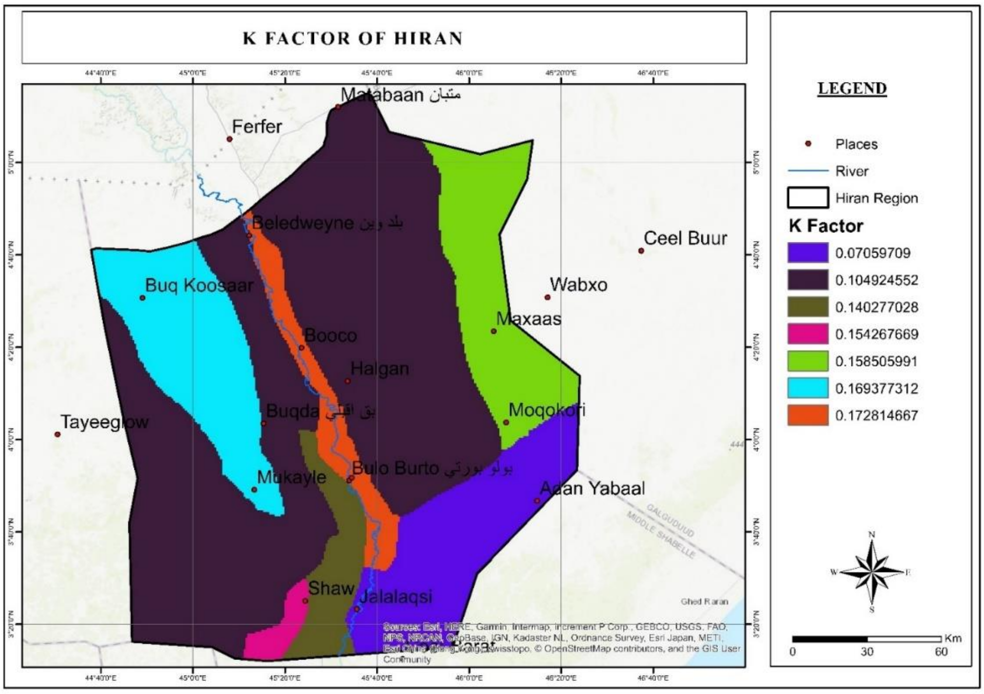

Figure 6.18 K – factor map of Hiiran region

As shown in Figure 6.3.2.1 areas near the river course have high K – values, creating more erosion. However, most areas in Baledweyne, Booco, Halgan, and Bulobarde have fewer K – values even though Jalalaqsi was recorded as the lowest K – values area in this region.

6.1.3.3 Topographic Erosivity (LS – Factor)

The slope length factor (L) and slope steepness factor (S) mainly reflect the effect of Topography on erosion. Slope steepness reflects the influence of the slope gradient on erosion. The L and S factor increase generally produces higher overland flow velocities and correspondingly more significant erosion. Topographic Erosivity factor in Hiiran region is in the ranges from 0 to more than 180 as shown in Figure 6.19

