Vol. 19(4), pp. 455-465, April, 2023
DOI: 10.5897/AJAR2021.15613
Article Number: 81F04F770637
ISSN: 1991-637X
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African Journal of Agricultural Research

Full Length Research Paper

Zoning and agro-climatic characterization of hotspots in the Tana-Beles Sub-Basin – Ethiopia

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Received 26 April, 2021; Accepted 16 July, 2021

Agro-climatic zonation is very important for planning crop patterns and to bring out the agricultural potential of a region. It must be done based on a specific development objective and on a rational basis. The objective of the present study was to classify the Tana Beles sub-basins (TBSB) into homogenous agro-climatic patterns and assessing suitability for crops that could be growing in each Agro-climatic zone. The climate data for mean annual rainfall and temperatures for the period from 1970 to 2015 was downloaded from WorldClim2, and the DEM used to retrieve the altitude data has been obtained from Shuttle Radar Topography Mission (SRTM). The methodology proposed by FAO with some local considerations was attempted to classify the Agro climate classes of the Tana Beles Sub basins. A decision tree classifier (DTC) of ENVI tools was used to classify the Agro-climatic parameters. During the process of zonation, we classified the TBSB into 6 thermal regimes and 3 rainfall distribution regimes that were overlaid over 6 altitudinal classes. Finally, the TBSB was classified into 9 agro climate zones (ACZs) as Moist Dega, Moist Kolla, Moist Wiena Dega, Moist Wurch, Wet Alpine Wurch, Wet Kolla, Wet Weina Dega, Wet Wurch, and Wet Dega. More than 80% of the ACZs in the TBSBS were identified as suitable for the main crops.

Key words: Agro climate zones (ACZ), crops, WorldClim2, decision tree classifier (DTC), Tana Beles sub-basins (TBSB).

INTRODUCTION

Climate is among the most important factors that determine the agricultural potentials of a region and the suitability for a specific crop. The agriculture sector is highly dependent on environmental conditions; a quantitative understanding of the climate of a region is essential for developing improved farming systems, crop improvement research programs, and establishing principles for improved resource management (Reddy, 1983). A practical approach to this can be by classifying a region into agro-climatic zones based on homogeneity in weather variables that have the greatest influence on crop growth and yield. In line with this, Troll (1965) outlines that climate is represented by thermal and moisture regimes that form small geographic areas, resulting in a variable mosaic of specialized areas, capable of supporting varied land-use systems. The approach is used to categorize agro-climatically uniform geographical areas for agricultural developmental

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planning and other interventions.

Previous studies by Cocheme and Franquin (1967), Hargreves (1975), FAO (1983), Batjes (1994), and Bisht et al. (2013) have tried to group an area into different distinct agro-climatic groups using different techniques at different spatiotemporal resolutions of climate variables. To describe some of these, Batjes (1994), delineated four moisture availability zones in Jamaica by using monthly rainfall and potential evapotranspiration data collected from 141 meteorological stations by using GIS. Anand et al. (2009) classified the agro climate of Maharashtra state in India into six Agro Climate Zones (ACZs) using weekly rainfall and potential evapotranspiration data of 47 stations using raster modelling environment in GIS. A relatively recent study by Bisht et al. (2013), divided the entire state of Uttarakhand (India) into twelve Agro-climatic zones using remote sensing and GIS techniques; their study was based on annual rainfall and temperature data collected from 32 meteorological stations.

In Ethiopia, due to the importance of altitude in mountain systems; or due to the strong influence on temperature and rainfall, land users have traditionally classified their environment in relation to topography. In 1768-1773, a traveller called James Bruce used the term 'Kolla' for the 'hottest part of Abyssinia' and 'Dega' to signify 'the hill, or high ground' (Bruce, 1790). Later on, the Abyssinians divided their country into Kolla (the lowlands), Deka Woina (1,500-3,000 m a.s.l.), and Deka (above 3,000 m a.s.l.) as quoted by Rohlfs (1883). Dove (1890) described major agricultural zones in northern Ethiopia more precisely based on altitudes as, Kolla (< 1800 m a.s.l.), Weyna Dega (1800 – 2400 m a.s.l), and Dega (> 2400 m). Huffnagel (1961) confirmed this traditional zonation and added a further zone at high altitudes, called ‘Wurch’, for areas higher than 3800 m a.s.l. During the late 20th century, the Ethiopian traditional system uses mean daily temperature in addition to altitude to divide the country into five climate zones (Gemechu, 1977). Though the most useful zonation for agricultural purposes is the ACZs which use the water balance concept, the length of the growing season (including onset dates) at certain probability levels (NMSA, 1996); a relatively robust classification can also be made using the rainfall distribution through the year; giving the distinction between the mono-modal and the bi-modal and a diffuse rainfall region (Haile and Yarotskaya, 1987). Furthermore, the Ministry of Agriculture (MOA) and the Ethiopian Institute of Agricultural Research (EIAR) have elaborated the Traditional ACZs into 33 finer classes (Gorfu and Ahmed, 2012). Since the impact of climate change can be significantly variable in different regions, even on smaller scales, it is important to conduct such a study at critical agro-ecological regions for agricultural developmental planning and implement adaptation and mitigation strategies.

The main aim of the present study is to categorize the TBSB into agro-climatically uniform geographical areas using altitude, precipitation, and temperature. These sub-basins are regarded as one of Ethiopia's growth corridors, with large-scale development projects such as the Tana-Beles hydropower plant (Operational), the Grand Ethiopian Renaissance Dam (GERD), and the Tana-Beles sugar factory under construction to support the country's Growth and Development Plan (GTP). This study can aid in the technological transformation from one location to other regions, particularly knowing the advantages and limitations of different zones. Moreover, the delineation of homogeneous agro-climatic zones can help to interpret the present cropping pattern, as well as suggest new cropping patterns (units) appropriate for agricultural practices.

Climate and agriculture in the TBSB

Like many other parts of Ethiopia, the climate of the TBSB is highly correlated with the seasonal propagation of the Intertropical Convergence Zone (ITCZ) (Kassahun, 1987; Asnani, 2005; Muthusi et al., 2005). As averaged over 1979-2015, the mean annual rainfall and temperature for the TBSB are 1412.16 mm and 19.34°C respectively. However, owing to the complex topography, the regional rainfall, and temperature distribution is not uniform in place and time. The evaporation rate of the TBSB is low in spring due to soil water constraints and high in summer when the rainy season starts. The evaporation rate increases, reaching its peak in October just after the rainy season when soils are all still wet; and solar radiation is stronger than in August and September due to reduced cloud cover (World Bank, 2001). Lake Tana and Beles sub-basins have been identified as the first of the five proposed growth zones in the country. This can be associated with the water availability at the sub-basins that can be used for different agricultural and hydrological projects. Lake Tana, the largest lake in Ethiopia and the third_largest in the Nile basin, is located in these sub-basins, mentioning the region as water storage of Ethiopia. The majority of the rainfall pours down from May to September, with the largest amount falling in July (World Bank, 2001).

