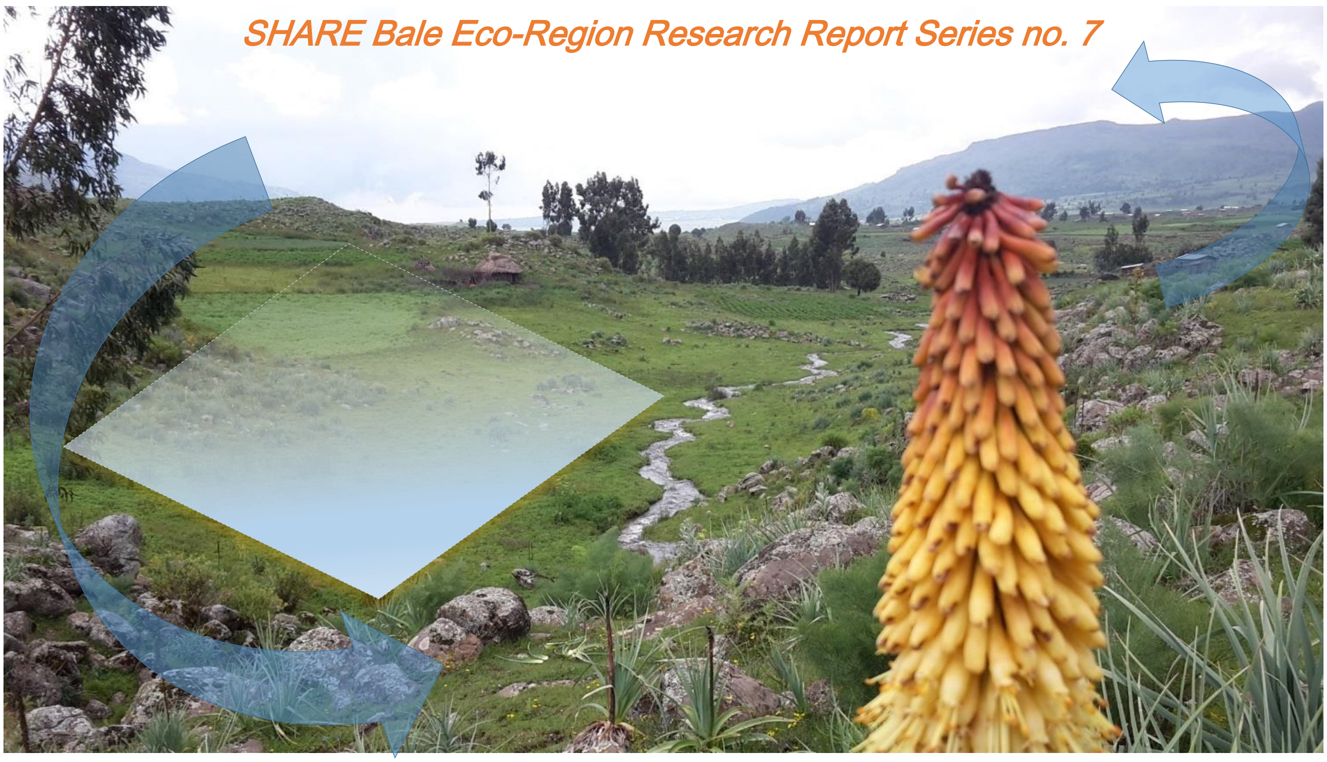
# Drivers of hydrological dynamics in the Bale Eco-Region



**ABOUT THE SHARE BALE ECO-REGION PROJECT**

Conservation of Biodiversity and Ecosystems Functions and Improved Well-being of Highland and Lowland Communities within the Bale Eco-Region (BER) is one of the European Union (EU) funded projects that stands for Supporting Horn of Africa Resilience (SHARE). In Ethiopia, the project covers 16 districts (Districts) in West Arsi and Bale Zones of Oromia Regional State, around 22,000 $km^2$, with a population of about 3.3 million. The project life span is 42 months starting July 2014 and ending in November 2017. Five partners are implementing the project: Farm Africa, SOS Sahel, International Water Management Institute (IWMI), Frankfurt Zoological Society (FZS) and Population Health and Environment (PHE).


*Location of the Bale Eco Region (BER) in Ethiopia*

**Acknowledgements**

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## Acronyms

| | |
|---|---|
| BER | Bale Eco-Region |
| BERSMP | Bale Eco-Region Sustainable Management Programme |
| BFI | Base-Flow Index |
| BMNP | Bale Mountains National Park |
| DHS | Domestic Household Survey |
| ENVI | ENvironment for Visualizing Images |
| EPA | Environmental Protection Authority |
| ETB | Ethiopian Birr |
| EWCA | Ethiopia Wildlife Conservation Authority |
| FZS | Frankfurt Zoological Society |
| GIS | Geographic Information System |
| GRDC | Global Runoff Data Centre |
| IWMI | International Water Management Institute |
| ITCZ | Inter-Tropical Convergence Zone |
| KII | Key Informant Interview |
| LULC | Land Use and Land Cover |
| masl | meters above sea level |
| MoWIE | Ministry of Water Irrigation and Energy |
| NMA | National Meteorological Authority |
| OFWE | Oromia Forest and Wildlife Enterprise |
| PFM | Participatory Forestry Management |
| PHEEC | Population, Health and Environment- Ethiopian Consortium |
| SHARE | Support for Horn of Africa Resilience |

# 1 Background

This report attempts to provide insights into the direct and indirect drivers of hydrology in the Bale Eco-Region. Some key drivers are natural, such as slope, rainfall and evaporation, and soil type. Other drivers are strongly depending on human activities, for example land cover/land use change, deforestation, water use, etc. These drivers are discussed in this report. By knowing the drivers, further insight can be brought to the relative impact of project interventions to the hydrology at the watershed, landscape and eco-regional level.

Through soil and water conservation in the watershed, the SHARE project aims to improve the hydrology of the watershed by increasing water availability in the dry season and reduce peaks in the wet seasons. To be able to measure this impact and distinguish it from natural variations, a long term (5-10 years) period is required. The short project time-frame does not allow for trend analysis with a sufficient level of confidence, and analysis of the of impact soil and water conservation activities on the river flow regime and sediment loads. This report concludes with a description of the 3 stations where water level, weather parameters and sediment load is being monitored in order to better understand the hydrology of the region and its drivers.

## 1.1 Location of the Bale Eco-Region

The BER is located in the Oromia Region and consists of sixteen Woredas in the Bale and West-Arsi Zones of the Oromia region[1]. Out of the sixteen Woredas, seven are the so-called focal Woredas of the project which are the focus of project interventions (Figure 1). The BER covers a total land area of about 38,036 km$^2$. The BER spans across an altitude of 272 masl in the South to 4,377 masl in the North. The Sanetti Plateau is located in the central northern part of the BER and is, with an estimated surface area of 400 km$^2$, Africa’s largest alpine habitat. The altitude of the plateau ranges between 3,550 and 4,377 masl at Ethiopia’s second highest peak at Mountain Tulu Dimtu. In the coldest months, frost and even snow occur.

[1] Geographically, the BER lies within the coordinates of 38N5118.21 longitude and E5.332.5 latitude, to 41N.233.9 longitude and 5.2339 latitude.

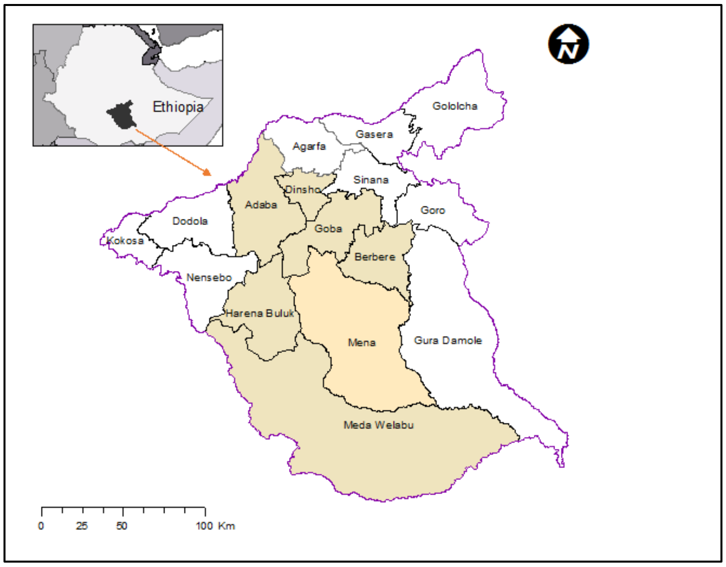


Figure 1. Location of the BER in Ethiopia, its 16 Woredas and 7 focal Woredas (shaded).

The area is called a water tower because of the many springs in the area and because it supplies water to two international river basins. The BER forms the upper catchments of both the Genale Dawa (also called Juba) and Wabe Shebelle River basins (Figure 2).

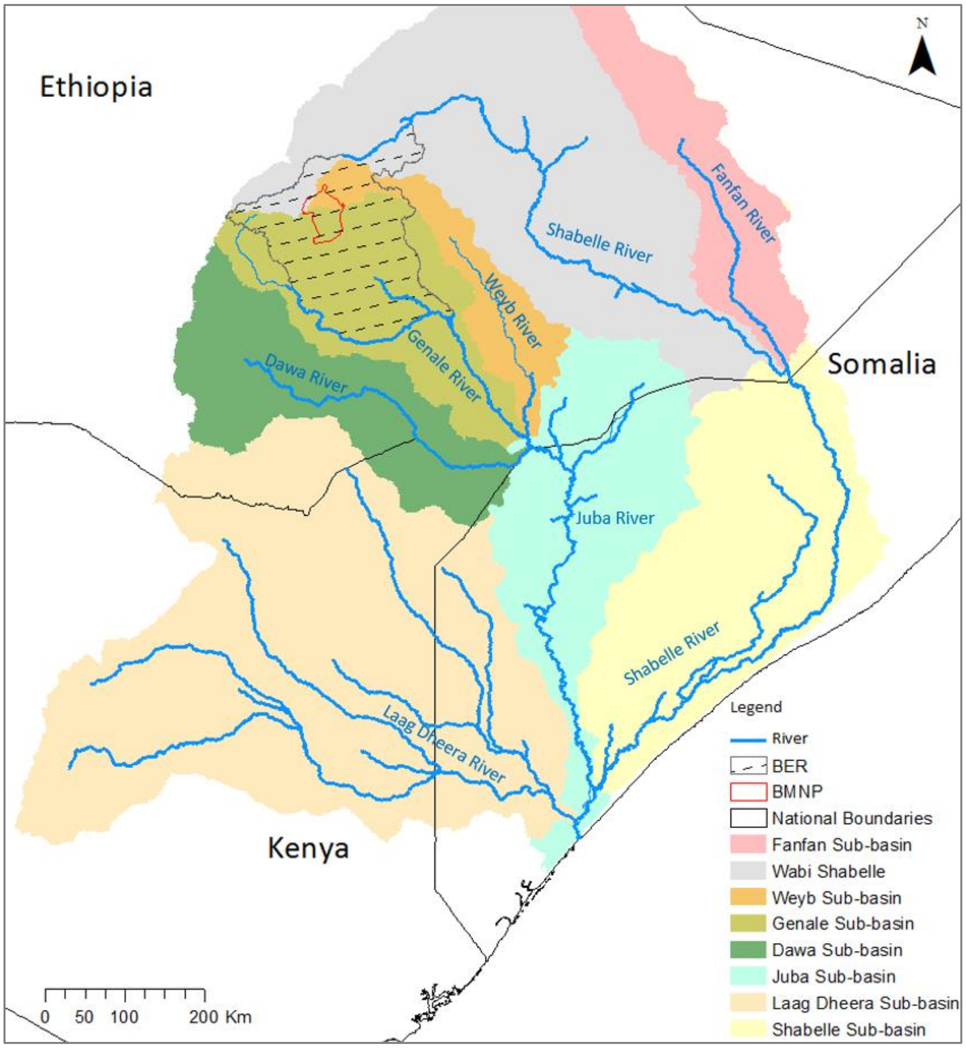


Figure 2. Location of the BER (area with black dash lines) and Bale Mountains National Park (BMNP), delineation in red) in the Wabe Shebelle (striped) and Genale Dawa River Basins (not striped) in the Horn of Africa.

Source: original GIS data produced by FAO Somalia Water and Land Information Management (SWALIM)

The northern area (16% of BER area) drains into a tributary of the Wabe Shebelle River Basin. The southern part drains into the Genale River Sub-basin (74% of BER) and Weyb sub-basin (10% of BER), which are both tributaries of the Genale Dawa River.

While the BER provides natural resources to an estimated 3.3 million people living inside the BER, an estimated 30 million people live in the two river basins combined (Mohammed 2013). Downstream communities are critically dependent on water supply from these river systems. These communities live partly in Ethiopia's Somali Region located to the East of BER and South Central Somalia located to the South East of the BER (Figure 2).

Today, the BER still holds enormous potential for development in a number of sectors. In the area of food security, high potential exists for agricultural intensification and expansion. There is also huge opportunity for further promotion of all the resources that the BER has to offer for national and international tourists. However, care is needed to ensure sustainable development and to safeguard critical natural resources, including water.

## 1.2 Demographics

Projections based on the latest census (CSA 2007)[2], give an estimate of the human population in the BER as 3.3 million. Out of this, a total of 1.6 million people living in the 16 Woredas are expected to benefit directly or indirectly from the project. Some 0.4 million residing in five Woredas in lowlands have pastoralist or agro-pastoralist livelihoods (CSA 2007). The BER has a largely rural population, and a number of small towns. The largest settlements in the BER are Robe (44,382), Goba (32,025), Dodola (24,767), Adaba (17,875), Delo Mena (14,289), and Dinsho (3,609) (CSA 2007). In terms of religion, the population of BER is mainly Islamic (89.3%), Christian Orthodox (10.3%) and Protestant (0.4%). Total fertility rate in the BER is high; 5.2% in West Arsi Zone and 5.8% in Bale Zone, compared to the national average (4.8%) (CSA 2007). A more recent Domestic Household survey (DHS), carried out in 2011, reported 4.8 children per women as the national average fertility rate and 5.6 as the average in the Oromia Region (DHS 2012).

## 1.3 Land use and land cover

Land Use and Land Cover (LULC) of the BER were classified after ground truthing and analyses with ENvironment for Visualizing Images 5.0 Software (ENVI) were completed. The following categories are found in the BER, ranked from most dominant to least dominant:

1. ***Woodland*** *(33% of total):* In terms of density, the crown covers of the upper stratum covers 5-10 percent of the area, where trees are able to reach a height of 5 meters at maturity. Wood lands are characterized by open, even or uneven tree layer. Trees are dominant in the total vegetation;
2. ***Farmland and rural settlements*** *(27% of total):* Area used for annual crops, both rain-fed and irrigated, and dispersed rural settlements. In remotely sensed images, the separation of dispersed settlements from the surrounding farm plots was very difficult. Hence, they were lumped together;
3. ***Shrublands*** *(18% of total).* Shrub lands are areas covered with woody vegetation mainly composed of shrubs (generally more than 0.5 m and less than 5 m tall), with most of the individual shrubs not touching each other. Under this main class, the classifier 'Dense' refers to the shrub vegetation whose closed cover reaches 60-70 percent of the area it occupies. Conversely, the 'Open Shrub' identifier applies to where 20-10 percent of the area is covered by shrub more than 0.5 m and less than 5 meters tall and also includes open grassland area dominanted by grasses with only a few widely scattered shrubs and trees;
4. ***Forests*** *(14% of total):* Forest describes land where trees reach a minimum height of 5 meters at maturity and consists of closed forest, with the tree crowns covering 50-80 percent of the area. Excluding Erica Forest;
5. ***Grassland*** *(6% of total):* Grassland class pertains to the plant communities in which grasses are dominant (over 90 percent), shrubs are rare and trees are almost absent;

[2] This estimate constitutes the populations of Bale and West Arsi zones, as obtained from CSA 2007 census. As it does not include the populations of other regions and Oromiya zones dependent on the ecosystems services of BER, it is a conservative estimate.