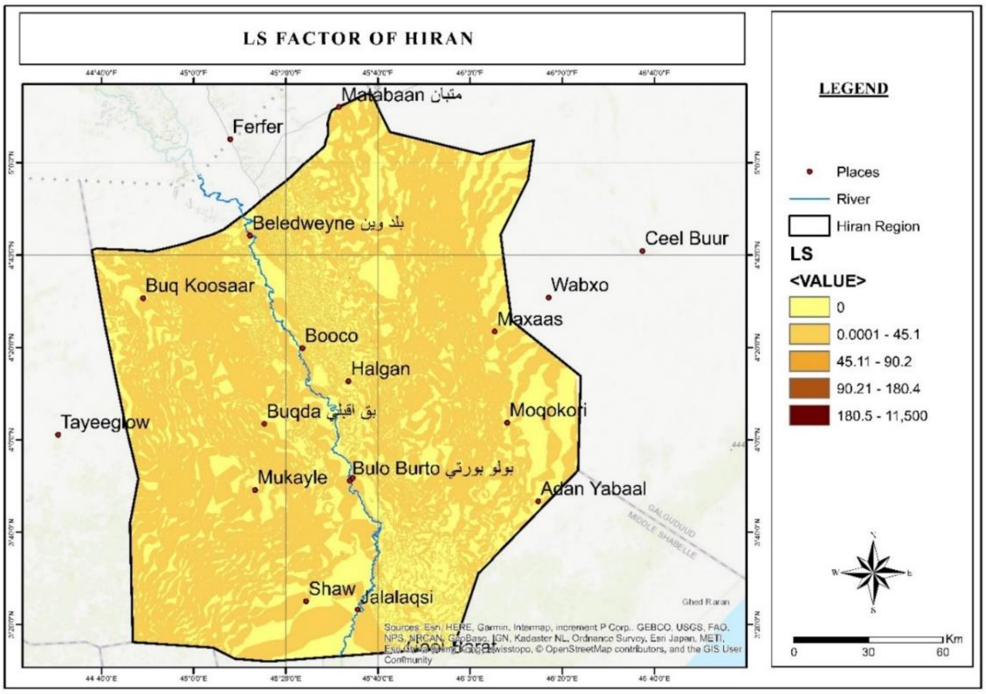

Figure 6.19 Topographic erosivity map of Hiiran region

As shown in Figure 6.18 majority of the study area has LS – Values ranging from 0 to 45 which indicates that the area has less topographic erosivity and these characteristics will make that the area is suitable for dam site selection.

6.1.3.4 CP – Factor

The cover management factor (C) and Protection factor P are crucial to the erosion because it is readily managed condition to reduce erosion. Soil loss is very sensitive to land cover in addition to relief. In the study area majority of the area is under dense and degraded forest. CP factor is less significant when land use and the land cover area comprise the maximum percentage of natural vegetation and plantation crops. The CP actor values in the study area range from 0 to 1. As shown in Figure 6.20 and Figure 6.21