Generally, the topography of the Blue Nile is composed of highlands, hills, valleys, and occasional rock peaks (Tesemma et al., 2010). This complex topography makes for strong local contrasts in precipitation and temperature, and soils are deeply weathered and erodible over most of the highland areas. Previous studies also show that rain around and/or in the current study region is characteristically intense and erosive (Nyssen, 2005; Worku, 2015). Soils in most of the Tana basin are derived from the weathered basalt profiles and are highly variable. In low-lying areas, particularly north and east of Lake Tana (the biggest freshwater natural reservoir in Ethiopia), and along with parts of the Gilgel Abbay, soils have been developed on alluvial sediments. In the Beles catchment, soils have largely been derived from basalts and the basement rocks (MoWR, 1999). The climate is generally characterized as tropical in the lowlands and temperate at higher elevations. Owing to the sloppy mountains and intensive rain particularly during the rainy season, it can be noted that erosive rains may affect the region. The climate characteristics associated with the soil properties have their effect on the agricultural sector in the area.

The agricultural practices of the TBSB are diverse; however, they can be classified generally as crop production and livestock raising. Though a large number of crops are grown in Ethiopia, that includes cereals; pulses; oilseeds, vegetables, root, and tubers; fruits; fibers; stimulants, and sugarcane (EIAR, 2007, 2011); grains are the most important field crops occupying about 86% percent of the area planted (USAID, 2009). Most of the rural inhabitants in the area are also farmers employed in rain-fed substance agriculture, cultivating crops such as cereals (rice, teff, millet, maize, wheat, and barley), pulses, oilseed, and vegetables. However, crop production in the TBSB is under threat from climate-related and other environmental effects. These include the effects of increased temperatures, changes in soil water balance, changes in the length of growing period (LGP), increased soil erosion and land degradation due to increased rainfall intensities, increased incidence of floods in flood-prone areas, and increased incidence and expansion of crop pests, diseases, and weeds mainly associated with increasing temperatures (Bewket et al., 2015). Traditional tillage practices, particularly on steep slopes, combined with overgrazing and deforestation are also contributing to soil erosion and soil fertility reduction, leading to a gradual decline of production in the area. These pressures combined with the fast-growing population, hence, improper utilization of the natural resource base (land, water, and biodiversity) show that agriculture in the TBSB is under threat from multi-directional sources.

Climate change may be one of the major sources of contributing challenge to humans and their livelihoods due to the fact that the livelihoods of farming communities face severe constraints related to intensive cultivation, overgrazing and deforestation, soil erosion and soil fertility decline, water scarcity, livestock feed, and fuelwood demand (Simane, et al., 2013). Climate change will also have a profound impact on the availability and variability of freshwater as the frequency of climatic extremes such as heatwaves, drought, and change in rainfall patterns increases in response to global warming (IPCC, 2012). This uncertainty of the availability of water resources will affect agricultural production, challenge socio-economic systems, and threaten environmental sustainability.

Furthermore, because of the region's high water reservoir, the communities in the TBSB are engaged in a variety of agricultural activities, with cereal crop production dominating. However, low productivity remains the major constraint of cereal cultivation, where yields are less than 1 ton per hectare (Pender and Gebremedhin, 2006). Moreover, even where agricultural production is increased, this success may be short-lived if attention is not quickly diverted to side effects that threaten other equally important development goals (Conway, 1985). Hence, the boundary conditions for sustainability in the TBSB are closely linked to the climate as the productivity of agriculture is sensitive to the timing as well as the amount of rainfall and temperature.

MATERIALS AND METHODS

Study area

The Tana and Beles sub-basins are sub-basins of the Abbay (Blue Nile) river in the northern highlands of Ethiopia, covering a total area of 28,655 km^2 (Figure 1). Geographically, the Lake Tana sub-basin extends from 10.95° - 12.78° N latitude and from 36.89° - 38.25° E longitude in the Northeastern part of the upper Blue Nile basin, while the Beles sub-basin is located between 10.20° - 12.00° N and 35.00° - 37.00° E in the western part of the upper Blue Nile basin. The mean elevation of the Tana basin is 2025 meters above sea level (m.a.s.l), with the highest elevations at some 4,100 m.a.s.l in the north-eastern part of the basin, and the mean elevation of Beles basin is 1190 m.a.s.l, with the highest point is 2,725 m.a.s.l at the water divide between the Tana and Beles basins (SMEC, 2007).

The soils in most of the Lake Tana basin are derived from the weathered basalt profiles and are highly variable. In low-lying areas particularly north and east of Lake Tana, and along with parts of the Gilgel Abbay, soils have been developed on alluvial sediments. In the Beles catchment soils have largely been derived from basalts and the basement rock according to the Ministry of Water Resources (MoWR). The total population in 2020 in the Tana and Beles basins is estimated to be about 4.2 million (CSA, 2007). Most rural inhabitants of the study area are farmers employed in rain-fed subsistence agriculture. Crop production and livestock raising are closely integrated into the agricultural system. The main crops cultivated in the area are cereals (rice, teff, millet, maize, wheat, and barley), pulses, oilseed, and vegetables.