6. ***Afro-alpine*** *(1% of total)*: Area classified as being in the Afro Alpine zone, being predominantly the Sanetti Plateau;
7. ***Erica forest*** *(1% of total):* Land covered by Erica tree. The Erica tree is very unique and has a protected status together with its entire habitat. Therefore it is not combined with category four, forests;
8. ***Water bodies*** *(0.1% of total):* Land covered by open water bodies, predominantly lakes.

Based on data from 2014, the most dominant LULC categories are currently woodlands, farmland and rural settlements, scrublands, forests, and grasslands (Figure 3). When analysing temporal dynamics of LULC between 2010 and 2014, the most notable changes in LULC were a reduction of the area of grass land (59,032 ha, 20%), shrub land (46,026 ha, 6%) and forest (23,537 ha, 4%) (Table 1). This reduction can largely be attributed to an increase in the area of cropland and rural settlements (159,805 ha, 18%).

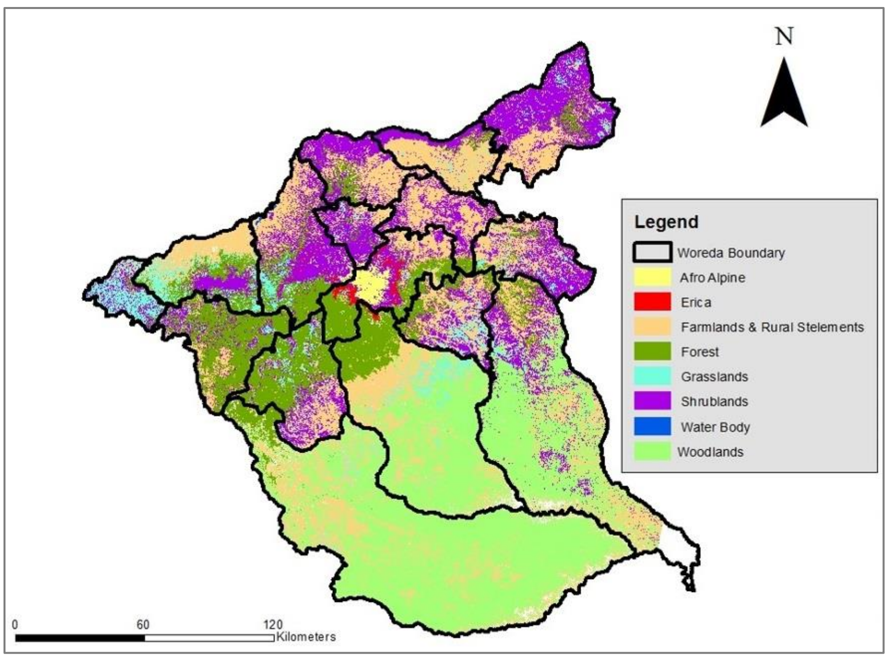


Figure 3. Dominant LULC classification in the BER in 2014.

Source: Farm Africa unpublished. The land use and land cover data was analysed by Farm Africa staff, using Landsat satellite images and classification was done using ENVI 5.0 Software.

Table 1. Land use land cover change in the BER between 2010 and 2014.

| Land use land cover type | Area (Ha) | | Change between 2010 and 2014 | |
|---|---|---|---|---|
| | 2010 | 2014 | Ha | % |
| Cropland and rural settlements | 869,080 | 1,028,885 | 159,805 | 18% |
| Grass Lands | 299,127 | 240,095 | -59,032 | -20% |
| Shrub Lands | 745,112 | 699,086 | -46,026 | -6% |
| Forest | 570,390 | 546,853 | -23,537 | -4% |
| Woodlands | 1,252,501 | 1,235,407 | -17,094 | -1% |

| | | | | |
|---|---|---|---|---|
| Afro Alpine | 43,699 | 31,815 | -11,885 | -27% |
| Erica Plants | 21,304 | 19,086 | -2,218 | -10% |
| Water Bodies | 2,404 | 2,391 | -13 | -1% |

Source: Farm Africa unpublished

Table 1 indicates that in the period 2010-2014 land conversion has taken place at a significant scale. Cropland and rural settlements have increased by 159,805 ha in a period of just 5 years at the cost of other LULC categories. The observed reduction in area of water bodies is likely to reflect natural variability in the area of wetlands/open water bodies.

## 1.4 Bale Mountains National Park and other protected lands

The Bale Mountains National Park, which is one of the most important protected areas in Ethiopia was established in 1970. The park covers an area of 2,150 $km^2$ which accounts for roughly 6% of the total area of BER (38,036 $km^2$) (Figure 4). The park derives its uniqueness from the large number of endemic plant and animal species. It is also unique due to the different vegetative landscapes that are strongly determined by altitude. In 2009, the park was nominated as a UNESCO World Heritage site because its high wealth of biodiversity and the landscape are regarded "of exceptional natural beauty"[3].

The Ethiopia Wildlife and National History Society published a special edition of its journal in 2011, called Walia-Special Edition on the Bale Mountains (Randal et al 2011). It contains a rich collection of scientific papers with results from decades of research in a number of areas such as wildlife, ecology and vegetation, resource use and protected area management. What the edition lacks is the links and importance of the BER to the wider surrounding landscape, especially downstream areas that are benefiting from the flow of ecosystem services generated in the BER.

[3] For more information, see the description made by UNESCO: http://whc.unesco.org/en/tentativelists/5315/

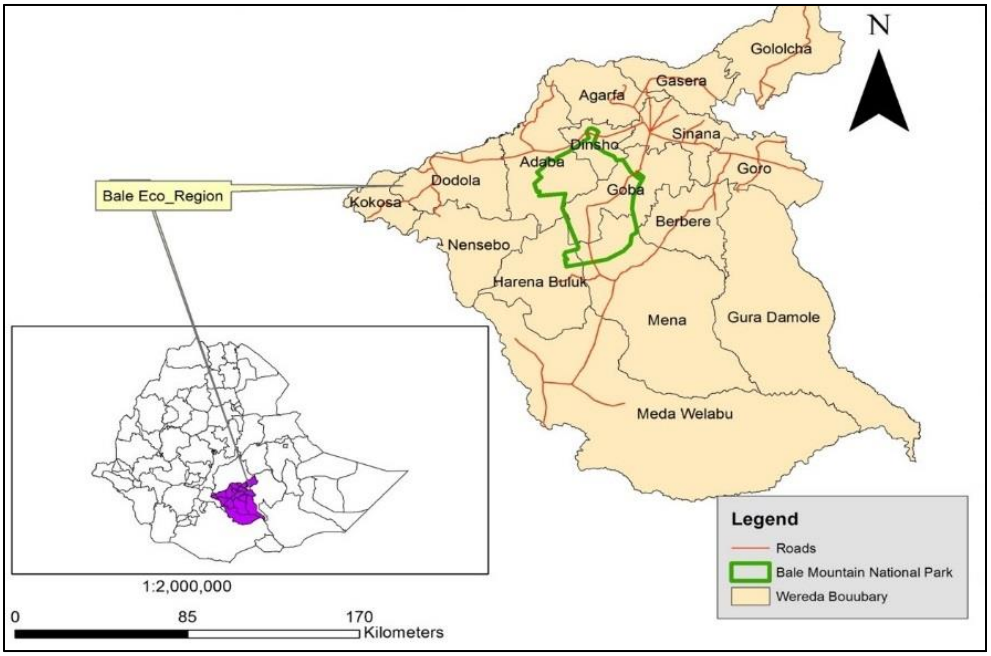


Figure 4. Location of the Bale Mountains National Park in the BER.

The national park serves another important function in the conservation and building up of soils and for infiltration of rainwater to recharge groundwater. Any degradation of the park area would have potentially severe implications for the water balance, sediment loads in the rivers and the livelihood of people living in downstream areas.

## 1.5 Livelihoods and sources of income

The predominant livelihoods in the BER are mixed farming and agro pastoralism. Findings from the household survey carried out in 2015 showed that 45.7% and 47.5% of the households practice mixed farming and agro pastoralism respectively (Table 2). A small percentage of households practice only pastoralism (2.7%) and pure farming (3.6%). 32.3% of all households have supplementary income from alternative sources. The most common source of alternative income is gained from honey production (25.9% of all households), and a few households grow spices and coffee. The survey showed that none of the communities in the project Kebeles are currently deriving any income from tourism in and around the Bale Mountains National Park.

Table 2. Sources of income and livelihoods in the BER.

| Livelihoods | Project Kebeles | | Control Kebeles | |
|---|---|---|---|---|
| | No. of Households | % of total | No. of Households | % of total |
| Pastoral | 6 | 2.7% | 6 | 2.8% |
| Agro Pastoral | 105 | 47.7% | 112 | 51.9% |
| Mixed farming | 101 | 45.9% | 90 | 41.7% |
| Pure farming | 8 | 3.6% | 8 | 3.7% |
| | | | | |

| | | | | |
|---|---|---|---|---|
| Alternative livelihood practices; of which: | 71 | 32.3% | 81 | 37.5% |
| Honey Production | 57 | 25.9% | 54 | 25.0% |
| Spices | 6 | 2.7% | 13 | 6.0% |
| Tourism (tours & trails) | 0 | 0.0% | 2 | 0.9% |
| Coffee | 8 | 3.6% | 12 | 5.6% |
| Total | 220 | 100.0% | 216 | 100.0% |

Source: Wenni Consult 2015

The average annual cash income of households in the BER is 7,157 Ethiopian Birr (ETB) (363 USD) [4]. The average cash income of households in highland, midland and lowland respectively was ETB 10,004 (470 USD), 6,541 (307 USD) and 4,182 (196 USD) in the project intervention Woredas (Figure 5). The reasons for this altitudinal disparity cannot be explained without further research but speculatively may reflect differences in availability of rain and/or water, limiting the natural capacity (feed and water availability) to keep livestock. Higher cash income in the highlands and mid-altitude zones are likely due to higher incomes generated from mixed farm and livestock keeping communities highland compared to the predominant pastoralist livelihoods in the lowlands. Malaria being exclusively prevalent in the lowlands (and some in mid-altitude) may also disproportionally affect productivity, however the validity of this proposition has not been researched as far as known.

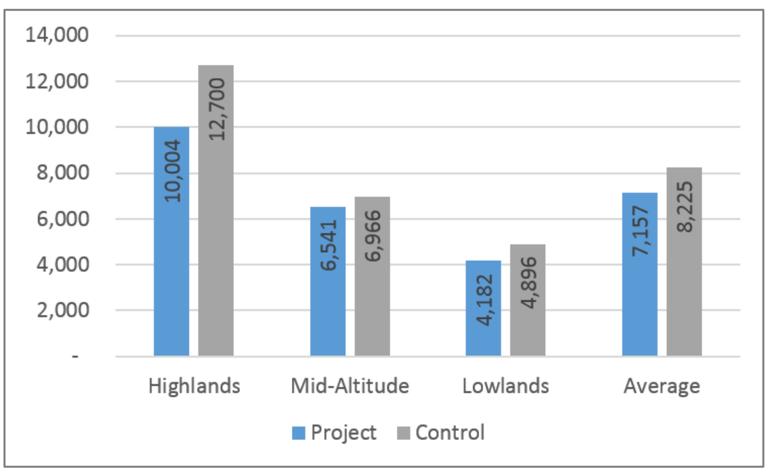


Figure 5. Household cash income by agro-ecological zone

Source: Wenni Consult 2015

## 1.6 Health and well-being

Most health indicators are found at the regional level and unfortunately not at the zonal level. Data presented here are all averages for Oromia, taken from the most recent Demographic and Health Survey (CSA 2012).

[4] 1 USD is equivalent to 20.82 Birr based on the exchange rate taken from oanda.com on 27 November 2015

All mortality rates are higher than the country average, however they are not the highest of the country. Neonatal mortality is 40 per 1,000 live births compared to 37 for Ethiopia. Post-neonatal mortality in Oromia is 32 per 1,000 live births compared to 22 for Ethiopia. Infant mortality is 73 in Oromia, compared to 59 for Ethiopia. Child mortality is 42 per 1,000 live births in Oromia compared to 31 for Ethiopia. Under-5 mortality is 112 per 1,000 live births in Oromia, compared to 88 for Ethiopia.

Nutritional status of children under 5 are only found for Ethiopia at the country level; 44% are stunted, 10% suffer from wasting in Ethiopia, and 29% of the total population are underweight. Estimated life expectancy at birth is 62 years for males and 65 years for females. The burden of disease measured in terms of premature death is estimated at 42,966 disability adjusted life years lost per 100,000 people, which is the highest in sub-Saharan Africa. Most common diseases in Ethiopia are malaria (absent in highlands), acute respiratory infections, diarrhea and HIV/AIDS (WHO 2014). Malaria is typically found below 2,000 masl, so mid altitude and low altitude zones will have malaria cases.

# 2 Physical geography

## 2.1 Altitude and slope

The BER covers a wide range in altitude levels with over 4,000 meters difference between the lowest (272 masl) and the highest (4,385 masl) point (**Error! Reference source not found.**).

Knowing information about slopes is important as it is an important factor for calculating soil erodibility and assessing erosivity of rainfall. It is also a major factor in characterizing suitable types of land use and is an important factor determining land cover. The BER has slopes that range from flat (8% of total area) to extremely steep slopes (3% of total area) (Figure 6). The steepest slopes are located mostly around all sides of the Sanetti Plateau.

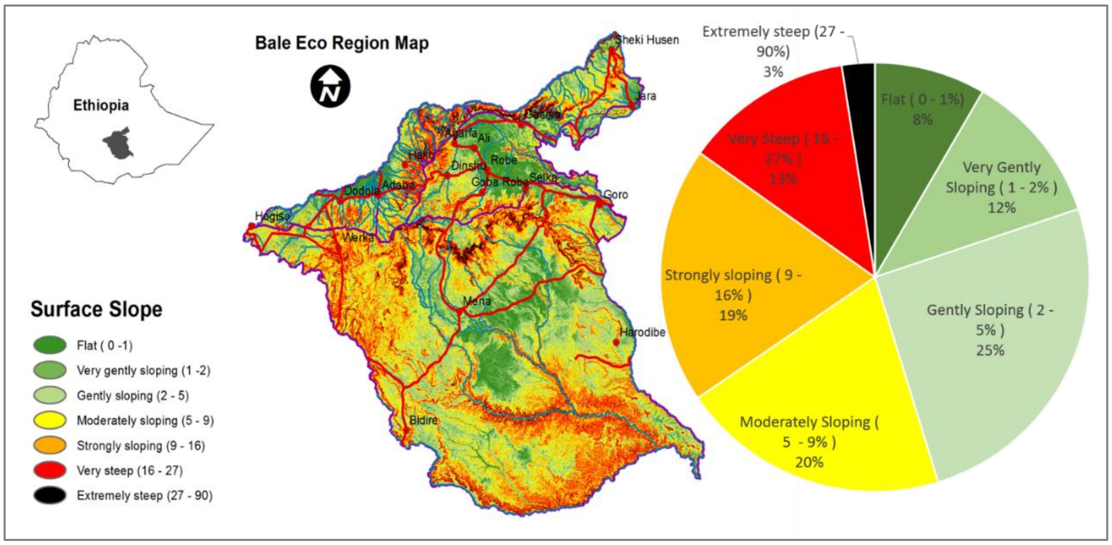


Figure 6. Variation of surface slope in the BER. Source: SWALIM Project.