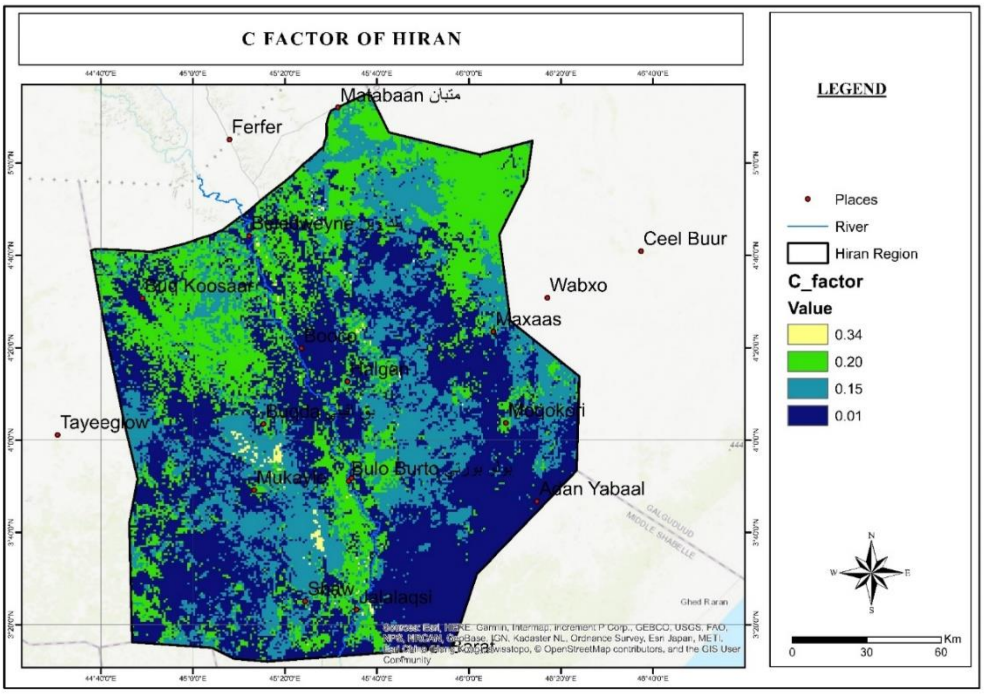

Figure 6.20 C – factor of Hiiran region

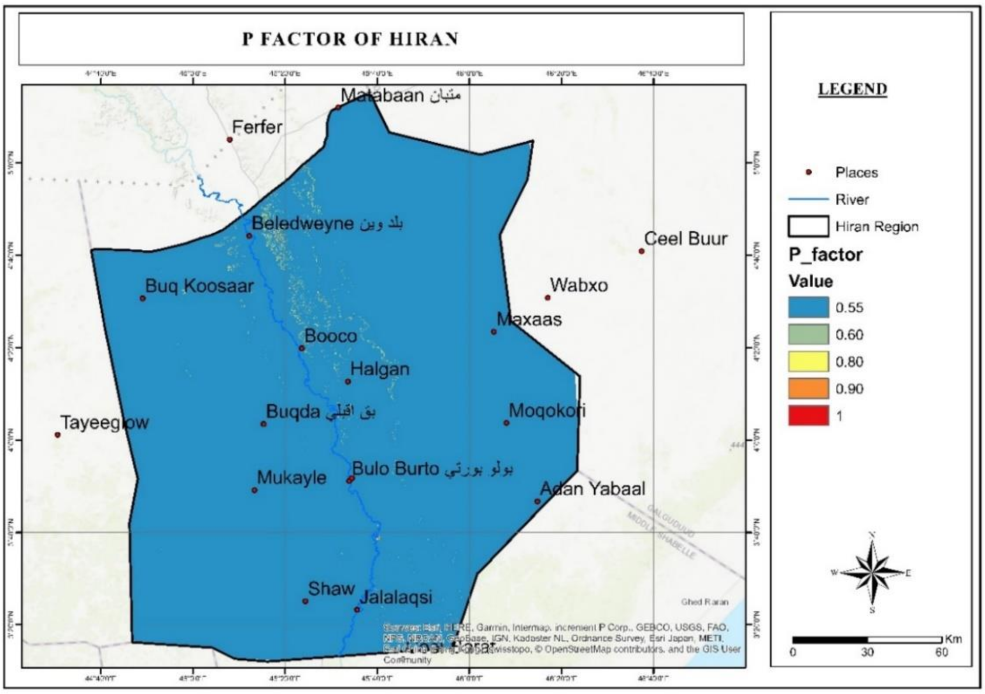

Figure 6.21 P – factor of Hiiran region

From Figure 6.20 and Figure 6.21, the majority of the areas near Baledwayne, Booco, Halgan, and Buqda have CP- factor ranges from 0.01 – 0.55, which makes these areas are more suitable for dam site selection.

6.2 Results

After analyzing all important parameters for dam site selection, we have given each layer a certain weight to create a composite suitability map.

The average annual soil erosion potential (β) has been computed by multiplying the developed raster from each soil erosion factor.

$$\beta = R \times K \times LS \times CP$$

The final β factor map displays the average annual soil loss potential of the Shabelle river basin in the Hiiran region, as shown in Figure 6.22. Results show that the study area has a gentle slope, so the erosion loss is obtained at a low rate and within acceptable limits. Areas near Baledweyne have relatively higher soil loss, slightly more than $40 t/ha$ yearly, even though most of the study area has soil loss between $0 - 20 t/ha$ yearly. Table 6.12 summaries soil loss classes with soil erosion intensity type

Table 6.12 Soil loss classes in Hiiran region

Soil Loss Classes (t/ha/yr.)	Erosion Intensity Type	LULC Type
0 – 10	Very low	densely forested, grassland, and shrubland
10 – 20	Low	open grassland and rainfed cropland
20 – 30	Medium	open shrubland
30 – 40	Hight	Broadleaved deciduous forest
> 40	Very high	bare areas