Data sources and data quality

The study uses primarily three types of agro-climatic data sets namely: Altitude (m), mean annual rainfall (mm), and mean annual temperature (°C). The observed climate data (monthly rainfall and monthly temperature) used to analyze the climate characteristics of the study area was collected from the National Meteorology Agency (NMA) of Ethiopia for the 1980-2015 periods. Additionally, climatological averages of the same climate parameters but collected at an annual time scale which is used for agro-climatic classifications were downloaded from http://worldclim.org website (WorldClim 2.0). WorldClim 2.0 is a high-resolution (1km) interpolated gridded climate data for global land areas, except Antarctica (Fick and Hijmans 2017). This data set is gridded from more than 60,000 weather stations across the world and multiple satellite-derived data, which is useful for various modeling frameworks; such as agricultural and ecological applications, including estimation of yield potential and the gap in a cropping system; estimation of growing degree days and temperature seasonality; spatial targeting of intensification and implementing adaptation and interventions options based on current climate variability (Hijmans et al., 2005; Fick and Hijmans, 2017). This

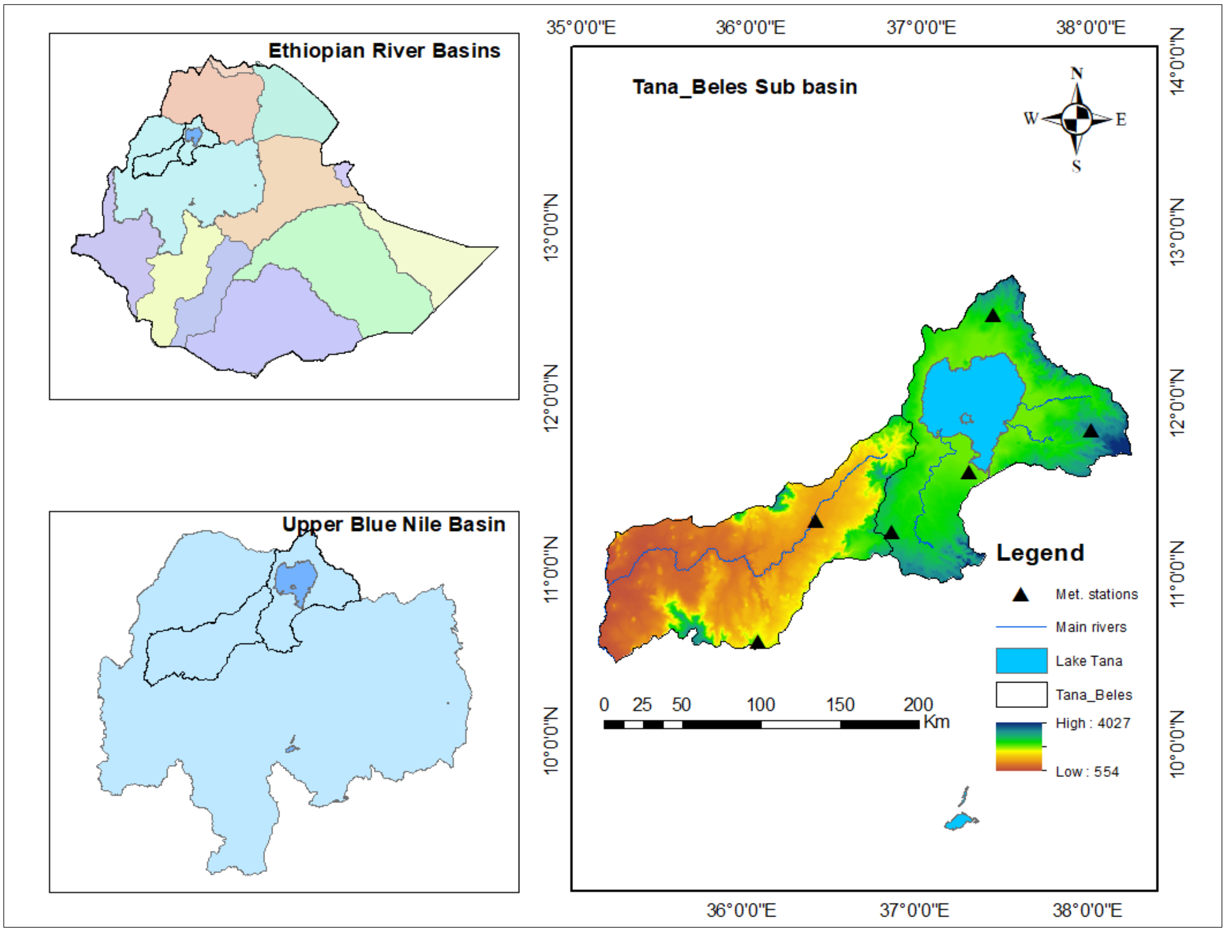

Figure 1. Location and Topography of the study area; Ethiopia (top left), the Upper Blue Nile Basin (bottom left) and Topography, Meteorological stations, and Lakes in the TBSB (Right).
Source: Author

Table 1. Geographic characteristics, Climatology, and data record periods of the selected stations

Station Name	Sub-basin	Longitude (°)	Latitude (°)	Elevation a.s.l (m)	Rf (mm)	T (°C)	Data record
Bahirdar	Tana	37.36	11.57	1800	1369.2	19.8	1980-2015
Bullen	Belles	36.08	10.60	1659	1370.2	21.6	1980-2015
Dangila	Tana	36.97	11.28	1220	1599.0	17.4	1980-2015
Debretabor	Tana	38.03	11.88	2140	1476.0	15.7	1980-2015
Gondar	Tana	37.41	12.55	2380	1048.5	20.2	1980-2015
Pawe	Belles	35.08	10.8	1119	1568.1	23.6	1980-2015

°=Degrees, mm= millimeters
Source: Author

database can also provide basic information which is important for agriculture, climate, and drought monitoring.

The topographic data was obtained from the integrated mapping of Digital Elevation Model (DEM) obtained from Shuttle Radar Topography Mission (SRTM), Gorelick et al. (2013); which was also used in an earlier mapping of different agro-ecological zones in Ethiopia (Temesgen et al., 2017). The other group of data set (crop data), management, and related agro-climatic characteristics were collected from the Amara National Regional State Bureau of agriculture and rural development.

Table 1 describes the geographical location, elevation, and record period of the meteorological stations used in the present study. Station selection has been done based on quality, long-range data, and representation of various climatic zones in the TBSBs. Surface- based observations particularly rainfall and temperature can face a number of errors either from the observer's

Table 2. Ethiopian traditional climate zones as characterized by Altitude in meters, Mean Annual Rainfall in millimeters, Mean Annual Temperature in Degree Celsius, Traditional Climate zone and climate class.

Altitude (m)	Mean Annual Rainfall (mm)	Mean Annual Temperature (^{o}C)	Traditional Climate zone	Climate class
> 3200	> 2200	< 11.5	Wurch	cold and moist
2300–3200	1200–2200	11.5-17.5	Dega	cool and humid
1500–2300	800–1200	17.5-20.0	Weina Dega	cool sub-humid
500–1500	200–800	20.0-27.5	Kolla	warm semiarid
< 500	< 200	> 27.5	Bereha	hot arid

available at https://allaboutethio.com/tclimate.html

record or from failure in the measuring instrument. For this reason, routine quality checks were done by visualizing the data, and outliers such as negative values of rainfall as well as minimum temperature values that are greater than the maximum temperature values in a particular month were replaced by the appropriate values based on Metadata. In this study, we also implemented descriptive statistics to simplify a large amount of data in a sensible way and further improve the quality of the datasets and remove outliers.