## 2.2 Soils

The soil data are presented below as geographical distribution (Figure 7) and fraction of total area (Figure 8). Six soil types combined account for over 75% of the BER. The most dominant soil types is leptosol (20%), followed by cambisol (17%), vertisol (12%), nitisol (12%), luvisol (11%) and calsisol (7%).

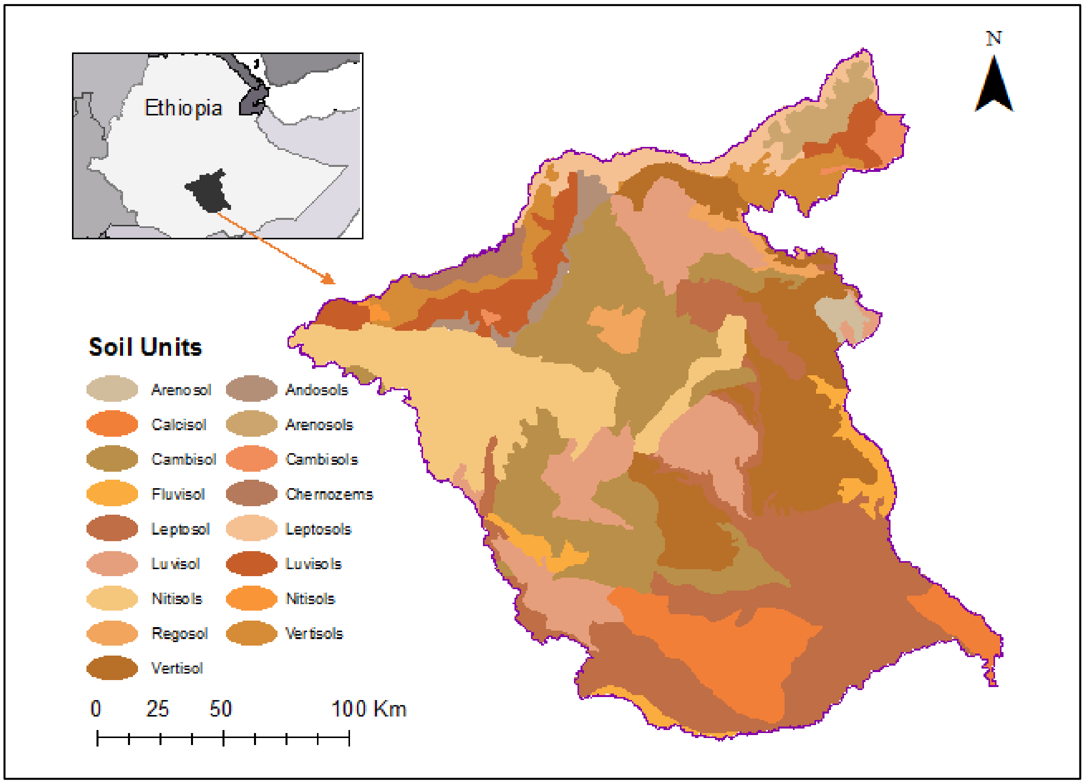


Figure 7. Soil map of the BER.

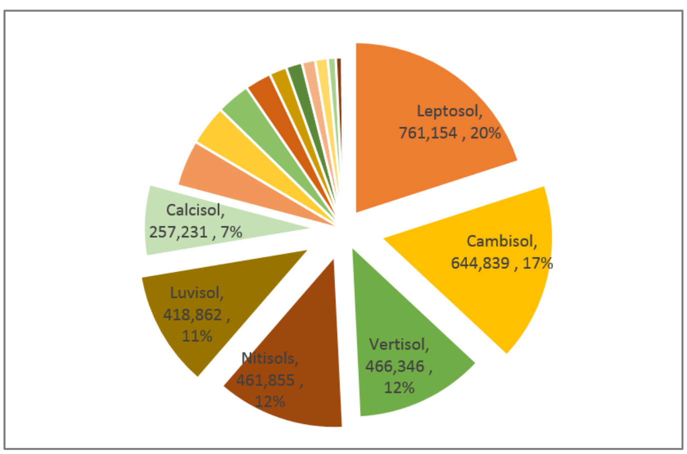


Figure 8. Distribution of soil types in BER. Numbers in hectares.

Source: SWALIM Project.

Leptosols are limited in depth by continuous hard rock within the 30cm of the surface, and therefore these soils have limited potential for root penetration and plant growth. Erosion is known to be the greatest threat in particular in montane areas such as the BER. Steep slopes with shallow and stony soils can be transformed into cultivable land through terracing by manually removing the stones and using as terrace fronts (FAO 2001).

Cambisols are moderately developed soils characterized by the absence of appreciable quantities of illuviated clay, organic matter, aluminum and/or iron compounds. The soils can host a wide range of vegetation types and are mainly used as grazing land and/or forestry in steep lands of BER.

Vertisols contain heavy clay and have deep cracks in the dry season as a result of alternate swelling and shrinking. Their fine texture and poor internal drainage account for the often poor workability of Vertisols, both in the wet and dry season. Vertisols areas lend themselves to large scale mechanized farming than low-technology farming.

Nitisols are well drained soils containing more than 35% clay throughout their profile with a gradual increase of the clay content from the top soil down to the B-horizon. Nitisols are also very porous and have a high moisture storage capacity and are among the most productive soils of the humid tropics. They are also less erodible than most other soils.

Luvisols are fertile soils and are suitable for a wide range of agricultural uses, but may also be sensitive to erosion. Calcisols are known for having a substantial accumulation of calcium carbonate. Most Calcisols have a medium to fine texture and a good water holding capacity. Sheet erosion and gully formation may occur when the surface soil is silty and crusts have developed.

## 2.3 Climate

The BER exhibits a wide range of temporal and spatial climate variability, which is predominantly determined by differences in altitude. The Bale Mountains are reported to have had a glacier area possibly of up to 180 $km^2$ during the last glacial period, from approximately 110,000 to 12,000 years ago (Osmaston et al 2005).

It is anticipated that Ethiopia will be severely impacted by the effects of climate change and there is a lot of donor money earmarked to combat the negative impacts. At the country level, there is huge level of uncertainty with regards to what the effect of climate change will be in Ethiopia. For the Eastern part of the country, decreased rainfall and increases in temperature as well as changes in rainfall patterns may result in more frequent occurrence of droughts, a higher frequency of heavy rains and higher peaks in runoff (EPCC 2015). No data were found on any scenarios of climate change impacts specifically for BER.

### 2.3.1 *Rainfall*

Rainfall data derived from the Wabe Shebelle and Genale Dawa Basin delineated for BER show a range from 1,142 to 637mm, with a mean rainfall of 923mm (Figure 9). Rainfall varies with altitude and is highly variable. The highest mean annual rainfall is observed in the high altitude, western part of the BER.

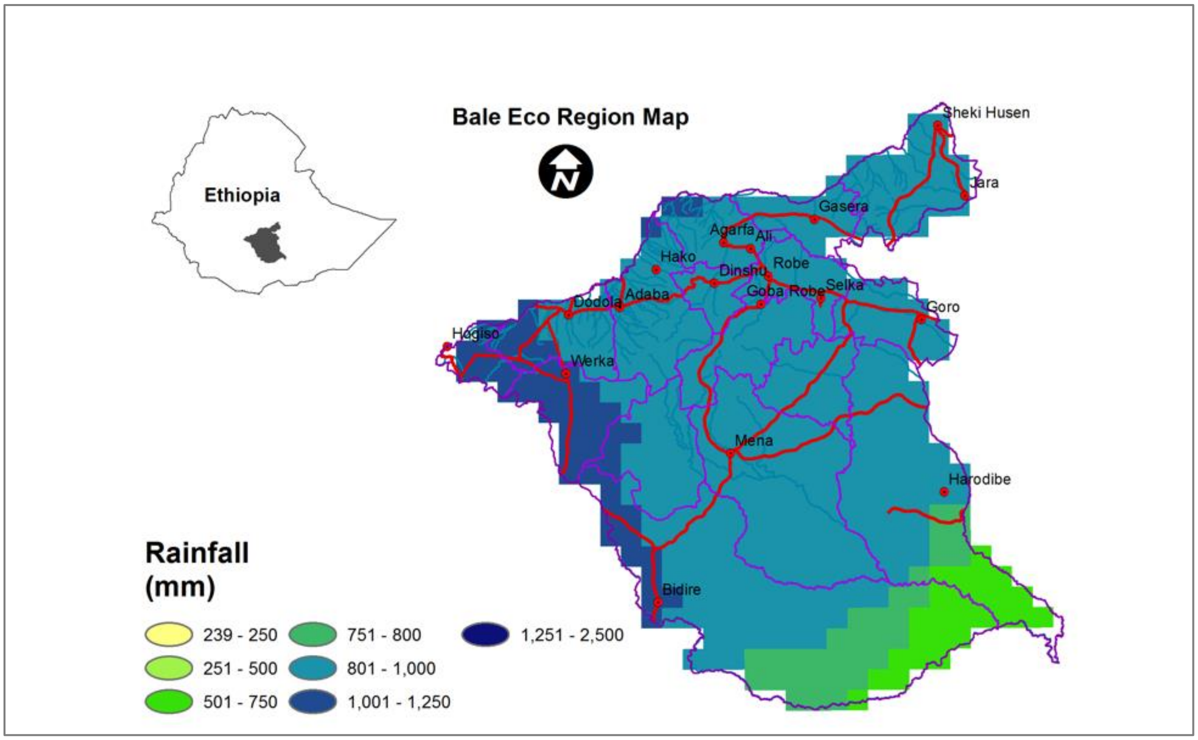


Figure 9. Distribution of rainfall in the BER.

Source: SWALIM project.

While the below periods of available data for the NMA stations show a large number of years (Table 3), the actual data received from NMA have a lot of gaps with some years missing data for one or more months and some months missing data for one or more days (See Figure 10). In particular the station in Goba only has data available for the 1950's and early 1960's. Average annual rainfall is characterized as presented in the below table (Table 3).

Table 3. Information on weather stations and data in the BER, obtained from NMA office in Robe town, Bale.

| Altitude zone | Station name | Average annual rainfall (mm yr$^{-1}$) | Altitude (masl) | Period with complete data |
|---|---|---|---|---|
| High Altitude | Goba | 838 | 2700 | 1954-1962 |
| | Adaba | 773 | 2420 | 1957- 2012 |
| | Dinsho | 1,585 | 3072 | 1984-2012 |
| Mid Altitude | n.a. | - | 1,300 – 2,300 | - |
| Low altitude | Dello Mana | 1,017 | 1090 | 1993-2008 |

Source: NMA

| year/station name | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dello mena | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Dinsho | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 10 | 7 | 12 | 2 | 0 | 0 | 0 | 12 | 10 | 9 | 12 | 8 |
| Goba | 9 | 12 | 10 | 0 | 12 | 12 | 12 | 12 | 12 | 12 | 11 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Adaba | 0 | 0 | 0 | 10 | 12 | 12 | 12 | 11 | 9 | 0 | 0 | 0 | 11 | 12 | 12 | 12 | 12 | 12 | 10 | 12 | 0 | 7 | 11 | 11 | 10 | 3 | 0 | 0 | 0 | 0 |

| year/station name | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dello mena | 0 | 0 | 0 | 8 | 11 | 12 | 5 | 6 | 8 | 8 | 12 | 12 | 12 | 0 | 9 | 12 | 12 | 11 | 12 | 12 | 12 | 12 | 5 | 12 | 11 | 12 | 11 | 12 | 10 | 12 | 10 | 7 | 3 |
| Dinsho | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 10 | 12 | 12 | 12 | 10 | 11 | 12 | 12 | 11 | 8 | 7 | 0 | 0 | 11 | 5 | 12 | 11 | 11 | 6 |
| Goba | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Adaba | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 11 | 0 | 0 | 0 | 6 | 12 | 12 | 10 | 12 | 12 | 12 | 11 | 12 | 12 | 12 | 11 | 8 | 10 | 6 | 6 | 11 | 11 | 12 | 11 | 10 | 5 |

legend: Number indicates number of months with available data

Complete year

Incomplete year

Figure 10. Chronogram of Rainfall data from NMA stations in Bale

The highlands have rainfall that roughly ranges between 800 and 1,000 mm $yr^{-1}$, based on records from the highland towns of Goba (972 mm $yr^{-1}$), Adaba (810 mm $yr^{-1}$) and Dodola (842 mm $yr^{-1}$). The relatively high annual rainfall recorded in the lowlands of Delo Mena (1,017 mm $yr^{-1}$) should be treated with caution since it is based on a record of just a few years and as one would anticipate less rainfall at lower altitudes as shown in the distribution of rainfall (Figure 9).

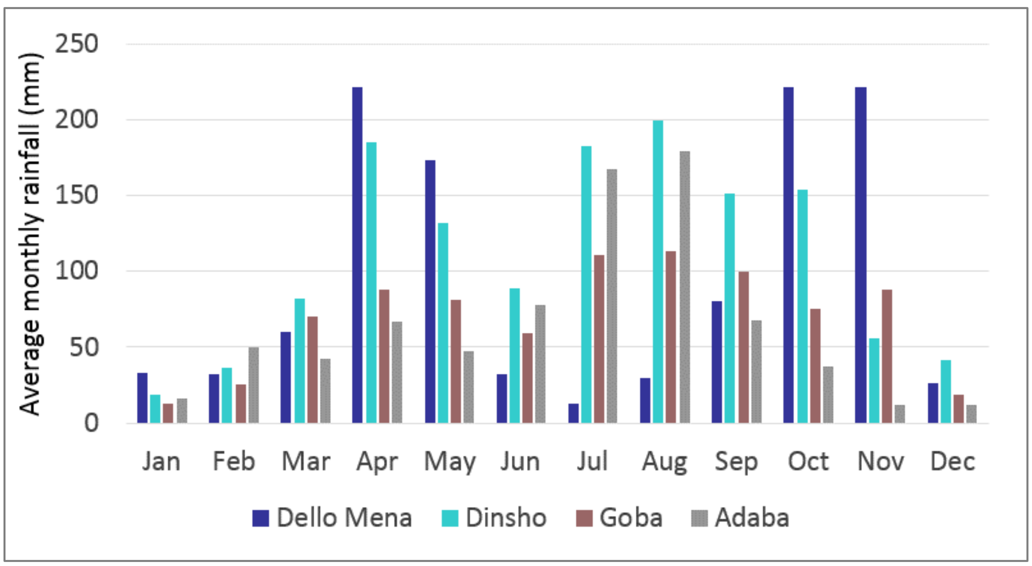


Figure 11. Monthly distribution of rainfall at available NMA stations in the BER. Source: NMA.

The rainfall pattern shows two rainy seasons at all stations, which can be explained by the annual movement of the Inter-Tropical Convergence Zone (ITCZ), which is influences rainfall in Southern Ethiopia. The rainfall pattern has *Belg* season during March to May: the main rainy season. The smaller rainy season runs from October to December (*Bega* season). The Northern high altitude part of the BER does however receive substantial rain in other months, most notably during July to September (Figure 11).