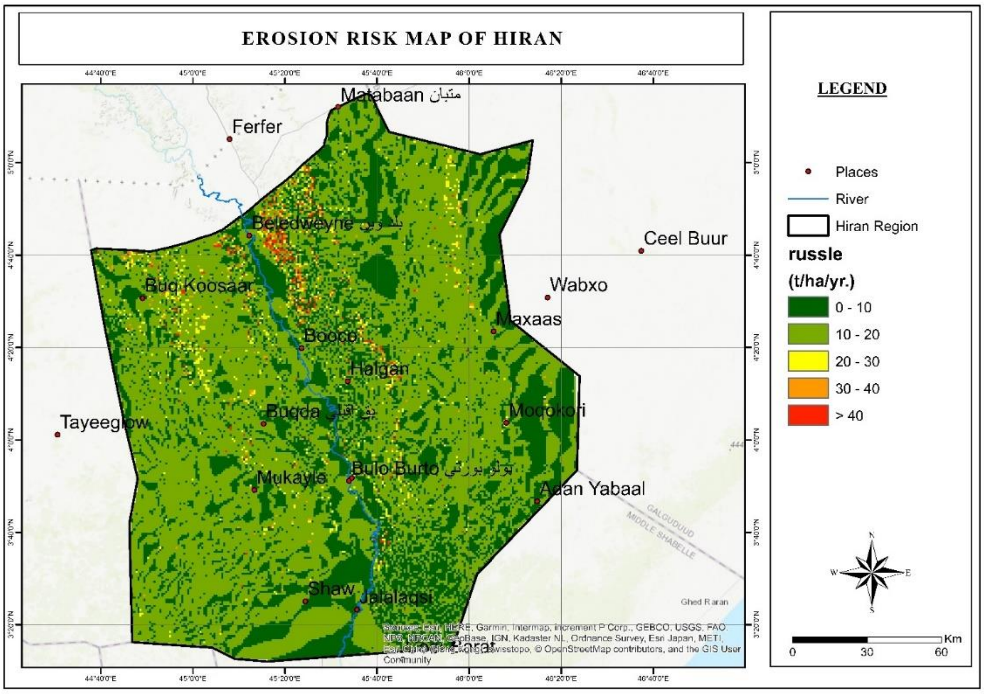

Figure 6.22 Soil erosion map of Hiiran region

Figure 6.22 shows that the average annual soil loss of less than 10 ta/ha/year is negligible. This amount has been recorded under very densely forested grassland and shrubland, and low soil erosion (10 – 20 t/ha/yr.) was found mainly in open grassland and rainfed cropland areas. In contrast, medium erosion was found in the areas of open shrubland, while high and very high soil erosion was found in the areas such as broadleaved deciduous forest and bare areas, respectively. After creating a soil erosion map, we have also generated a flood risk map to analyze the best position for dam construction Figure 6.23 shows a flood risk map