Unlike the other tropical countries which have mostly four seasons in Ethiopia, there are three seasons, in which each season is composed of four months based on climatological means of rainfall and temperature. The three seasons are locally known as Bega (October, November, December, and January), Belg (February, March, April, and May), and Kiremt (June, July, August, and September) as mentioned in Degefu (1987) and Gissila et al. (2004). Similarly, the present study divided the time series of monthly rainfall and temperature data into seasonal and annual time series categories.

Agro_climate zoning

Agro_climate zoning is the classifications of a region into land units in terms of major climate components, dominant crops, and superimposed on moisture availability period (length of the growing period) (FAO, 1983; Anand et al., 2009). In the present study to delineate the ACZs of the TBSB three different layers of agro_climate parameters viz. altitude, rainfall, and temperature were classified by using the (DTC) algorithm.

The DTC is a nonparametric supervised method that classifies the binary data input hierarchically into branched splits. It classifies any given geographical region into homogeneous zones based on logical instruction by the user (Bisht et al., 2013).

The decision tree is composed of three types of nodes; the root node, internal nodes, and leaf nodes. The root node represents a classification of the input data set into two or more different subsets.

The internal node represents the possible categories of the specific values in the tree structure; this node is connected to the root (parent) node at the top and the leaf (child) node at the bottom. The third node of the DTC the leaf node represents the target class of the classification.

The present study also applies a similar approach to the rainfall and temperature data downloaded from http://worldclim.org (WorldClim 2.0) to delineate the climate zones in the TBSB. The DTC (algorithm) in ENVI software was used to delineate agro-climatic zones. DTC classifies the geographical region into a homogeneous zone based on logical instruction by the user (Bisht et al., 2013). Finally, after the process of zonation, the rainfall and temperatures of the TBSB fall under or near the traditional climate zones of Ethiopia in Table 2. The inverse distance waiting (IDW) interpolation method was used to interpolate each data points into spatial patterns by using version 10.2 ARCGIS software.

Suitability analysis

Agro-climatic suitability analysis is a multicriteria evaluation, which aims at identifying the most appropriate climatic conditions for future farming systems according to specific requirements, preferences, or predictors of some activity. An agro-climatic zoning scheme is a standard tool for prioritizing agricultural research because it offers relevant and available information about target environments (Nuarsa et al., 2019).

The agro_climatic suitability class is divided into four classes, which are Highly Suitable, Moderately Suitable, Marginally Suitable, and Not Suitable (FAO, 1976; Djaenudin et al., 2003; Nuarsa et al., 2019). In the present study, the agro-climatic suitability analysis focuses on a specific agro_climate class to which a range of crops can grow.

Because rainfall, altitude, and slope greatly affect the temperature and humidity, the agroclimatic parameters used in this study consist of rainfall, temperature, and altitude. The other parameters by one or other means depending on these agro_climatic conditions; such that slope on altitude and humidity on rainfall or temperature.

RESULTS AND DISCUSSION

Climate characteristics based on observational data

Table 3 shows the monthly descriptive statistics of the monthly rainfall averaged from 1980 to 2015. From the table it can be noted that the mean annual rainfall received is lower during the dry months (December, January, and February) and higher during the wet months (July and August). Conversely, in the same table, the Coefficient of variation is lower during the wet months and higher during the dry months. This implies the erratic nature of rainfall during the dry months. Similarly, the seasonal and annual time series distribution of rainfall anomalies is illustrated in Figure 2. Seasonal rainfall shows variability from year to year; while the variability is relatively less during the main rain season (Kiremt) when compared to the dry seasons. The mean annual rainfall also varies from about 950-2000 mm. while the seasonal and annual rainfalls show an increasing trend as indicated by the red line (positive slope); the rate of increase seems insignificant. The coefficient of determination (R2) values is also very small indicating the

Table 3. Descriptive statistics of monthly rainfall for the 1980-2015 study periods

Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
minimum	0.0	0.0	0.1	3.9	16.6	77.0	210.8	263.9	116.2	17.6	1.3	0.0
mean	2.8	2.6	16.8	32.4	108.4	208.6	351.0	359.7	202.7	95.2	19.6	7.5
maximum	22.2	24.6	87.2	87.7	202.9	286.9	465.8	479.3	284.7	220.4	52.5	56.7
Standard deviation	4.6	4.5	18.0	24.5	50.3	44.8	58.0	50.8	38.5	49.0	12.8	11.6
Coefficient of variance	163.7	174.9	106.8	75.5	46.4	21.5	16.5	14.1	19.0	51.5	65.6	153.4
Skewness	2.8	3.7	2.1	0.7	0.0	-1.0	-0.5	0.3	-0.3	0.8	0.8	3.1
Kurtosis	8.4	16.4	5.7	-0.5	-0.8	1.9	0.4	0.2	-0.2	0.1	0.0	10.9