Due to the high inter-annual variability of rainfall in the BER it is difficult to see a correlation between rainfall and altitude. In addition, due to the limited availability of data points it is not possible to conclude anything with enough confidence (Figure 12).

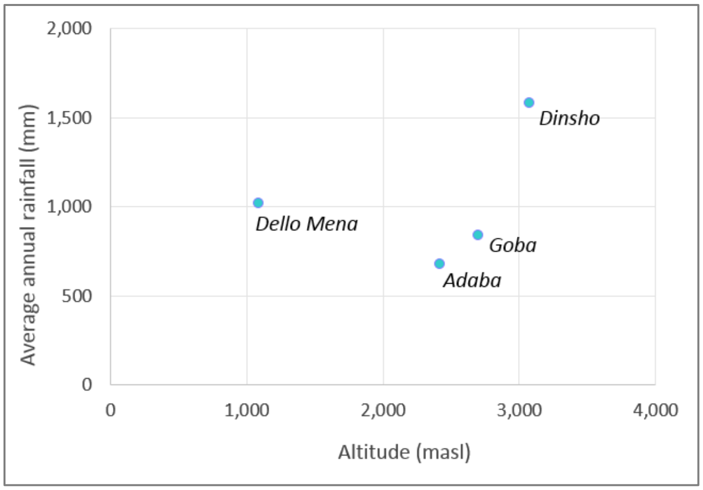


Figure 12. Average annual rainfall against altitude in the BER.

### *2.3.2 Temperature*

Available data on temperature show a number of gaps (Figure 13), making it difficult to see trends over time.

| year/station name | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dello mena | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Dinsho | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 12 | 0 | 6 | 0 | 0 | 0 | 0 | 4 | 0 | 8 | 12 | 3 |
| Goba | 2 | 11 | 6 | 0 | 12 | 12 | 12 | 12 | 12 | 12 | 11 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Adaba | 0 | 0 | 0 | 0 | 0 | 1 | 12 | 11 | 9 | 0 | 0 | 0 | 11 | 12 | 12 | 12 | 12 | 11 | 9 | 1 | 0 | 0 | 1 | 2 | 2 | 2 | 0 | 0 | 0 | 0 |

| year/station name | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dello mena | 0 | 0 | 0 | 8 | 11 | 12 | 5 | 6 | 8 | 0 | 0 | 12 | 12 | 0 | 9 | 12 | 12 | 11 | 2 | 11 | 12 | 12 | 5 | 12 | 11 | 12 | 11 | 12 | 10 | 12 | 10 | 5 | 6 |
| Dinsho | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 10 | 12 | 12 | 12 | 10 | 4 | 0 | 12 | 11 | 9 | 7 | 0 | 0 | 11 | 5 | 12 | 11 | 11 | 6 |
| Goba | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Adaba | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 12 | 8 | 0 | 0 | 7 | 12 | 12 | 10 | 12 | 12 | 12 | 11 | 12 | 12 | 12 | 11 | 8 | 10 | 6 | 6 | 11 | 11 | 12 | 11 | 10 | 5 |

legend: Number indicates number of months with available data
Complete year
Incomplete year

Figure 13. Chronogram of temperature data from NMA stations in Bale.

The air temperature of the BER varies with altitude (Figure 14). Dinsho is the highest and also the coldest station, with occasional daily minimum temperature measured below zero. Dello Mena is the warmest station with day-time temperatures exceeding 30 degrees Celsius in the first quarter of the year. There is typically not much variation in temperature through the year, with slightly more variation in the lowlands (Dello Mena).

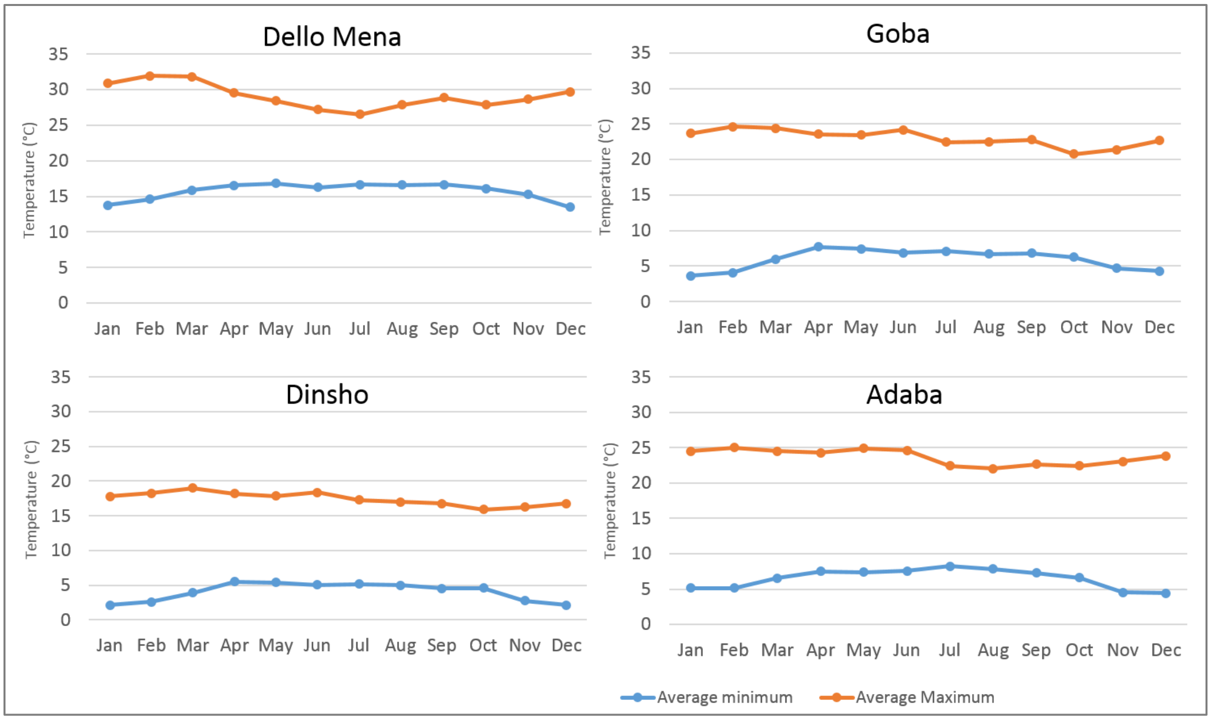


Figure 14. Monthly variation of temperature at available NMA stations in the BER.

Source: NMA

Average annual temperature observed against altitude seems to show an inverse linear correlation (Figure 15). Both average annual minimum and maximum temperature seems to increases with decreasing altitude in the BER.

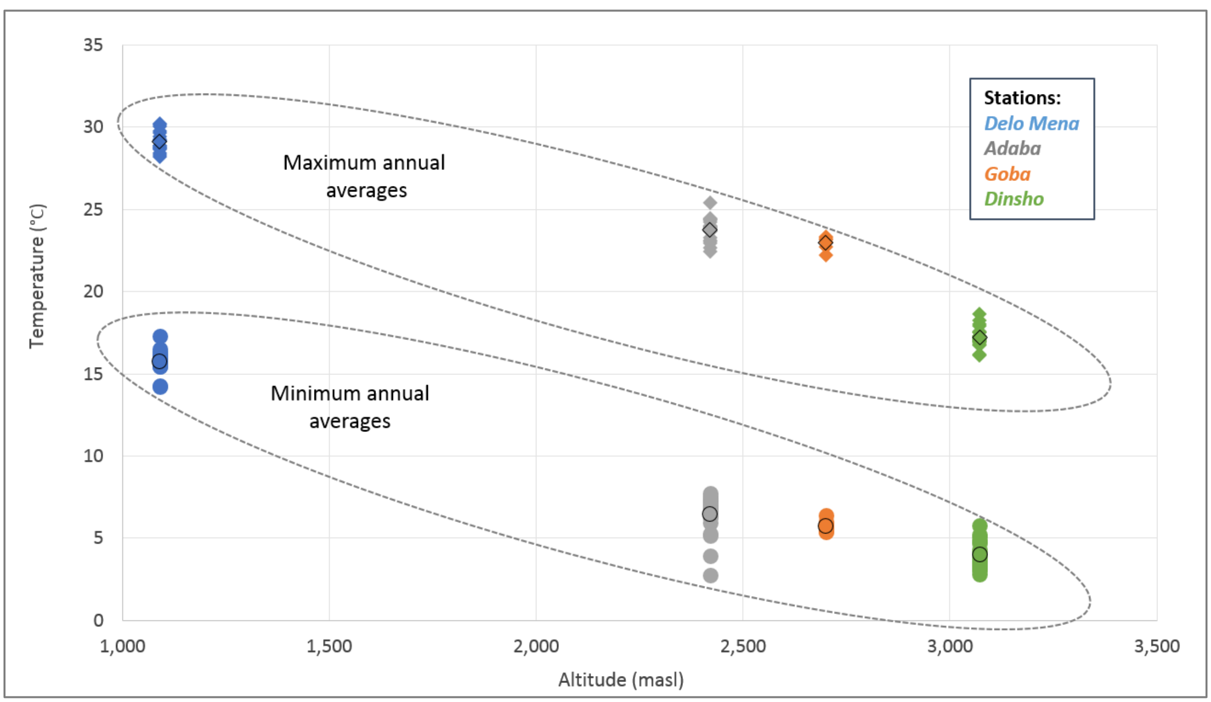

Figure 15. Variation of average annual temperature against altitude.

## 2.4 River network and watersheds

### *2.4.1 River runoff*

The BER has a high number of natural springs originating from the Bale Mountains. As discussed above they are the source of two large rivers. All rivers found in the BER are either tributaries of the Genale Dawa River[5] or the Wabe Shebelle River. The catchments of these are international basins and together comprise 30% of the surface area of Ethiopia. The Genale Dawa Basin covers Ethiopia, Kenya and Somalia while the Wabe Shebelle covers Ethiopia and Somalia only.

The Genale Dawa and Wabe Shebelle River Basins share a number of similarities in terms of catchment area (221,000 and 297,000 $km^2$ respectively), annual rainfall range (200-1,500 and 200–1,300mm) and population number (17 million and 13 million) (Mohammed 2013). Average run-off differs considerably; the Genale Dawa (6,600 $Mm^3$) carries roughly twice the volume of Wabe Shebelle per year (3,387$Mm^3$) (Table 4). This is explained by the runoff coefficient being more than double in the Genale Dawa (0.060) compared to the Wabe Shebelle Basin (0.027). However, run-off coefficients in both basins are very low relative to most basins in the world.

Table 4. Major characteristics of the Genale Dawa and Wabe Shebelle River Basins.

| Basin Characteristics | Genale Dawa | Wabe Shebelle |
|---|---|---|
| Catchment area ($km^2$) | 221,000 | 297,000 |
| in Ethiopia | 143,650 (65%) | 188,700 (64%) |
| in Somalia | 66,300 (30%) | 108,300 (36%) |
| in Kenya | 11,000 (5%) | - |
| Average Annual Runoff ($Mm^3$) | 6,600 | 3,387 |
| Average Annual Rainfall (mm) | 500 [200-1,500] | 425 [200 – 1,300] |
| Runoff coefficient (-) | 0.060 | 0.027 |
| Average Potential Evaporation (mm) | 1,300 – 2,300 | 1,300 – 2,300 |
| Population Number (M) | 17 | 13 |
| | | |

Source: Mohamed 2013

The Wabe Shebelle River Basin stretches over a large part of South East and South Central Ethiopia from where it enters Somalia and flows through Mogadishu to Kismayo. The Genale Dawa River Basin also covers a large part of South Central Ethiopia and South Central Somalia. This basin includes the sub-basin called Laag Dheera, covering mostly the Northern Eastern part of Kenya. The Laag Dheera River joins the confluence of the Wabe Shebelle just before the Somali town of Kismayo.

Data from GRDC stations is from months within the years 1951-1979, depending on the station, while MoWIE stations provide more recent data, from years 1978-2007, but only for the Ethiopian river sections. A summary of station and data analysed can be found in Table 5 and a map with their location on the river network in Figure 16.

[5] The Genale Dawa River is also known as the Juba River.

Table 5. Summary of flow data analysed.

| Station Name (Name used to reference within repot) | Catchment area (km²) | Larger River Basin | Years analysed | Total years analysed | Data source |
|---|---|---|---|---|---|
| **Wabe below bridge (Wabe)** | 1,035 | Wabe Shebelle | 1976-1994, 1996-2007 | 30 | MoWIE |
| **Genale – Chenemasa (Chenemasa)** | 10,574 | Genale Dawa | 1984-2007 | 24 | MoWIE |
| **Genale – Helewe (Helewe)** | 54,093 | Genale Dawa | 1984-1997, 1999-2007 | 23 | MoWIE |
| **Juba - Lugh Ganana (Juba)** | 179,520 | Genale Dawa | 1951-1967, 1970-1976 | 24 | GRDC |
| **Shebelle – Afgoi (Afgoi)** | 278,000 | Wabe Shebelle | 1954-1959, 1961-1972 | 18 | GRDC |
| **Shebelle - Belet Uen (Belet Uen)** | 211,800 | Wabe Shebelle | 1954-1959, 1961-1974 | 23 | GRDC |

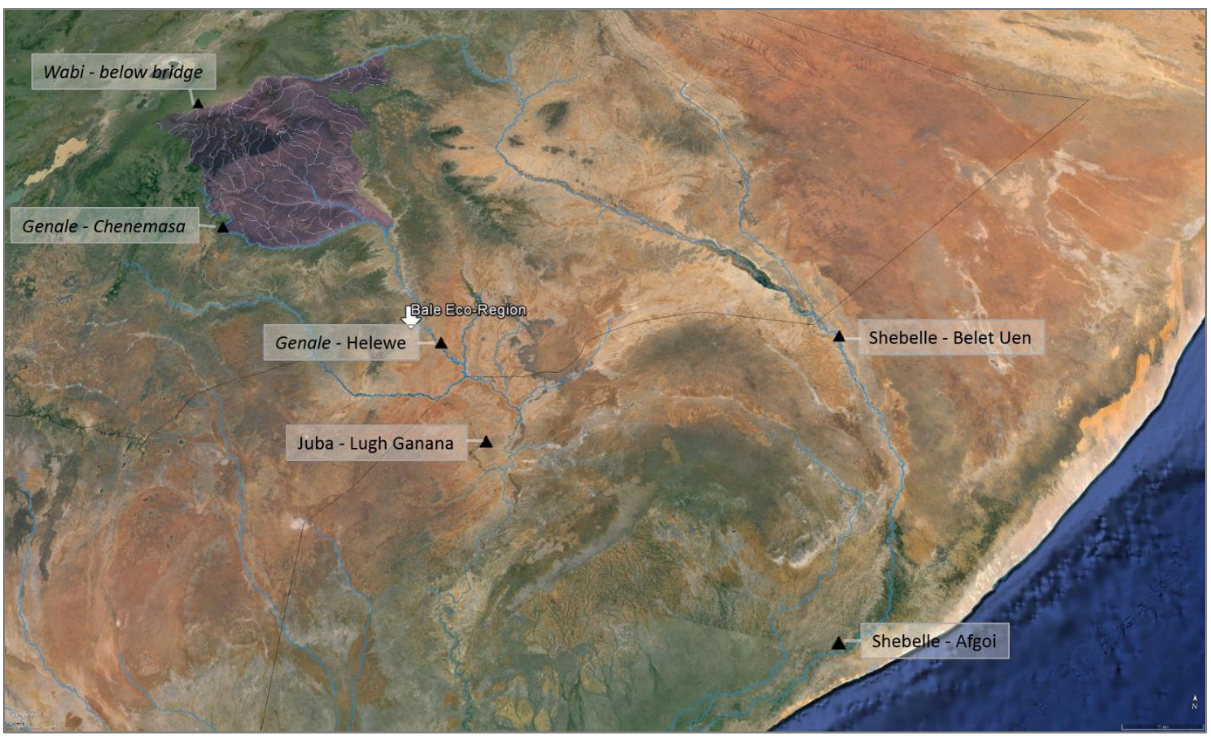


Figure 16. Location of the stations with streamflow records

Figure 17 shows the hydrograph for the Helewe station for the years of data used in analysis (1984 – 2007). The graph illustrates baseflow of the region and relative proportion of flow during cited disaster events (Table 6). Generally, rivers in the BER and downstream exhibit a "flashy" seasonal nature where peak flows quickly come and go during two rainy seasons each year. Flood events, shown in red, are either obvious peaks in the hydrograph (such as in late 1997-early 1998), or peak events following longer periods of low flow (such as in the May 2005 flood event). Other peaks in the hydrograph likely resulted in downstream floods, although specific evidence is not readily available.