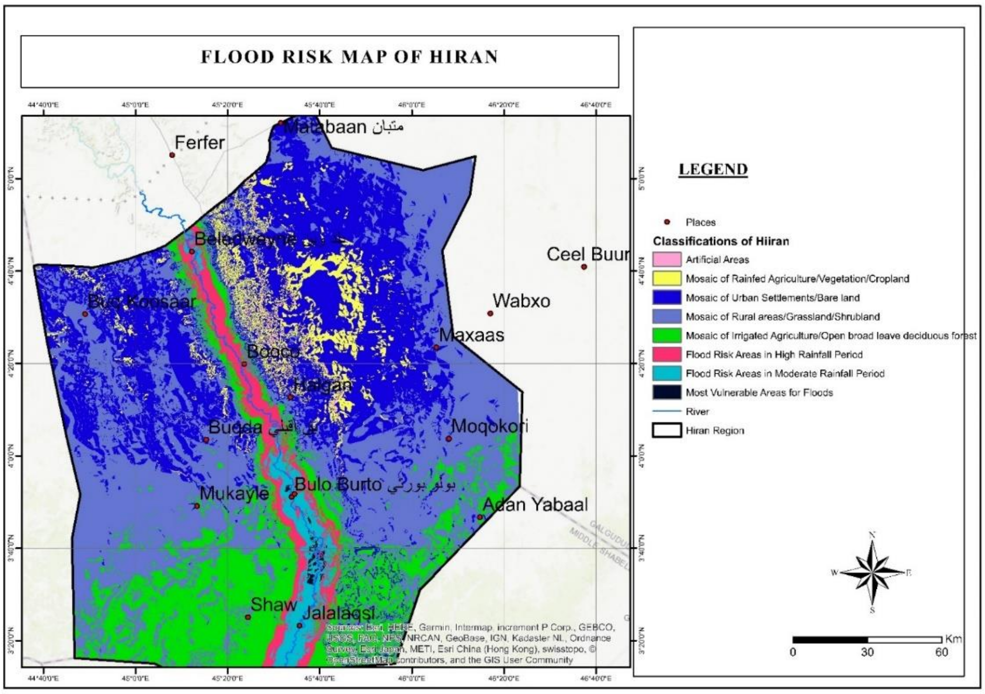

Figure 6.23 Flood risk map in Hiiran region

For the topographic Settings, we have analyzed different layers and created the map of each layer before the final map of dam site selection was generated. However, the AHP process has been performed to give a certain weight for each layer Table 6.13 shows the weight of each layer

Table 6.13 Weighted overlay for the final Map

Layer	Weight %
Elevation	4.15
Aspect	4.71
Land use land cover	6.80
Soil	9.61
Slope	10.70
Rainfall	14.69
River buffer	18.84
River discharge	30.51

After giving each layer a certain weight, the final map was generated to identify which area has a maximum point for selecting the site. However, the optimal site for dam construction must fulfil the highest score from each layer, as shown in Figure 6.24, Figure 6.25 and Figure 6.26. The distance of the selected dam sites is approximately two kilometres from the river however, this distance makes the sites more suitable for harvesting rainfall and river flow when the river is a full bank. Moreover, it is also far from the flood vulnerable areas. As it was mentioned in the analysis, flood reaches nearly one kilometre from the river when there are middle and high floods. Three sites were scored the highest points, and then it was compared between them after adding one more parameter to decide if there is one area that would be selected which one is more suitable than the other two. Table 6.14 summarises.