Source: Author

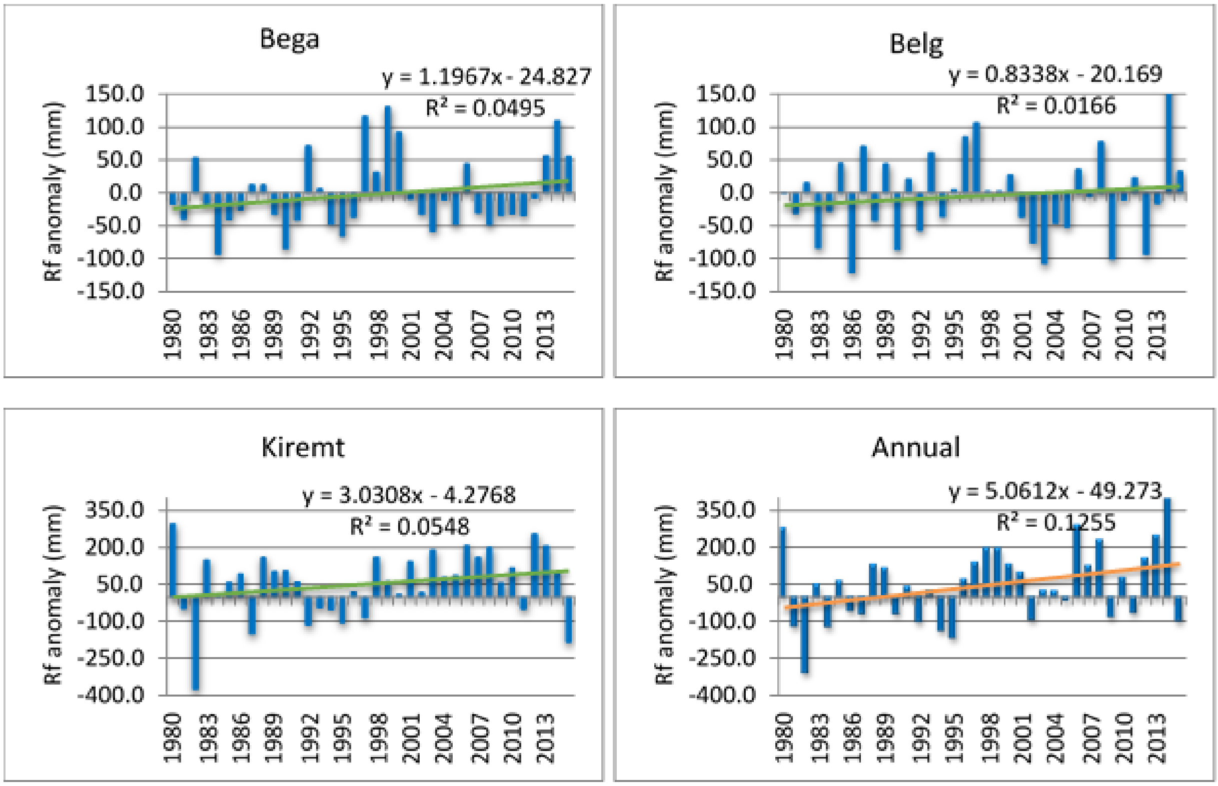

Figure 2. Anomalies of the seasonal and annual rainfall in millimeters during 1980–2015
Source: Author

disagreement in regression of rainfall with time.

Generally, the rainfall distributions in the TBSB characterized by a monomodal rainfall regime, receiving most of the rain (70 to 90%) in one season (June to September). However, in the southern parts of the Tana basin, the months of April to May are also an intermediate season where minor rains often occur (Enyew et al., 2014).

Consequently, a coefficient of variance analysis conducted by Addisu et al. (2015) has indicated that a significant annual rainfall variation was recorded from the whole weather stations in the Lake Tana basin during the last 40 years. Significant annual rainfall variability implies that climate change resulted in climate variability and extreme weather conditions. And any minor change in the intensity or amount of rainfall imposes a severe challenge on the rural people since its main livelihood depends on agriculture which is also dependent on the short rainy season. Similarly, studies of rainfall patterns on the Beles sub-basin summarize that rainfall is highly variable spatially and temporally (Tilahun, 2006; Worqlul et al., 2014, 2017). The present study is also consistent with the previously worked analysis in characterizing the rainfall in the TBSB.

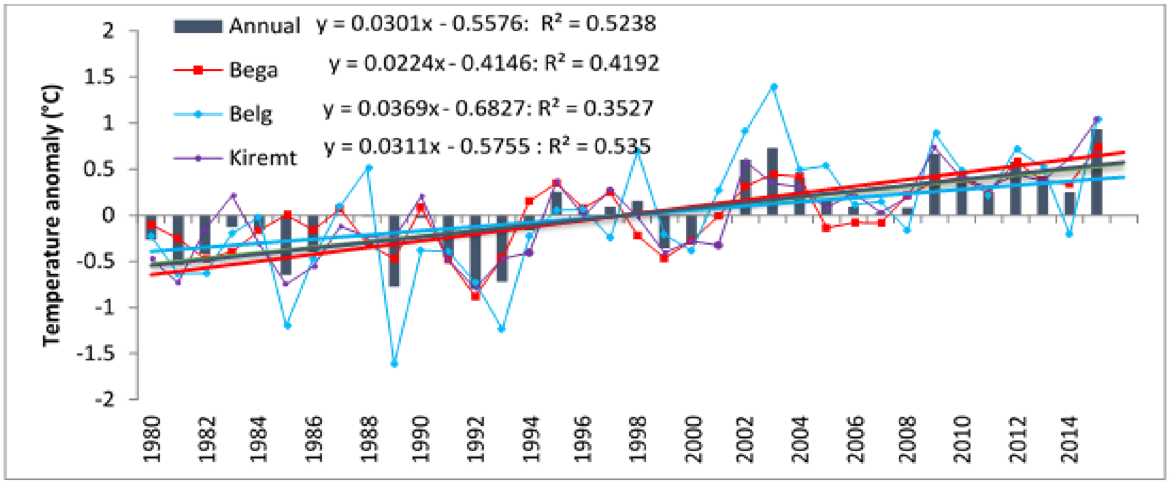

Figure 3. Seasonal and annual anomalies of the Average temperature over the TBSB
Source: Author

On the other hand, the mean seasonal and annual Temperature in the TBSB is illustrated in Figure 3. The average temperature in the TBSB had increased in all seasons during the study period 1980-2015. And Belg Temperatures show higher deviations in time as shown in the figure relative to the other seasons. This could be due to that as Belg is the second short rainy season where rainfall is erratic; temperatures could have been affected by the wet and dry conditions of the season. The mean annual average temperature ranges from 6°C to higher than 27°C. while the seasonal and annual increase in trends of temperature is well captured by the trend lines (slopes); the R2 values also show how temperature increase had been consistent with time as compared to rainfall. The Mean annual temperature generally increases from North (the mountainous region) to South (The lower parts of the Beles river).

Previous studies have shown a spatial and temporal variation of temperature in Ethiopia in general and in the TBSB in particular. For example, the United Nations Development Program (UNDP, 2008) on its country basis climate profile reports that mean annual temperature was increased by 1.3°C between 1960 and 2006. During the same period, the report also shows an increase of hot days and hot nights by 73 and 137 each year, respectively. Similarly, the National Meteorology Agency of Ethiopia mentions that the mean annual minimum temperature an increase of 0.37°C every decade; whereas, the maximum and the mean temperature showed no significant increase (Tadege, 2007). In the case of the TBSB, results revealed that there has been an increasing trend of the mean temperature in the Tana sub-basin (Addisu et al., 2015) and Beles sub-basin (Worqlul et al., 2017). Identified ACZs Based on altitude, annual average rainfall, and temperature distributions the TBSB was divided into nine agro-climate zones. Figure 4a and b show the spatial distribution of rainfall and temperature in the TBSB. The map of the ACZs of the TBSB has been illustrated in Figure 4c.