Periods of recorded drought are also illustrated. The streamflow quantity during the 1985 recorded drought appears similar in magnitude to many other years, despite being a drought year. This may suggest that drought conditions were experienced in many other years that appear similar in magnitude to flows in 1985, or that the drought did not impact this specific catchment area. In the case of the recorded 1992 drought, no peak flow event occurred during either of the two rainy seasons. Finally, streamflow patterns during drought years 2002–2004 barely surpass the mean monthly flow (404 $m^3 s^{-1}$), peaking at only 520 $m^3 s^{-1}$. These repeated years of low-flow may also have contributed to the devastation experienced in the subsequent flood of May 2005 by leaving communities unaccustomed to and unprepared for high flows.

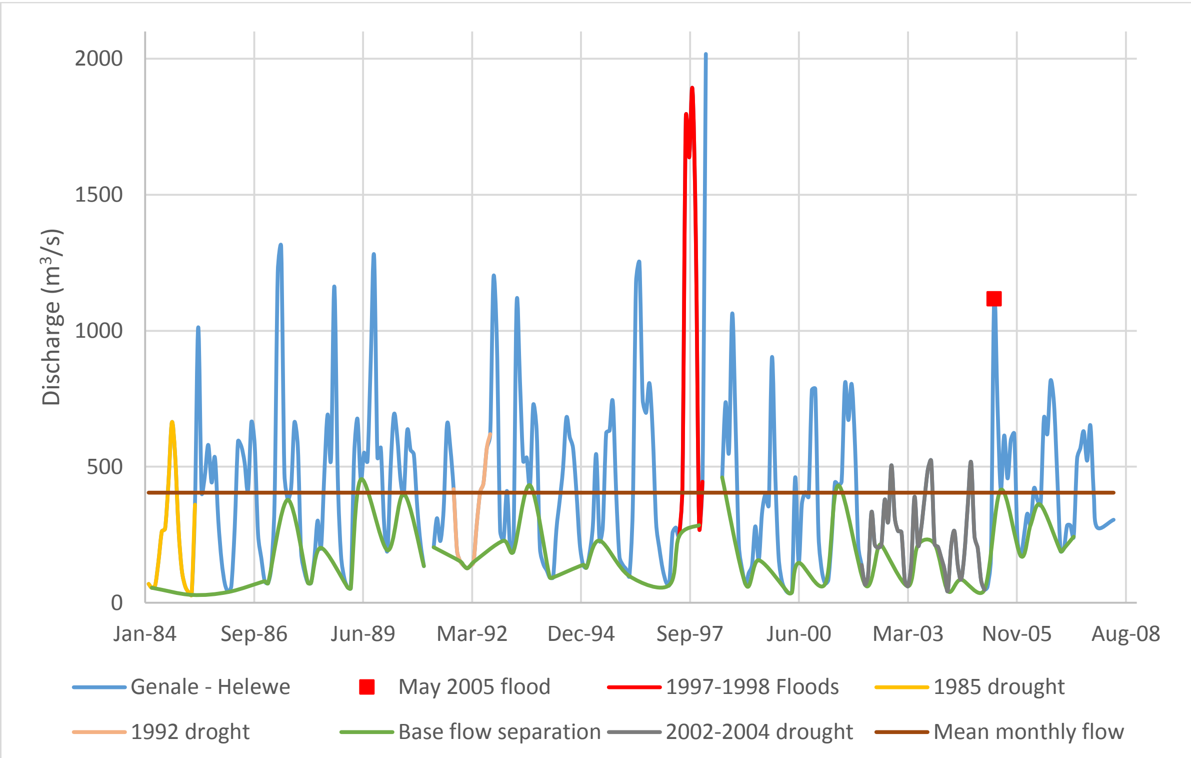


Figure 17. Genale - Helewe station hydrograph (1984-2008). Various disaster events, base flow separation and mean monthly flow highlighted to illustrate relative proportion of streamflow.

Source: MoWIE unpublished.

The peak flow shown in Figure 17 (2,017 $m^3 s^{-1}$) is not used in the flood frequency analysis because there are more than three months of data missing from that year. However, since it is clearly a peak flow event, it is worth mentioning in the analysis.

Figure 18 presents average runoff at the different stations with different catchment areas. The stations located in the upper parts of the basins (Wabi below bridge, Genale stations) show a much higher runoff compared to the ones located in the lower parts of the Genale and Shebelle Basins (Juba, Shebelle stations). This can be explained by large differences in rainfall, slope and soil types in the sub-catchments typically found in most river basins; which result in higher runoff coefficients in the upper parts of the basins.

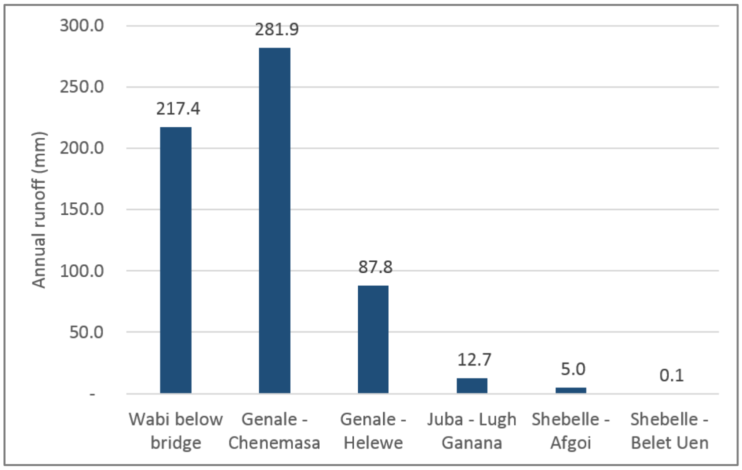


Figure 18. Mean annual runoff normalized for catchment size for all six stations. Source: MoWIE and GRDC.

Figure 19 shows observed annual flow at the three stations operated by the MoWIE. For those years with no data presented there was incomplete data; no data existed for at least several weeks or months.

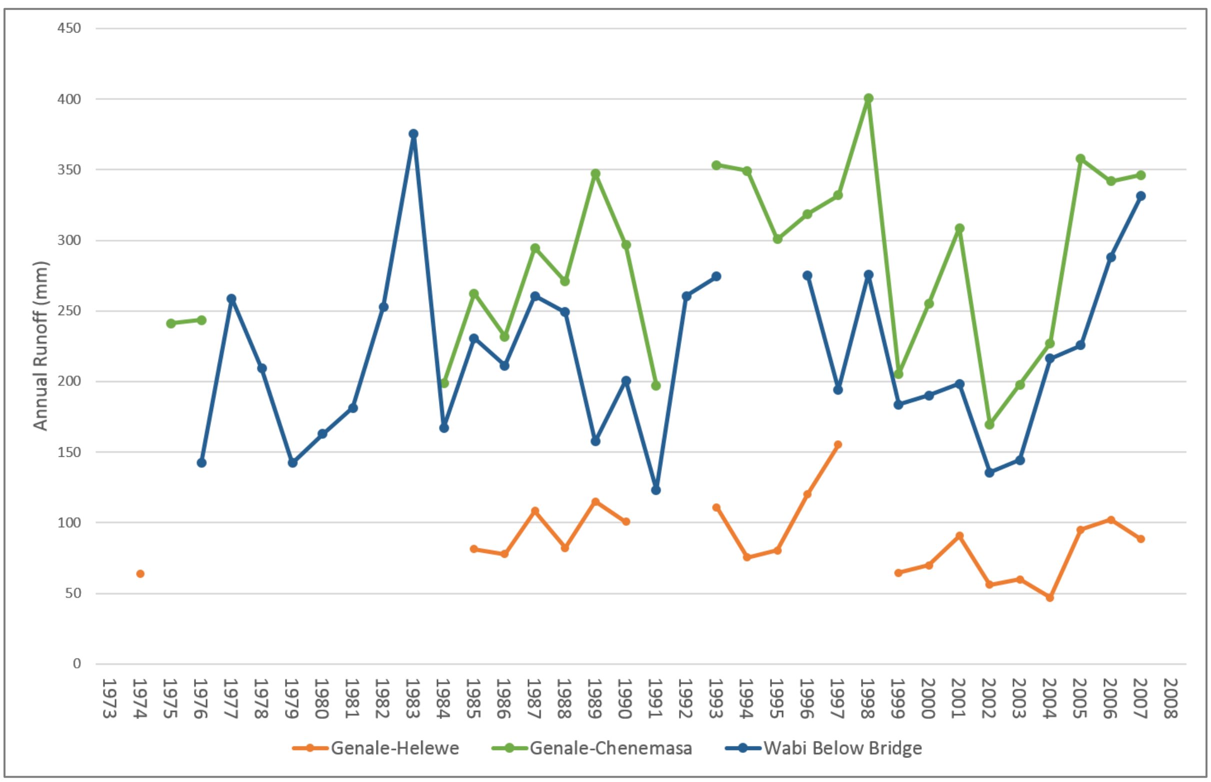


Figure 19. Observed annual flow at three stations. Source: MoWIE

The Genale Helewe River and Genale Chewe River display a largely similar variability between the years. Variability can be largely attributed to variation in rainfall; wet years such as in 1989 is visible in the streamflow records as well as in the rainfall graph. However, lack of complete rainfall records makes it difficult to show convincing evidence of this correlation.

The figure below (Figure 20) shows recorded monthly variation of average runoff at MoWIE stations. Two stations both in the Genale Basin with a largest catchments show two peaks in run-off, in the periods April-May and July-October, which is also reflected in the monthly rainfall graph (Figure 11).

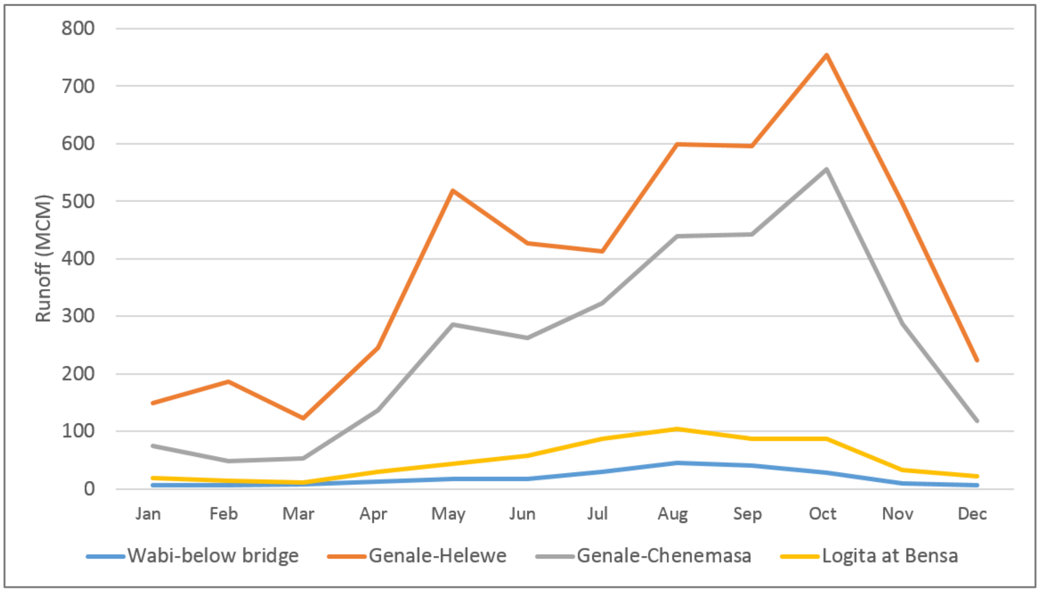


Figure 20. Average variation in monthly runoff. Source: MoWIE.

## 2.5 Wetlands and floodplains

The BER has large areas of floodplains and in the high altitude zone permanent wetlands. However, as far as known, these have not yet been properly assessed and mapped. A map produced by the United Nations only shows some floodplains along the Wabe-Shebelle and Genale-Dawa rivers, further downstream of the BER (Figure 21).


Figure 21. Map of lakes, rivers and wetlands in Africa with a zoom in on Ethiopia.

Source: United Nations http://www.zonu.com/fullsize-en/2009-11-07-10918/African-Wetlands.html

The Bale Mountains are discussed briefly in an extensive work published by Hughes and Hughes (1992). The section on Bale states that "*there are about a 100 lakes each a few hectares in area, and many bogs are set in the quaternary basalt of the Goba Plateau (also known as Sanetti Plateau) well above the tree line*". There is no mention of some large swampy waterlogged areas found in the region as well.

In a more recent reference (Abebe and Geheb 2003), the Bale Mountains are briefly mentioned, listing; numerous alpine lakes including Garba Guracha, and swamps and floodplains. The wetlands and floodplains of the BER are supposed to serve important functions in regulating, filtering of run-off and also as areas of infiltration for groundwater recharge. The extent of these functions and impacts of any changes in the sizes of these areas will be modelled as part of the hydrological assessments. Wetlands and floodplains are also use extensively for livestock grazing.

# 3 Natural resources management and use

## 3.1 Flooding

Changes in land cover and land use in mountainous areas are known to affect the risk of flooding. There is evidence that a reduction of forest cover amplifies flood events in developing countries (Bradshaw et al 2007) as more rainfall directly turns into run-off instead of being slowed down or buffered by forests. However, others have brought nuance to this conclusion by claiming that forest are not in all circumstances good for the 'water environment' (Calder 2002). Another study showed that population density alone can explain up to 83% of reported flood occurrences, which is considerably more than forest cover or deforestation (<10%) (Van Dijk et al 2009). Land use management also affects the hydrology of the catchment. Ideally, land use interventions should be tailored to the specific characteristics of the water catchment (Pattison and Lane 2012).

In the BER, flood events have occurred regularly in the form of flash floods in the lowland sections, as can be seen from the state of river beds and evidence of sheet erosion. More severe flood events have been reported particularly in the lower sections of the Wabe Shebelle basin (Table 6, Figure 22).