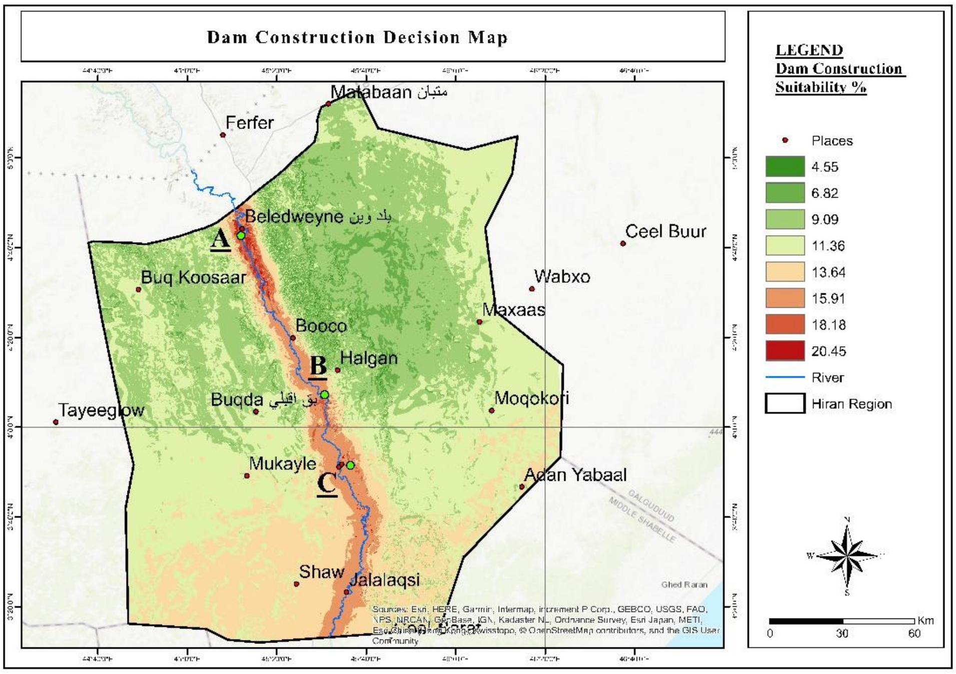

Figure 6.24 Map of dam sites in Hiiran region

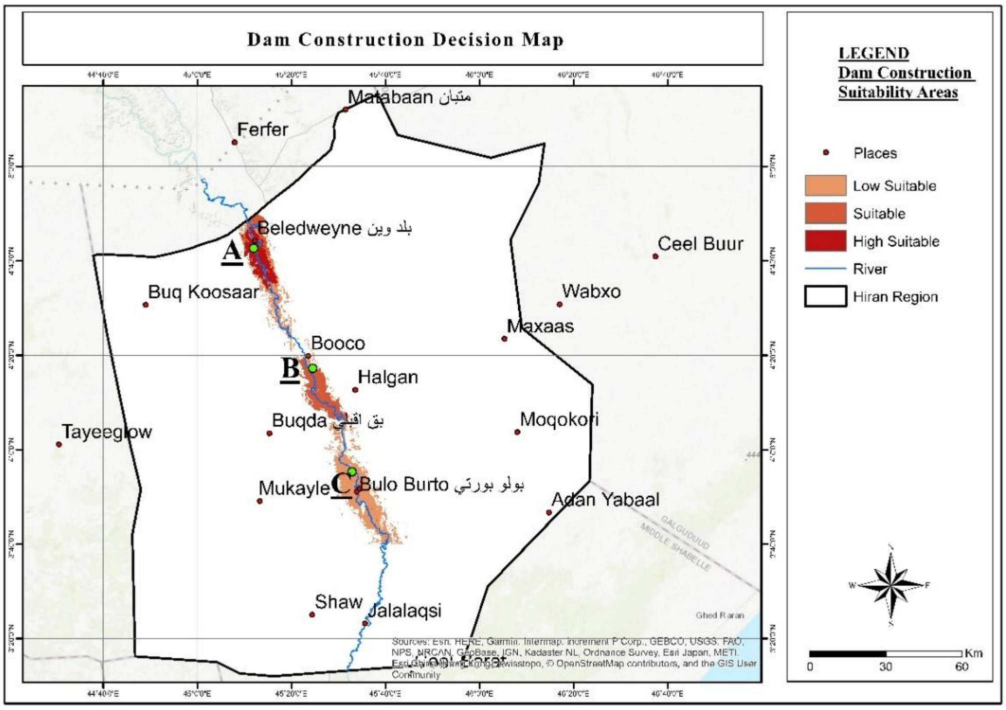

Figure 6.25 Map of dam construction suitable areas in Hiiran region

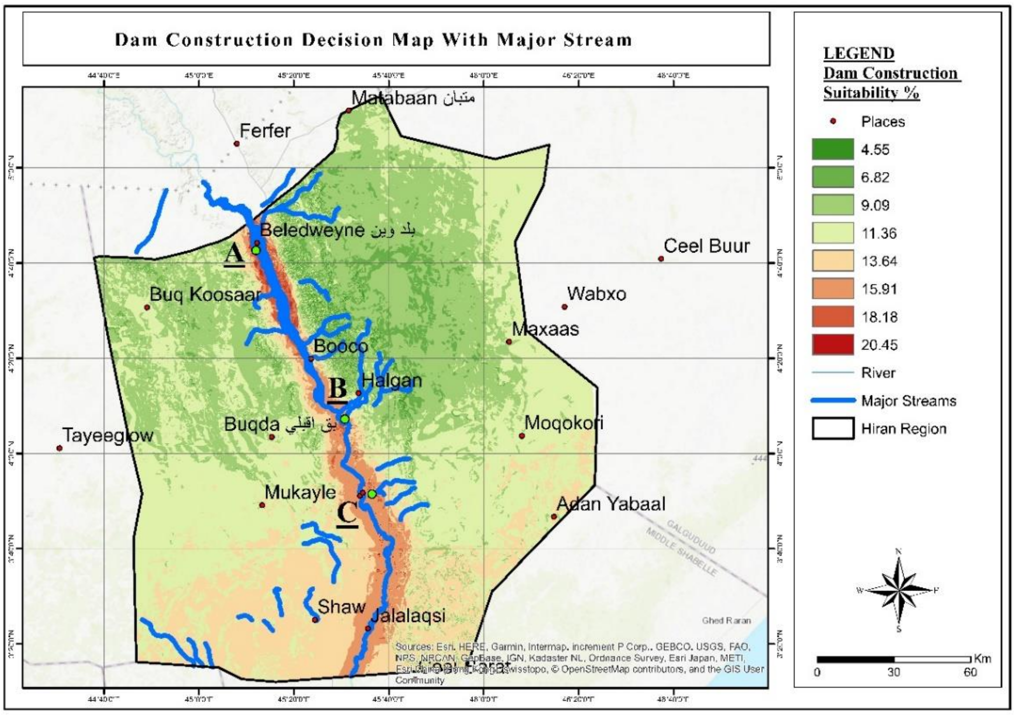

Figure 6.26 Map of dam sites with Major streams in Hiiran region

Table 6.14 Summary of three dam sites in Hiiran

Dam site	Soil Erosion (t/ha/yr.)	Rainfall (mm)	River runoff (m^3/s)	Population
Dam A	10 – 20	297.7 – 314.4	473.6	85429
Dam B	0 – 10	275.6 – 297.6	489.3	15000
Dam C	0 - 10	344.0 – 413.90	176.0	23589

Based on Table 6.14 Beledweyne has more population than any other city in the region. Moreover, 79/21 was recorded as urban/rural ratio in this region.

Dam A has many advantages than other two dam sites

1. River runoff

The river runoff in this area is slightly less than the river runoff in Buda, however, the soil erosion level, marginally higher, may reduce the river velocity.

2. Population size

Baledweyne is the capital city of this region. However, the city has the highest population size, and this population most of the dry season, they extract water from the river. Alternative water storage will help the population of this area.

3. Rainfall

The rainfall data in this area is significantly reliable; however, when the rainfall hits well, there will be more water available to store.

Chapter 7

Conclusion and Recommendation

7.1 Conclusion

Increased water demand in the Hiiran region and increased water scarcity due to poor rainfall and high evapotranspiration, population growth, accelerated economic development, and pollution levels have necessitated a more strategic surface water resource strategy. On the other hand, Ethiopia envisioned a plethora of irrigation development projects, including constructing massive irrigation schemes near the Ethiopian-Somali border, where the river flows into Somalia territory. These development plans may have a severe impact on Somalia's water security.

Downstream, the government of Somalia built some medium-scale water reservoirs in the middle Shabelle region during the 1970s to store the river flow during high rainfall using the classical method. However, with a low level of technological advancement at that time, the selection of the dam in this location didn't incorporate all the necessary parameters that determine site selections, resulting in the selected site's failure. Moreover, with upstream development, increased water demand, and floods in the Hiiran region, the river flow reaches this location with less streamflow.

Within a year, as well as from year to year, there are significant flow changes in the Hiiran region. However, in this location, the availability of reliable flow is a critical element in dam design and site selection. Furthermore, during the selection of a suitable dam site, the high flood season was taken into the consideration. Different calculations were used to analyze the flood frequency of streamflow measurements. In comparison to the river's catchment areas, the flood volume in Hiiran is quite small. However, a number of natural and man-made factors have exacerbated the region's flood problems, which can be summarized as follows:

1. Due to silt deposition, riverbed levels are increasing higher than adjacent land.
2. During dry seasons, people break levees to irrigate land.
3. Natural flood plains are being encroached upon.

Drought is also a recurring issue in the iver basins. Low-flow streamflow evaluations were carried out in order to plan for the worst-case scenario of flow availability.

The river's water quality is also a matter of concern, as both human and livestock populations consume river water directly.