Moist Dega

This ACZ is basically situated in the mountainous areas (Semien mountains). This zone consists of 5.26% of the total area of the TBSB. The average altitude of the zone ranges from 2300 to 3200 m. The annual average rainfall and temperature of this zone are 1200 mm and <10°C respectively.

Moist Kolla

This ACZ is located in the lower end of the TBSB.it is Moist Woinadega

This zone covers the maximum area of the TBSB, which is about 33.85% of the total geographical area. The average elevation of the zone ranges from 1500-2300 m. The average annual precipitation falls between 900-1400 mm and the annual temperature range of this zone is between 10-20°C. Lake Tana (the largest lake in Ethiopia) is situated in this agro-climatic zone. Hence, the presence of the lake makes the zone have specific climatic characteristics than the other ACZs.

Moist Wurch

This zone is found in the northeastern tips of the TBSB at an altitude ranging from 3200-3700. The chained mountains of Gunna are scattered in this zone. The area covered by this agro-climatic zone is some 0.12% of the total geographical area. The average annual precipitation

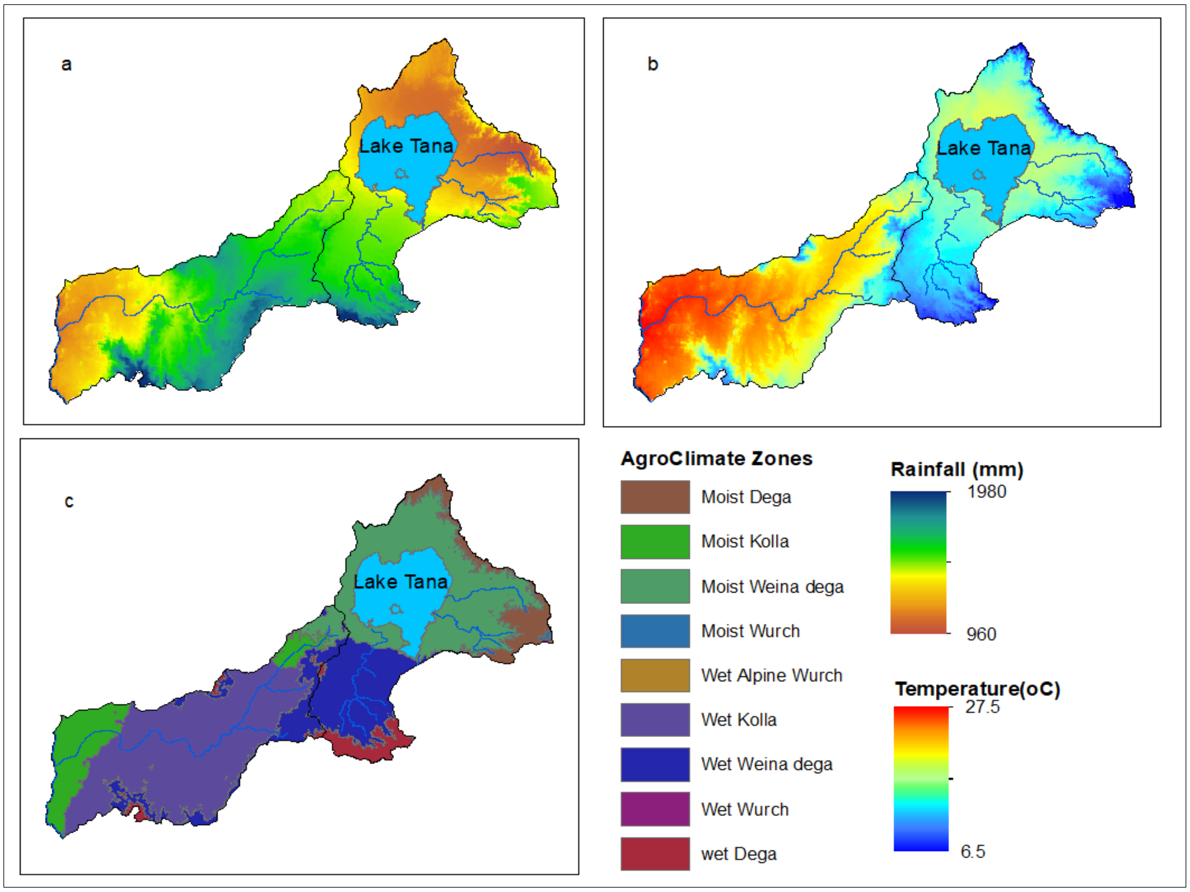

Figure 4. Agro-Climate zonation of the TBSB: a) Mean annual rainfall from the World Clim version 2, b) Mean annual temperature from the world Clim version 2, and c) Major agro climate classes of the TBSB.
Source: Author

of this zone is 900 to 1400 mm and the average annual temperature 5 to 10°C. Owing to the high mountain's altitude the area has characteristically cold temperatures.

Wet Alpine Wurch

The annual average precipitation of this zone is >1400 mm and the temperature is between 10-20°C. The zone is not much important as it is confined to only 0.03% of the total geographical area of the sub-basins. It is scattered in the high mountains of the TBSB therefore the coverage is clearly invisible on the map of Figure 4c.

Wet Kolla

This ACZ is found at the lower plains of the TBSB at altitudes between 500 and 1500 m. The area covered by this agro-climatic zone is 30.90% of the total geographical area. The average annual precipitation in this zone is >1400 mm and the annual range of temperature is 18-25°C. Generally, this is the second-largest agro-climatic zone in the TBSB.

Wet Woina Dega

This ACZ covers about 17.31% of the total area, southeast of the TBSB around the upper Gilgel river which flows from Lake Tana. The average altitude of this zone is 1500-2300 m. The average annual precipitation in this zone is >1400 mm and the annual range of temperature is 10-15°C.

Wet Wurch

This zone covers 0.06% of the total geographical area of the TBSB. The annual average temperature of this zone is 5-10°C and the precipitation is >1400mm. The zone is found at a similar altitude with Moist Wurch however the average annual precipitation received is different.

Wet Dega

The area covered by this ACZ is 3.62% of the total

Table 4. Agro-climatic zonation (Altitude in meters above sea level, Annual rainfall in millimeters and Average annual temperature in Degree Celsius) with the main crops in the Beles sub-basin.