Table 6. Historical flood events: impacts determined from news media sources for BER and downstream Wabe Shebelle and Genale Dawa river basins.

| Date | Disaster event & casualties reported | Source |
|---|---|---|
| 1979, 1981, 1983, 1985, 1992, 2002-2004 | Droughts, food shortages | http://www.africa.upenn.edu/Hornet/arsi-bala1099.html<br>IFPRI / http://pdf.usaid.gov/pdf_docs/PNABI218.pdf<br>http://www.unicef.org/infobycountry/ethiopia_23994.html<br>http://www.theguardian.com/world/2003/apr/18/famine.ethiopia |
| Oct 1997-Feb 1998 | El Niño related flooding | http://www.africa.upenn.edu/eue_web/strp0298.htm<br>http://www.fao.org/docrep/004/w7832e/w7832e00.HTM |
| May 2003 | Flooding: 91,000 people affected, 64 reported deaths | http://apps.who.int/disasters/repo/9888.pdf |
| May 2005 | Flooding: 100,000 affected, 154 deaths | http://news.bbc.co.uk/2/hi/africa/4488971.stm<br>http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=14884 |
| Nov 2008 | Flooding: 11 deaths<br>At least 52,000 people abandoned their homes, 14 Kebeles and 85 villages in Kelafo, 164 hectares farmland washed away. | http://nazret.com/blog/index.php/2008/11/17/flooding_in_ethiopia_kills_11_maroons_hu<br>http://www.irinnews.org/report/81526/ethiopia-thousands-displaced-by-floods-in-somali-region |

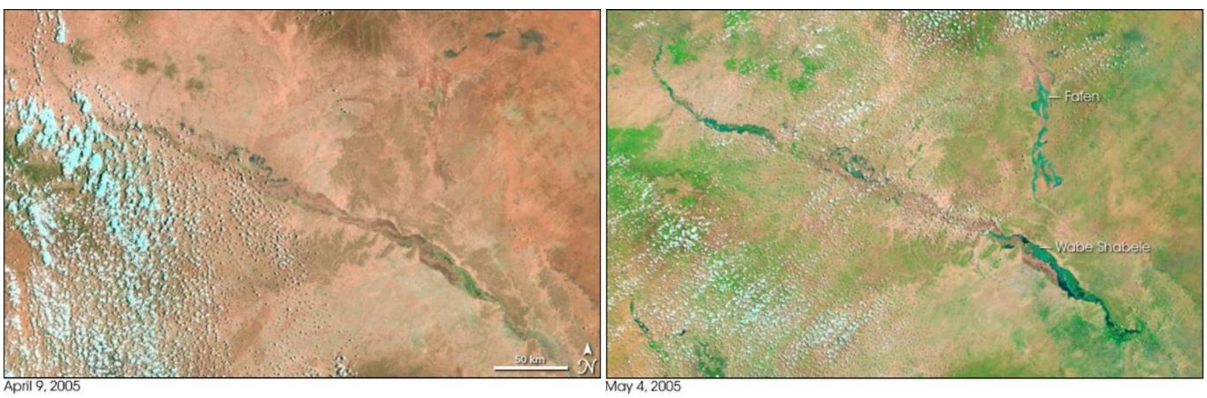


Figure 22. Two satellite pictures showing the Shebelle and Fafen Rivers in Ethiopia and Southern Somalia.

Left picture showing the area before the floods, taken on April 9, 2005. Right picture showing the area after heavy rainfalls which caused floods along the rivers on May 4, 2005. Source: NASA satellite images: http://visibleearth.nasa.gov/view_rec.php?id=19988

The FAO have published a report that analyses the hydrology of the Juba and Shebelle rivers for the purpose of irrigation and flood management (Basnyat and Gadain 2009). The study describes that: "*Upper parts of the catchments of the two rivers lying mostly in Ethiopia contribute most of the flows in the Juba and Shabelle Rivers in Somalia including floods generated by high intensity rainfall in the upper catchments".* This statement illustrates the hydrological links between the highlands of Ethiopia and the lowlands in Somalia. The report also states that more than 90% of total runoff in the Juba and Shebelle Rivers are generated in Ethiopia.

## 3.2 Flood frequency analysis

Flood frequency analysis uses historical river flow data to predict the likelihood of occurrence of flood events with different flood magnitudes, expressed as recurrence interval. Thus $Q_{25}$ is the flood flow that occurs on average every 25 years (i.e. with a return period of 25 years), though the actual intervals may vary considerably around the average. Analysis of flood frequency involves fitting a statistical distribution to the series of annual maximum flows, ranked by the magnitude of flow (Victorov, 1971).

In this study, flood frequency analysis was performed using a log-Pearson Type III distribution, which was considered most suitable for analysing flood occurrences in the Shebelle and Genale River Basins. Maximum daily flow values for each year were obtained from the MoWIE stations and maximum mean monthly flow values for each year were used from the GRDC stations. Because only mean flow values were available for GRDC stations, it is certain that the actual flood peaks were higher than the monthly values indicate. Flows for return periods, of 2, 5, 10, 25, 50, 100 and 200 years were calculated.

Flood frequency recurrence intervals can be helpful in preparing communities for the largest possible flood. For instance, through hydrological modelling it is possible to estimate the area flooding, discharge velocities, and other impacts on nearby communities with the largest flood event (the 200 year interval flood in this report). Infrastructure, such as roads and bridges, can also be designed to withstand higher magnitude floods, thereby decreasing the risk of failure.

Figure 23 and Figure 24 display flood frequency analysis results for both catchment area standardized discharge values ($m^3 s^{-1} km^{-2}$) and non-standardized discharge values ($m^3 s^{-1}$) respectively.

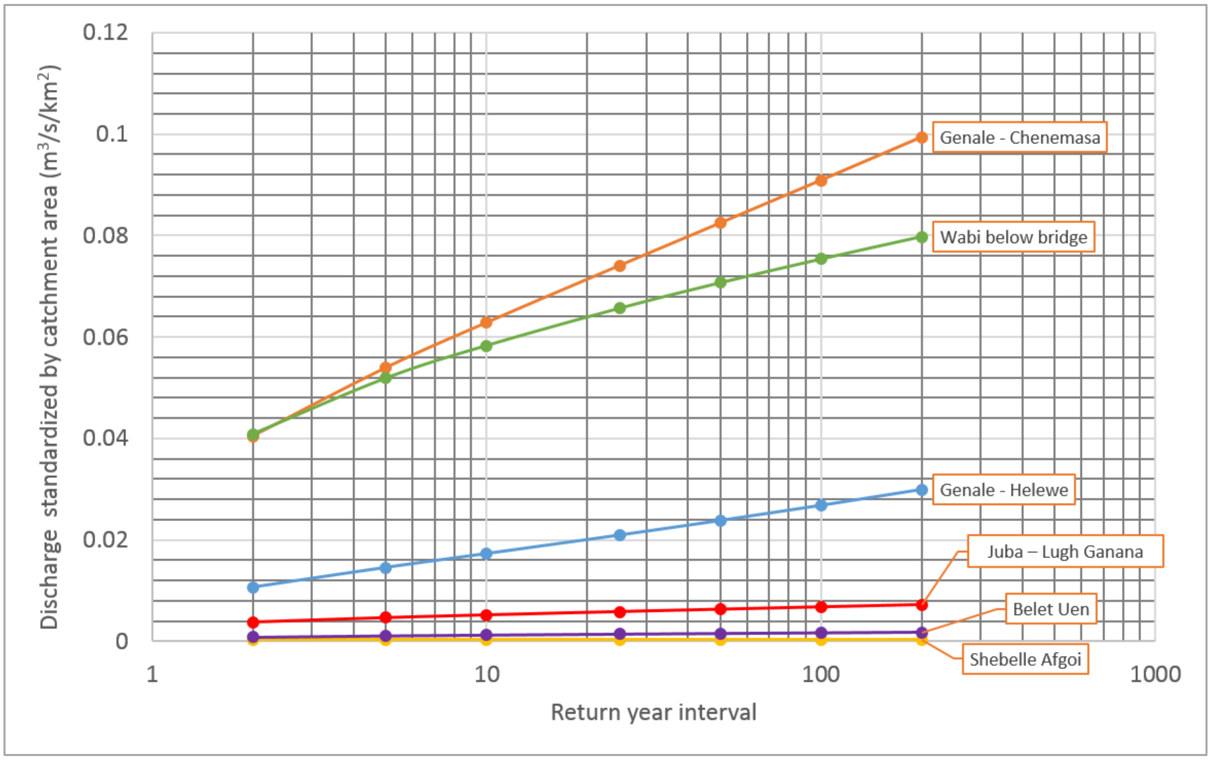


Figure 23. Flood frequency return year intervals for all stations using log-Pearson Type III analysis methods and maximum monthly streamflow values for each year analysed (listed in Table 6). Discharge values are standardized by catchment area.

It is worth restating two data source notes prior to interpretation of flood frequencies. First, GRDC stations will show trends from historical data (1951-1979) and MoWIE stations from more recent data (1978-2007). Second, GRDC station flood recurrence intervals and discharges will be a conservative estimate since data originated as mean monthly flow, thus smoothing out any peaks.

The return year interval predicts the probability of floods reaching a specific magnitude, or discharge value, once in a given time interval. In Figure 23, the Chenemasa shows the largest discharge value predictions for each recurrence interval. It can be said that the probability of the Genale River (at this station) reaching a flow of 0.1 $m^3s^{-1}km^{-2}$ is once in 200 years. Thus, a flood with this magnitude has a 0.5% chance of happening in any given year. Helewe, downstream of Chenemasa station, has the same probability (0.5%) for only a 0.03 $m^3s^{-1}km^{-2}$ flood event. Afgoi station has the lowest magnitude per unit catchment area for all return year intervals, likely due to other basin characteristics as suggested previously, as well as smoothing of peak flow values into a mean monthly flow.

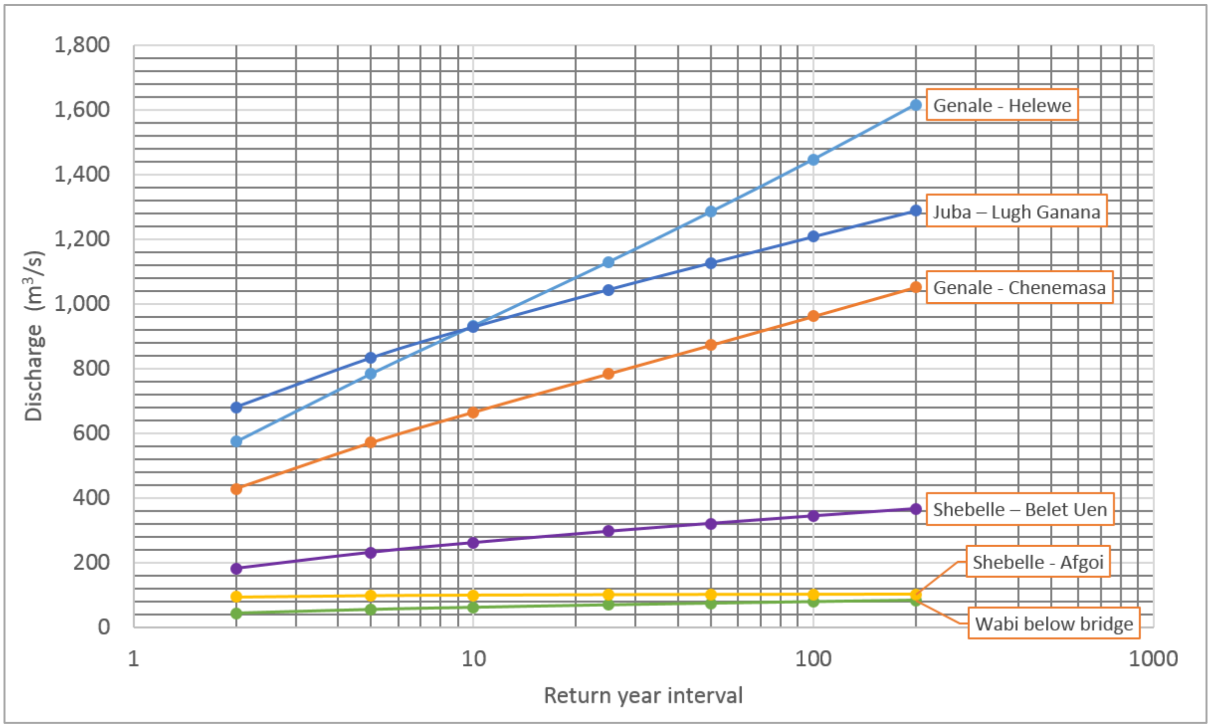


Figure 24. Flood frequency return year intervals for all station using log-Pearson Type III analysis and maximum monthly streamflow values for each year analysed (listed in Table 6).

Without standardizing flows by catchment area, it is more difficult to compare each station. However, additional insights may be gained about individual stations when considering station location. Figure 24 shows return year interval flood magnitudes of Helewe is the highest of all six stations. These two stations are the lowest within the Genale Dawa River basin analysed here. Comparing the discharge values with the lowest two stations within the Wabi Shebelle watershed, Afgoi and Belet Uen, it can be seen that the Genale Dawa can produce higher magnitude floods. Additionally, the percent difference between a 2 year recurrence-interval event and a 200 year recurrence-interval event at the Juba statin (31% difference) is much greater than the Afgoi station (3.5% difference). Thus, as recurrence interval increases on the Genale River, the flood magnitude increases more than the lower Shebelle River.

The 2005 floods, discussed previously, had a peak flow rate of 867 $m^3s^{-1}$ at the Helewe station, corresponding to a recurrence interval of between 5 and 10 years. Thus, it can be said that a flood with a magnitude of 867 $m^3s^{-1}$ has a 10% - 20% (approximately 15%) probability of occurring in any given year. The peak flow in the Helewe hydrograph (Figure 17) of 1,116 $m^3s^{-1}$, occurring during the 97'-98' El Niño flood events, has a recurrence interval of 25 years, and a probability of 4% of occurring in any given year.

### *3.2.1 Future work*

It is noted that drought and streamflow quantity are influenced by a number of catchment processes not described in this report. Linking streamflow analysis to land use, geologic characteristics, soil characteristics, rainfall and climate would enhance the understanding of flooding frequency and low-flow frequency in the BER. Grouping stations into homogenous regions based on the catchment characteristics will enable a regional frequency analysis, as performed by Clausen and Pearson (1995).

The water year analysed should not separate a single season into two years of data. In subsequent analysis, water years should be defined at the start of a season (Smakhtin 2001). For instance, in the BER a hydrological year could begin in June at the start of the *Kremt* rainy season. In this report, water years were defined by calendar year and could potentially have split two minimum values for streamflow which occurred in one season over two separate years.

To begin to define drought for the region, a low-flow frequency analysis of annual minimum flows would estimate the likelihood that streamflow will remain below a particular low-flow threshold for a particular duration (Zaidman et al 2002). Similar to the flood frequency analysis performed for this report, the low-flow frequency analysis would provide a 'recurrence interval' for low flow values. The Weibull, Gumbel, Pearson Type III, and log-normal distributions are commonly used for this type of analysis (Smakhtin 1995).

Finally, the effect of using non-consecutive years of data in flood frequency analysis should be better understood. In order to use more consecutive years of streamflow data, hydrograph infilling and editing techniques, such as those described by Gustard and Demuth (2009), could be used on water years with missing data.

## 3.3 Soil erosion

### *3.3.1 Causes and nature of soil erosion*

In some areas of the BER, especially highlands and lowlands, soils are eroding which has an impact on the hydrology of the region. The mid-altitude cluster is generally blessed with good vegetative cover which reduces the potential soil erodibility. Soil erosion in the highlands is caused by overgrazing (Figure 25 upper left) and cattle tracks (Figure 25 bottom left) and in the lowlands is caused by flash floods and resulting sheet erosion (Figure 25 upper right) and aggressive gully formation (Figure 25 bottom right).