The study proposes building a medium-scale water reservoir in the Hiiran region to reduce water scarcity and manage floods. The researcher applied multi-criteria decision analysis to determine a good site for irrigation and other water demands. However, the study looked at three primary parameters to determine which area had the best chance of being chosen as a dam site to meet the region's agricultural and other water demands.

Topographic settings, soil erosion factors, and riverbed analysis were analyzed.

The fundamental cause of flooding in the region has been identified as not only the occurrence of substantial rainfall but also the susceptibility of the riverbank. During the dry season, riparian converge on the river to get surface water, and they break the riverbank to irrigate their fields and livestock. During the rainy season, the river follows those channels and might produce floods, rather than the river course moving directly into downstream.

There are also flood potential regions along the riverbank resulting from plant removal, embankment erosion, water spills, or other signals that indicate a possible embankment vulnerability.

7.2 Recommendations

The Shabelle River Basin is an undeveloped, conflict-ridden region with a scarcity of water. Furthermore, the river basin lacks an agreement between its riparian countries on its uses. On the other hand, Ethiopia dominates in several key areas, including geographical location, river runoff and population.

Cooperation between the two countries is not a choice; it is a need for preventing conflicts and maximizing the use of the river's water resources.

All water infrastructure, such as reservoirs and relief channels, must be rebuilt in Somalia, and collaboration between two neighbouring nations about the use of the river basin must be emphasized and agreed, however, the following approaches can be used.

1. Cooperation amongst riparian countries in the basin system to create a shared strategy and management framework.
2. Integrated Shabelle River management that balances and optimizes the basin's water use.

Although regional economic integration appears to be a political impossibility at the moment, it may prove to be an unavoidable reality in the future, since the shared river might be one of the economic integration's driving forces.

For Somalia's part, they can propose that Ethiopia be granted access to a port along Somalia's long coastline subject to specific conditions, in exchange for Somalia receiving larger river flows for agriculture purposes, potentially enhancing regional economic integration.

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Curriculum Vitae

PERSONAL INFORMATION	
Name	Abdirahman Ahmed OMAR
Nationality	Somali
Email Address	D150201004@ogr.ikc.edu.tr
Hobbies	READING, SPORTS & CONFERENCES

EDUCATIONAL BACKGROUND	
2021	PhD, Urban Regeneration at Izmir Katip Celebi University, Turkey.
2015	Turkish Language Proficiency Certificate
2011	Master, Applied Mathematics and Statistics at Academy of Graduate Studies, Libya
2006	Math and Physics in Mogadishu University, Somalia.

WORK EXPERIENCE

2020	International Student Science Congress Organizing committee https://sciencecon.org/committee/organizing-committee/
2019	Collaborative International Students Projects Director in Izmir
2018	Turkey International Alumni Association. Izmir Representative http://tumed.org.tr/izmir-misafir-uluslararasi-ogrenci-dernegi-ziyareti/
2017	International Student President in Izmir Katip Celebi University
2016	Syrian Refugee Resilience Projects Teaching Director in Izmir Turkey
2016	Statistics Lecturer for Master Degree Students in Somalia International University. Somalia, Mogadishu.
Oct 2011- Jun 2014	Mogadishu University Lecturer, Bosaso Campus
Mar 2011 up to Jun 2011	Hargeisa University Lecturer, Hargeisa
02.2007–06.2008	Mogadishu University Lecturer, Mogadishu

PAPERS/Conferences	
May 2019	Streamflow Analysis https://sciencecon.org/2019-abstract-book/
May 2018	Water Resource Management Using RS and GIS in Arid and Semi-arid Regions of Somalia https://sciencecon.org/2018-2/
May 2017	Strategic Principles and Perspective for Urban Renewal in Post Conflict Countries: Somalia Case https://sciencecon.org/
Dec 2013	Research Guideline Book, 1st Ed. ISBN 0785965427123.
Feb 2011	Application of Orthogonal Polynomials in C++ http://www.biosciences.elewa.org/JAPS

	LANGUAGES
Somali	Native Language
English	Excellent
Arabic	Excellent
Turkish	Very good