Altitude (m)	>3700	**Dry Alpine Wurch** (grazing pasture)	**Moist Alpine Wurch** (primarly for garazing)	**Wet Alpine Wurch** (None/frost limit)	<10	Temperature (°C)
	3200-3700	**Dry Wurch**	**Moist Wurch** (Mostly Barley)	**Wet Wurch** (Only Barley)	10-15	
	2300-3200	**Dry Dega** (barley, Wheat, highland oilseeds, and highland pulses)	**Moist Dega** (Barley, Wheat and Pulses)	**Wet Dega** (Barley,Wheat,Nug and Pulses)	15-20	
	1500-2300	**Dry Weinadega** (Wheat, Teff, rarely Maize)	**Moist Weina dega** (Maize, Sorghum, Teff, rice, Insent rare, Wheat, Nug, Dagussa and Barley)	**Wet Weina dega** (Teff, Maize, Insent, Nug and Barley)	20-25	
	500-1500	**Dry Kolla** (Sorghum and Teff)	**Moist Kolla** (Sorghum, rarely teff, Dagussa and Ground Nut)	**Wet Kolla (**Sorghum and Dagussa**)**	25-30	
	<500	**Dry Bereha** (almost none except Irrigation)	**Moist Bereha** (root crops and maize)	**None**	>30	
		<900	900-1400	>1400		
		Rainfall (mm)				

N.B: shaded regions in the table are ACZs identified in the current study area
Source: Author

geographical area. The draining region of the upper Gilgle river and some parts of lower Beles belong to this zone.

The average annual precipitation range of this zone is >1400 mm and the annual temperature is 10-20°C. The generated ACZs are consistent with the Ethiopian traditional land users' classifications based on altitude. For example, (Bruce, 1790) named a small village west of Lake Tana near 'Avolei River' as 'Wainadega'. Huffnagel (1961) confirmed 'Wurch', for areas higher than 3800 m a.s.l. Such areas include the Simen Mountains, a high altitude area of Northern Ethiopia with the country's highest peak, Ras Dejen (4,533 m a.s.l.). The majority of the geographical coverage of the TBSB consists of Weina Dega (Moist and wet) totaling about 51.16%. A relatively recent study by Hurni (1998) also found that the most dominant Ethiopian agricultural belt is called Weyna Dega. He also stated that owing to the sufficient rainfall allowing at least one cropping season per year, all major rain-fed crops, particularly Teff and maize can be grown in most parts of this belt.

Agro_climatic suitability for crops based on FAO Guidelines

The crops growing in each ACZ are referred to in Error! Reference source not found. The agro climate suitability analysis was formulated based on the three agro-climatic parameters. According to the altitudinal differences while most of the TBSB is suitable; some mountainous areas particularly the northern part of the basin were identified as unsuitable.

Based on rainfall distribution most of the zones are highly suitable except for the deficit in the lower parts of Beles sub-basin. Thirdly based on temperature while most of the areas experience optimum temperature which is important for crop growth; however higher/lower temperatures in the lower Beles basin and upper Tana basin (mountainous area) leads to wilting/coldness. Generally, most of the TBSB is categorized as highly to moderately suitable for major crops and less are also considered as marginally suitable and unsuitable.

The present study is generally consistent in classifying the suitability of ACZs for major crops in the TBSB. According to the agroecological zoning of Ethiopia (Mengistu, 2003): An elevation above 3,700 m is classified as 'high wurch' (frosty-alpine) and thus unsuitable for agricultural purposes. This indicates the requirement of optimum temperatures for crop plants to reach certain stages is considerable (Raes et al., 2009). In general, when compared in Semi-arid tropical regions like the current study area temperature is less variable than rainfall, hence the dominant parameter affecting the growth of crops in the TBSB is rainfall. The duration of the rainy period in some tropical areas ranges 60 to 100 days, which is very short compared with the time the crop spends in the field (3-4 months). Thus, most crops grown in the area could suffer from moisture stress during their growth (Araya et al., 2010) (Table 4).

CONCLUSION AND RECOMMENDATIONS

In the present study, we classified the TBSB into climate zones Based on altitude, rainfall, and temperature patterns. The majority of the geographical coverage of the TBSB consists of Weina Dega (moist and wet) ACZ totalling about 51.16%. The wet alpine wurch which is situated in the mountain areas is found to be the smallest ACZ in area coverage (0.03%). The climate characteristics of the ACZ in the TBSB were found to be suitable for a range of crops except for the cold highlands. Owing to the sufficient rainfall allowing at least one cropping season per year, all major rain-fed crops can be grown in most parts of ACZs, particularly teff and maize. Generally, more than 80% of the ACZs were found to be suitable for the development of main crops in the area. Finally, information about a specific ACZ is very important to different agricultural practices experienced by farmers, governmental and non-governmental agencies involved in different development events. Moreover, policies designed depending on climatic conditions of a given place can be intended to minimize agricultural inputs and maximize outputs.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGMENTS

The authors appreciate the National Meteorological Agency of Ethiopia for providing the meteorological data and also thank the WorldClim 2.0 group members for making the gridded data available at the http://worldclim.org.

REFERENCES

Addisu S, Selassie YG, Fissha G, Gedif B (2015). Time series trend analysis of temperature and rainfall in lake Tana Sub-basin, Ethiopia. Environmental Systems Research 4(1):1-2.

Anand A, Mudit M, Vivek G, Pradyumna J, Manoj C (2009). Agro-climatic zonation of Maharashtra State using GIS. Transactions of the Institute of Indian Geographers 31:25-36.

Araya A, Keesstra SD, Stroosnijder L (2010). A new agro-climatic classification for crop suitability zoning in northern semi-arid Ethiopia, Agricultural and forest meteorology 150(7-8):1057-1064.

Asnani G (2005). Tropical Meteorology, revised edn, Vol. 1. Praveen Printing Press: Pune, India.

Batjes NH (1994). Agro-climatic zoning and physical land evaluation in Jamaica. Soil Use and Management 10(1):9-14.

Bisht H, Nain AS, Gautum S, Puranik HV (2013). Agro-climatic zonation of Uttarakhand using remote sensing and GIS. Journal of Agrometeorology 15(1):30

Bruce J (1970). Travels to Discover the Source of the Nile, in the Years 1768,1769, 1770, 1771, 1772, and 1773 G.G.J. and J. Robinson, London.

Cocheme J, Franquin P (1967). A study of the agro climatology of semiarid south off the sahara in west Africa. FAO/UNISCO/WMO Interagency Project Technical Report pp. 117-129.

Conway G (1985). Agro ecosystem analysis. Agricultural administration 20(1):31-55.

Central Statistical Agency (CSA) (2007). Central Statistical Agency Population and Housing Census of Ethiopia, Addis Ababa, Ethiopia, 2007.