Figure 25. Illustrations of different types of soil degradation in the BER.

Photo credit: Daniel Van Rooijen

Evidence on rates of soil erosion in the study area is relatively scarce, with most data generated in Northern Ethiopia and the Central Highlands (Haregeweyn et al 2015). Daba (2003) estimated an average gully erosion rate of 566 t $ha^{-1}$ $yr^{-1}$ based on aerial photos over a period of 31 years from the Northern part of the Wabe Shebelle Basin in the former province of Hararghe. Other studies report sheet and rill erosion from crop land at a rate of 7 (Herweg and Ludi 1999) and from mixed land at rates of 22 (Haregeweyn and Yohannes 2003) and 31 t $ha^{-1}$ $yr^{-1}$ (Muleta et al 2006).

However, FAO (1986) has reported higher rates of soil loss, in the range of 51–200 t $ha^{-1}$ $yr^{-1}$ (predominantly 51–100 t $ha^{-1}$ $yr^{-1}$) in parts of the Bale highlands. Such high rates of soil erosion are attributed to extractive agricultural practices, poor vegetation cover and tillage. The estimate of average annual soil loss for all types of land cover in the highlands of Ethiopia lies between 10 and 35 t $ha^{-1}$ and average values for croplands vary between 20 and 100 t $ha^{-1}$ (Bezuayehu et al 2002). These values of erosion rates are much higher than the rate of soil formation and conversion of parent material into soil. The rates of soil formation in Ethiopia, as estimated by Hurni (1983), vary between 2 and 22 t $ha^{-1}$ $yr^{-1}$.

An important factor contributing to soil loss is conversion of forest land to farmland combined with improper land use. A study carried out in Bale (Yimer et al 2007) showed a reduction of around 30% in soil organic carbon and total nitrogen content in the top 1 meter soil layer over a period of 15 years in areas that saw land conversion from native forest to cropland. Other likely causes of soil erosion are over-grazing, tree cutting, cattle tracks and possibly erosive farming practices on steep plots.

### *3.3.2 Consequences of soil erosion*

A consequence associated with soil erosion is the loss of nutrients in eroding soils. There is no quantified evidence of nutrient loss from the BER. However, the highlands of Bale show characteristics that are very similar to the Central and Northern Highlands of Ethiopia, where significant nutrient loss due to erosion is well documented (Adimassu et al. 2014, Erkossa et al 2015). The highlands are characterised by gradations of land degradation such as land conversion from forest to farm land, land clearing with fire, cattle overgrazing, and overexploitation of soils in crop-cultivation causing loss of top-soil structures, nutrients and reduced rainfall infiltration capacities. Erkossa et al (2015) reported yield reductions with losses of about 220 and 150 USD $ha^{-1}$ due to the loss of nitrogen and phosphorus, respectively.

Turbidity levels in rivers originating from the BER in are visibly high (murky colour), which is common in most Ethiopian rivers. A simple experiment was carried out to assess the amount of suspended and dissolved sediments in river water from the Shebelle River at Gode, Ethiopia (Figure 26). The experiment was carried out by UNICEF in June 2014 as part of a technical assessment of treatment of water for town water supply.

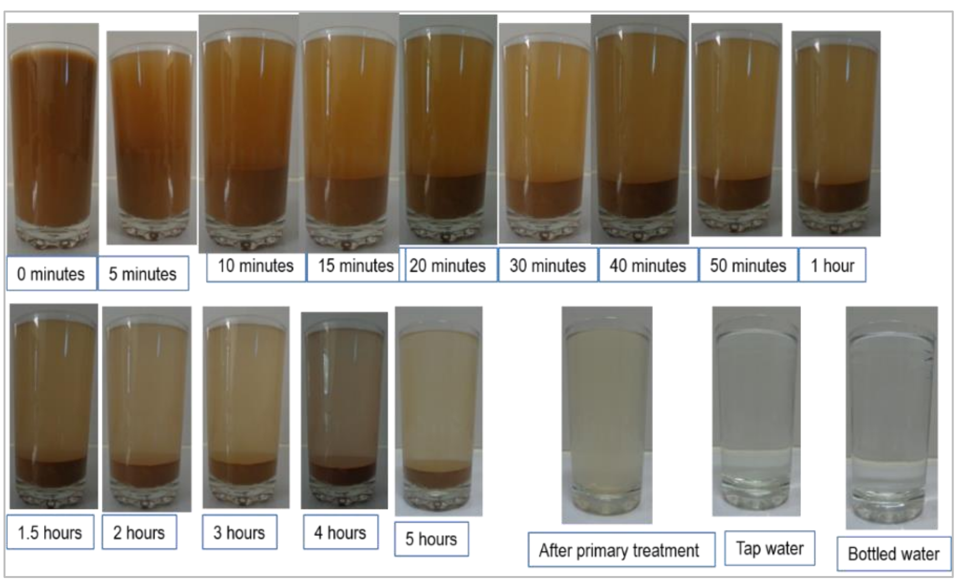

Figure 26. Change of visible turbidity of standing river water samples taken from the Shebelle River at Gode Town. Source UNICEF unpublished

Data on concentrations of suspended solids in rivers in the BER were obtained from MoWIE (2005) for selected sites in the Wabe Shebelle River. The rivers in the Wabe Shebelle Basin carry significant sediment loads in the two rainy seasons. In general the water in the first rainy season (April-May) is less turbid than the second rainy season (June-September), which may be related to changing vegetative cover. Rivers in the upper reaches during periods of high flow carry both suspended and bed load, as the turbulence and velocity of flow are high. In dry months, perennial rivers carry only a very small amount of suspended sediments (MoWIE 2005). Annual suspended sediment loads range between 0.11 and 15 million tonnes, depending on the size of the watershed area and associated run-off generated from the watershed (Table 7).

Table 7. Mean annual suspended load sediment transport at selected sites in the Wabe Shebelle Basin.

| River | Location | Watershed area ($km^2$) | Annual suspended sediment transported<br>Volume (S = 1.5) (million $m^3$) | Weight (million tonnes) | Volume per unit area ($m^3\ km^{-2}$) | Tonnes per unit area ($t\ km^{-2}$) |
|---|---|---|---|---|---|---|
| Wabe Shebelle at Malka Wakana | Long: 39,4, Lat: 7,2166, | 4,388 | 0.073 | 0.11 | 17 | 25 |
| Wabe Shebelle at Hamero Hedad | Long:42,28333, Lat: 7,36666 | 63,644 | 5.33 | 8.00 | 83 | 126 |
| Dakata at Hamero Hedad | n.a. | 15,188 | 3.33 | 5.00 | 220 | 329 |
| Wabe Shebelle at Gode | 5°57’N 43°27’E | 127,300 | 10 | 15.00 | 78 | 118 |
| Wabe Shebelle at Burkur | | 144,000 | 0.50 | 0.75 | 3 | 5 |
| Fafen at Kebri Dahar | 6°44’N 44°16’E | 25,600 | 1.66 | 2.50 | 65 | 98 |

Source: adapted from MoWIE 2005

By plotting annual sediment load against catchment area a very low sediment load at the Wabe Shebelle-Burkur site can be observed, as compared to most of the other sites (Figure 27). Before this site much of the sediment load is deposited onto large alluvial flood plains (MoWIE 2005). When omitting the Wabe Shebelle-Burkur data point, a linear correlation between sediment load and catchment area is apparent (Figure 28).

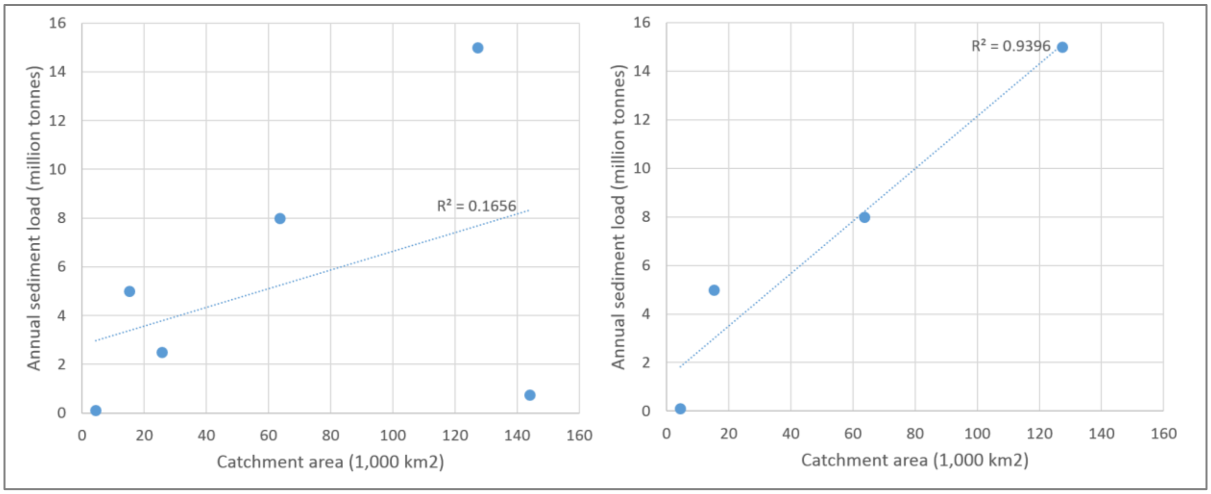


Figure 27. Annual sediment load against watershed area in watersheds in the Wabe Shebelle Basin with (left graph) and without data point of Wabe Shebelle-Burkur site (right graph).

Source: adapted from MoWIE 2005

Sediment mobilization from rain-fed agricultural fields has been noted as being one of the main contributors to land degradation, with average sediment concentration up to 45 kg $m^{-3}$ in Ethiopia's highlands where rainfed agriculture dominates the land use (Guzman et al 2013). As a consequence, siltation rates in open water bodies in Ethiopia are generally high compared to other countries. Local values for siltation rates in reservoirs in the water basins of BER have so far not been found. Values found in reservoirs in the Northern Tigray Region are in the order of 237-1,817 t $km^{-2}$ $y^{-1}$ with an average of 909 t $km^{-2}$ $y^{-1}$, and 70% of reservoirs under study reported to have significant problems associated with siltation (Haregeweyn et al 2006). These values are significantly higher than the values recorded for the Wabe Shebelle (Table 7). Problems associated to siltation in Ethiopian reservoirs are; loss of storage capacity resulting in shortages in water supply for irrigation and human consumption, higher dam operation costs and reductions in water quality (Wolancho 2012).

## 3.4 Groundwater

While groundwater is generally relatively well researched in Ethiopia (see for example Kebede 2013), no data are known about groundwater in the BER. Based on observations during field visits, groundwater tables are shallow in the highlands with the presence of wetlands and typical water-logged landscapes. In the mid-altitude, the groundwater table is also shallow with a large number of year-round springs typically present in that zone. In the lowlands, the groundwater table is likely to be lower, but typical groundwater levels are so far unknown. Groundwater seems to be underutilized across most of the BER but annual recharge rates need to be determined to ensure sustainable exploitation.

## 3.5 Forests

Forest degradation is severe in Ethiopia and recent figures (World Bank 2015) indicate that forest cover reduced 28% from 167,350 $km^2$ in 2007 to 120,144 $km^2$ in 2012. Oromia has about half of the country's remaining forest area, estimated at nearly 7 million hectares (i.e. 70,000 $km^2$) (FAO 2010). Ethiopia is marked as being in the late phase of forest transition (Pratihast et al 2014). Drivers of deforestation and forest degradation in Ethiopia are mainly the expansion of subsistence agriculture and grazing land. In the BER, average annual deforestation rate was estimated at 0.25%, based on remote sensing imagery (Farm Africa and SOS Sahel 2008). More recent data show a reduction in forest area (forest, woodlands, Erica forest) of about 2.3% between 2010 and 2014 (Table 8).

Table 8. Total forest area in BER during 2010, 2012 and 2014.

| Forest Type | 2010 | 2012 | 2014 | Change during 2010-2014 | |
|---|---|---|---|---|---|
| | ha | ha | ha | ha | % |
| Forest | 570,390 | 559,341 | 546,853 | 23,539 | 4.1 |
| Erica Plants | 21,304 | 20,925 | 19,086 | 2,218 | 10.4 |
| Shrub Lands | 745,112 | 713,070 | 699,086 | 46,026 | 6.2 |
| Woodlands | 1,252,501 | 1,215,785 | 1,235,407 | 17,094 | 1.4 |
| Total forest | 1,844,195 | 1,796,052 | 1,801,346 | 42,849 | 2.3 |

Source: Farm Africa unpublished

Forest fires are a recurring phenomenon in the BER, but have increased in severity during the last few decades. Over a period of 30 years the average area affected by fires has increased from 210 ha to 12,825 ha (Belayneh et al 2013). Most fire occurrences are said to be caused by cattle farmers, often to benefit grazing conditions. In early 2015, fires burned an estimated 30% of the forest area in the BMNP (Internal. Comm.).

## 3.6 Rangelands and livestock issues

Rangelands are abundant in the BER, and are important natural resource for the provision of fodder for livestock. Livestock are important assets of food security in Ethiopia, as milk and meat is provided from cattle, goats and camels, and meat, and also serve in social functions, as transportation and to supply draught power (Abate et al 2010). Rangelands constitute the largest land cover in the BER, with 44% labelled as "Wooded Shrub/Bush Grassland".

A comprehensive and relevant study was carried out by Flintan et al (2008), who assessed the challenges of livestock-based livelihoods in the BER and its interactions with wildlife and other natural resources. The main challenges reported are listed below in Table 9.

Table 9. Challenges of faced by livestock-based communities.

| Challenge | Description |
|---|---|
| Livestock disease | Disease prevalence is caused by animal stress arising from reduced in water and feed, cold temperatures and polluted water points. |
| Restriction of mobility and loss of grazing area | Restrictions of movement and grazing areas are caused by expansion of settlements and subsistence agriculture, as well as commercial agriculture, individual enclosures being put up and (re-)distribution of land to landless youth. |
| Lack of government support for livestock and pastoralism | A common complaint from respondents was that farmers and herders get little support from government extension services for livestock and livestock-related livelihoods. Instead the government "*almost solely promoted agriculture, there being no livestock 'experts' at the Woreda or Kebele level*". |
| Attacks by wild animals | Pastoral communities have reported an increase of hyenas and attacks by hyenas and other wild animals on cattle. |
| Conflicts between communities over grazing land | It is reported that due to reduction of available grazing area, the incidence and future risk of conflict has increased. |

| | |
|---|---|
| Presence of the Bale Mountains National park | The presence of the park is limiting grazing area and access, as perceived by some of the pastoralist communities, whereas others show no negative feelings towards the park. Cattle are not supposed to graze in the park, and rangers are actively chasing herders that have their cattle grazing within the park boundaries. However, the cattle population has increased fast in and around the park, since the establishment of the BMNP in 1970. |

Source: Flintan et al (2008)

# 4 Hydro-meteorological monitoring in the Bale Eco Region

IWMI in collaboration with the Water and Land Resource Centre have installed monitoring equipment in the three watersheds that represent the three distinct agro-ecological clusters in the Bale Eco-Region. At these monitoring stations is time series for water flow, sediment load in streams and weather parameters are being collected. The objective of these stations is to measure the impact of soil and water conservation interventions carried out by SHARE partners in the watersheds on the hydrology (peak and base flow) and water quality (sediment load) of the river. The interventions can be regarded as one of the drivers for positive change of the regions hydrology.

## 4.1 Description of the watersheds

### *4.1.1 Hora-Soba watershed*

This watershed is located in the highlands of the BER, near Dinsho Town. The watershed size is 1,071 ha and Altitude range 3,200-3,700 masl. The monitoring station is stationed at an altitude of 3,462 masl (see Figure 29). The catchment land cover dominated by cropland, grassland and Erica shrubland (Figure 30). The catchment has large areas with steep slopes (15-30% and 30-50%).

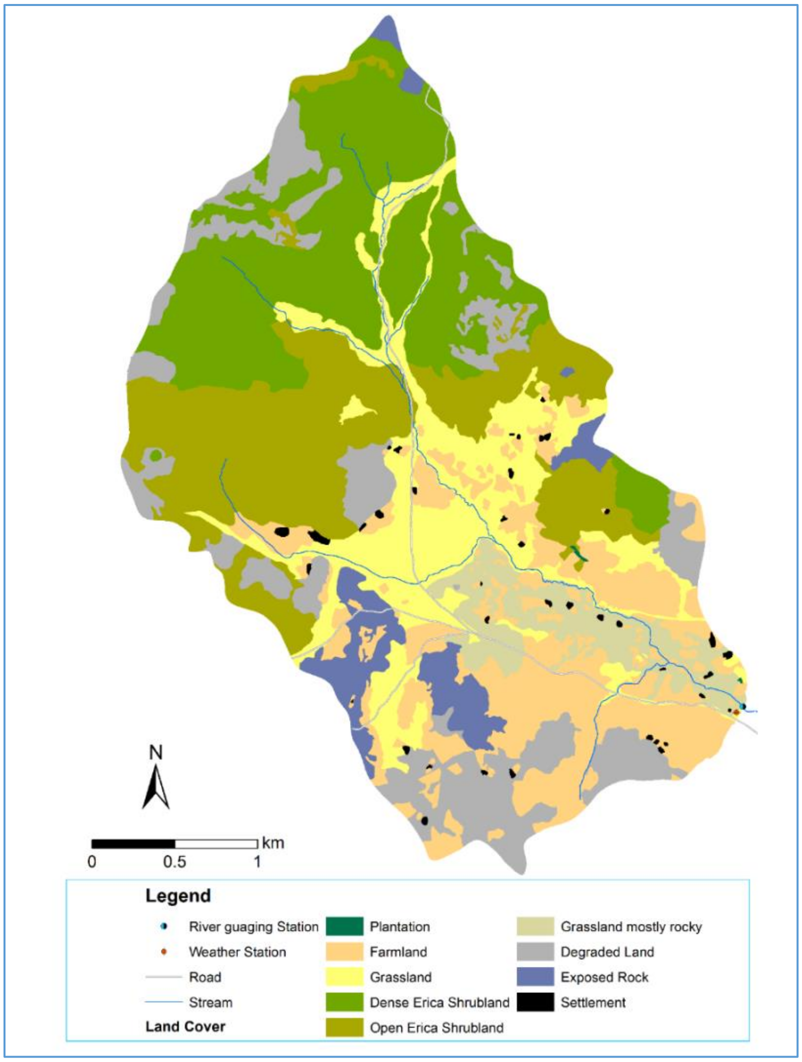


Figure 28. Land cover of Hora Soba Watershed

The following table shows the distribution of land cover categories for the Hora Soba Watershed.

Table 10. Distribution of land cover and land use of Hora Soba Watershed

| Land Cover | Area (ha) | Percentage (%) |
|---|---|---|
| Degraded Land | 142.0 | 13.6 |
| Dense Erica Shrubland | 240.6 | 23.0 |
| Exposed Rock | 48.6 | 4.6 |
| Grassland mostly rocky | 57.1 | 5.5 |
| Open Erica Shrubland | 214.6 | 20.5 |
| Plantation | 0.4 | 0.0 |
| Grassland | 159.1 | 15.2 |
| Farmland | 178.3 | 17.1 |
| Settlement | 4.6 | 0.4 |

| | | |
|---|---|---|
| Total(ha) | 1045.2 ha | 100 |

Figure 29. Weather station (left) and cross section (right) in Hora Soba Watershed. Photo credit: Daniel van Rooijen

### 4.1.2 *Hawo watershed*

Hawo watershed is located in the mid-altitude of the BER, at an altitude ranging between 1,642-2,169 masl. The watershed has a size of 289 ha. The monitoring station is located at 1,905 masl. Land cover is dominated by coffee/Enset plantation, cropland and forests (Figure 30). The watershed has a relatively high forest cover and is therefore generating a steady river flow (see Figure 31) from infiltrated rainwater.

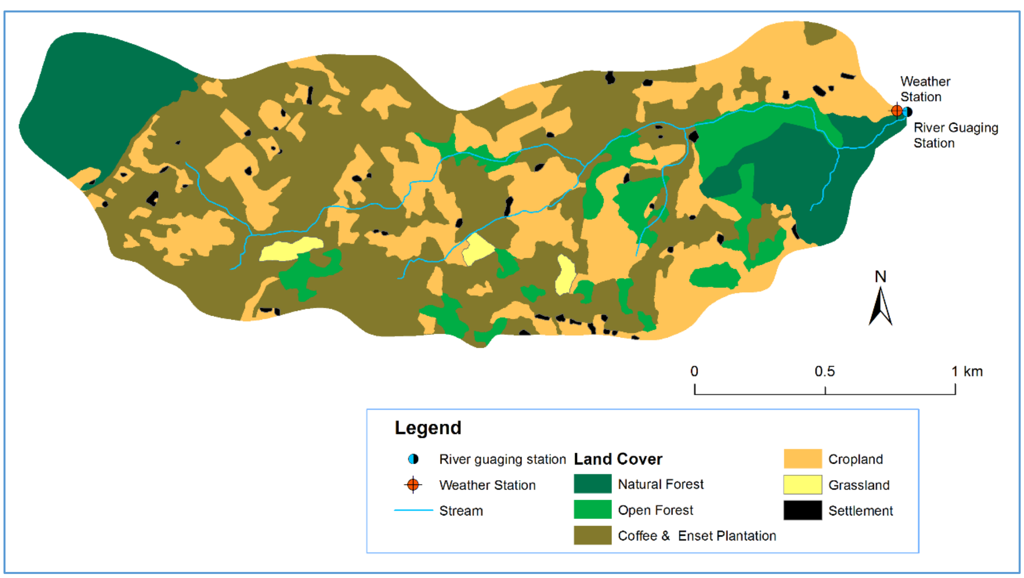


Figure 30. Land cover of the Hawo Watershed

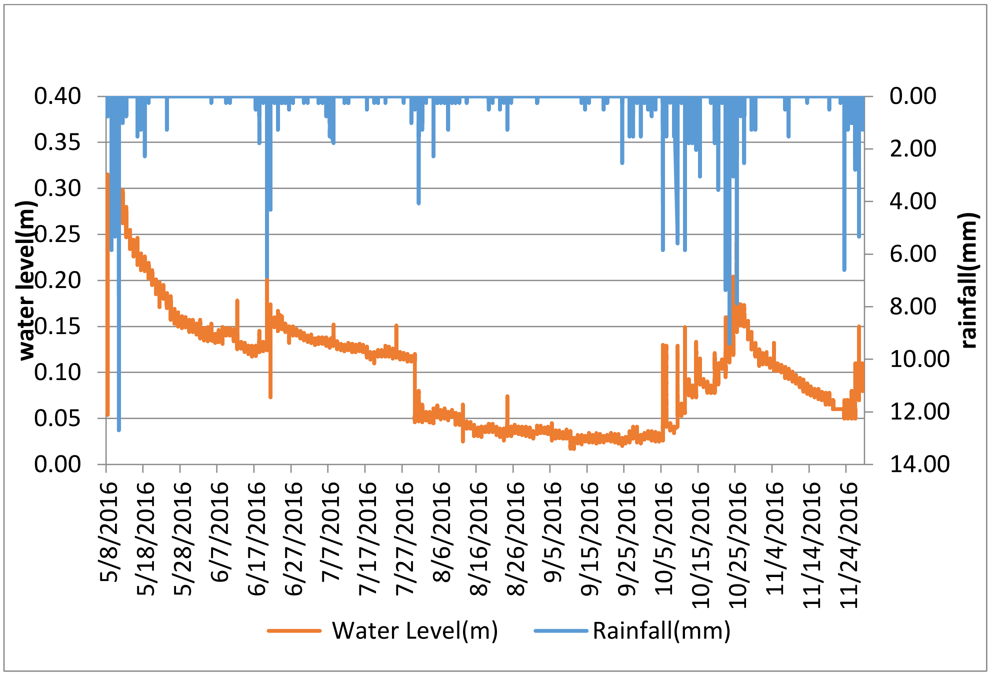


Figure 31. Recorded water level and rainfall during a selected period in the Hawo watershed

Figure 32. Weather station (left) and cross section (right) in Hawo Watershed. Photo credit: Daniel van Rooijen

Table 11. Distribution of land cover and land use of Hawo Watershed

| Land Cover | Area (ha) | Percentage (%) |
|---|---|---|

| | | |
|---|---|---|
| Coffee & Enset Plantation | 133.2 | 46.1 |
| Cropland | 81.7 | 28.3 |
| Grassland | 2.9 | 1.0 |
| Natural Forest | 41.4 | 14.3 |
| Open Forest | 26.9 | 9.3 |
| Settlement | 2.6 | 0.9 |
| Total | 288.7 | 100 |

### *4.1.3 Bekaye Watershed*

Bekaye watershed is located in the lowlands of the BER. The watershed has a size of 498 ha. and its land cover is dominated by cropland and grasslands. The observatory is located at an altitude of 1,327 masl

The catchment has flashfloods, which is typical for the lowland landscape in the BER (Figure 34).

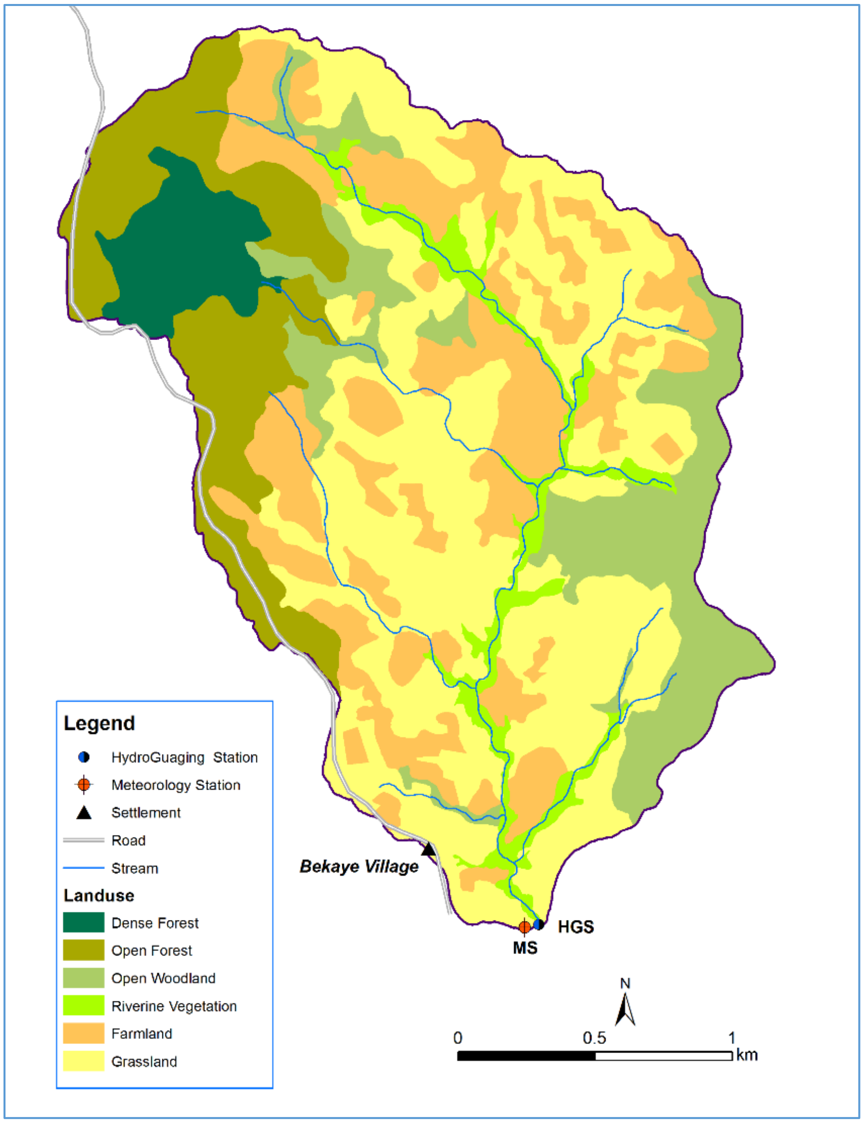


Figure 33. Bekaye Watershed Land cover map

Table 12. Land cover distribution in Bekaye watershed

| Land Cover | Area (ha) | Percentage (%) |
|---|---|---|
| Grassland | 184.7 | 37.1 |
| Farmland | 117.1 | 23.5 |
| Riverine Vegetation | 27.6 | 5.5 |
| Open Woodland | 71.9 | 14.4 |
| Open Forest | 71.7 | 14.4 |
| Dense Forest | 25.2 | 5.1 |
| Total | 498.1 | 100 |

The below figure shows that there is no base flow in the stream; river discharge only occurring during rainfall events.

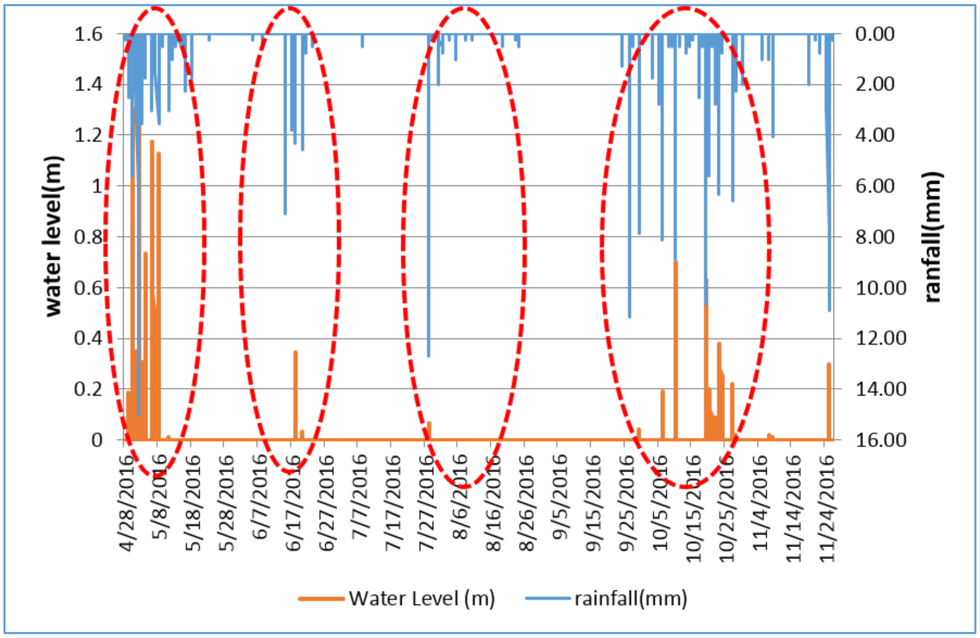


Figure 34. Recorded water level and rainfall in a selected period in Bekaye Watershed.

Figure 35. Weather station (left) and cross section (right) in Bekaye Watershed Photo credit: Daniel van Rooijen

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