Djaenudin D, Marwan H, Subagio H, Hidayat A (2003). Land Evaluation Technical Guide for Agricultural Commodities. Soil Research Institute. Soil Research and Development Center. Agency for Agricultural Research and Development, Bogor 154 p.

EIAR (2007). How to use crop technologies (Amharic version). EIAR, Addis Ababa P 173.

EIAR (2011). Coordination of National Agricultural Research System, Ethiopia. English and Amharic Version. EIAR, Addis Ababa.

Enyew BD, Lanen HA, Loon AF (2014). Assessment of the Impact of Climate Change on Hydrological Drought in Lake Tana Catchment, Blue Nile Basin, Ethiopia. Journal of Geosciences 3:174. doi: 10.4172/2329-6755.1000174.

FAO (1976). A framework for land evaluation. Soil Resources, Management and Conservation Service, FAO Land and Water Development Division. FAO Soils Bulletin 32. Rome, Italy.

FAO (1983). Land Evaluation for Rainfed Agriculture. Soils Bulletin. No. 52, FAO, Rome P 237.

FAO (2003). Country Pasture-Forage Resource Profiles-Ethiopia [Online].

Fick SE, Hijmans R (2017). WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. International journal of climatology 37(12):4302-4315.

Gemechu D (1977). Aspects of climate and water budget in Ethiopia. Addis Ababa University Press P 77.

Gorelik VS, Kudryavtseva AD, Orlovich VA, Sverbil PP, Tcherniega NV, Vodchits AI, Voinov YP, Zlobina LI (2013). Raman Scattering in Light and Heavy Waters. Journal of Russian Laser Research 34:523-530. https://doi.org/10.1007/s10946-013-9384-1

Gorfu D, Ahmed E (2012). Crops and Agro-ecological Zones of Ethiopia, Ethiopian Institute of Agricultural Research [Accessed: September, 2018].

Haile T, Yarotskaya L (1987). Onset and cessation of rains in Ethiopia. NMSA Memo, Addis Ababa, Ethiopia 34 p.

Hargreves G (1975). Water requirement manual for irrigated crops and rain fed agriculture. SL EMBRPA/ Utah University (P 40).

Hijmans RJ, Cameron SE, Parra JL, Jones PG, Jarvis A (2005). Very high resolution interpolated climate surfaces for global land areas. International Journal Climatology 25(15):1965-1978.

Huffnagel HP (1961). Agriculture in Ethiopia. FAO, Rome

IPCC (2012). Managing the risks of extreme events and disasters to advance climate change adaptation. A special report of working groups I and II of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, UK.

Kassahun B (1987). Weather systems over ethiopia. In: Proceedings of First Technical conference on meteorological research in Eastern and Southern Africa. Kenya Meteorological Department, Nairobi, Kenya pp. 53-57.

Mengistu A (2003) Country Pasture/Forage Resources Profiles: Ethiopia. Food and Agriculture Organization of the United Nations (FAO), Rome.

MoWR (Ministry of Water Resources) (1999). Ethiopian Water management policy. Addis Ababa: MoWR

Muthusi FM, Gathenya M, Gadain H, Kaluli W, Lenga FK (2005). Application of the Usgs Streamflow Model to the Nyando Basin,Western Kenya. European Journal of Scientific Research 12(1):9-19.

NMSA (1996). Climatic and agroclimatic resources of Ethiopia. NMSA Meteorological Research Report Series 1:1. Addis Ababa.

Nuarsa IW, Dibia IN, Wikantika K, Suwardhi D, Rai IN (2019). Gis based analysis of agroclimate land suitability for Banana plants in Bali Province. Indonesia. HAYATI Journal of Biosciences 25(1):11-17.

Nyssen J, Vandenreyken H, Poesen J, Moeyersons J, Deckers J, Haile M, Salles C, Govers G (2010). Rainfall erosivity and variability in the northern ethiopian highlands. Journal of Hydrology 311(1-4):172-187.

Pender J, Gebremedhin B (2006). “Land Management, Crop

Production, and Household Income in the Highlands of Tigray, Northern Ethiopia: An Econometric Analysis. In Strategies for Sustainable Land Management in the East African Highlands, edited by J. Pender, F. Place, and S. Ehui. Washington, DC: IFPRI.

Raes D, Steduto P, Hsiao TC, Fereres E (2009). AquaCrop-The FAO crop model to simulate yield response to water: II. Main algorithms and software description. Agronomy Journal 101(3):438e-447.

Reddy SJ (1983). Agro-climatic classification of the semiarid tropics I. A method for the computation of classificatory variables. Agricultural Meteorology 30(3):185-200.

Rohlfs G (1883). Meine Mission nach Abessinien. Auf Befehl Sr. Maj. Des Deutschen Kaisers, im Winter 1880/81 unternommen. Illustrated. F.A. Brockhaus, Leipzig 348 p.

Simane B, Zaitchik BF, Ozdogan M (2013). Agroecosystem analysis of the Choke Mountain watersheds, Ethiopia. Sustainability 5(2):592-616.

SMEC IP (2007). Hydrological study of the Tana-Beles sub-basins. Part 1. Sub-basins Groundwater Investigation Report.

Tadege A (2007) Climate change national adaption program of action (NAPA) of Ethiopia. Addis Ababa, Ethiopia: NMS (National Meteorological Agency: Federal Democratic Republic of Ethiopia, Ministry of Water Resources) 5(1):1613770.

Temesgen G, Taffa T, Mekuria A (2017). Erosion risk assessment for prioritization of conservation measures in Geleda watershed, Blue Nile basin, Ethiopia. Environmental System Resourses 6(1):1-14.

Tilahun K (2006). Analysis of rainfall climate and evapo-transpiration in arid and semi-arid regions of Ethiopia using data over the last half a century. Journal of Arid Environments 64(3):474-487.

Tesemma ZK, Mohamed YA, Steenhuis TS (2010). Trends in rainfall and runoff in the Blue Nile Basin: 1964-2003. Hydrological Processes 24:3747-3758. doi:10.1002/hyp.7893

Troll C (1965). Seasonal Climates of the earth. World maps of Climatology. Eds. E. Rodenwalt and H. Jusatz. Berlin: Springer – Verlag P 28.

World Bank (2001). Remote Sensing Studies of Tana-Beles Sub Basins. A Nile Basin Initiative project.

Worku LY (2015). “Climate change impact on variability of rainfall intensity in the upper blue Nile basin,” Proceedings of the International Association of Hydrological Sciences 366:135-136.

Worqlul AW, Maathuis B, Adem AA, Demissie SS, Langan S, Steenhuis TS (2014). Comparison of rainfall estimations by TRMM 3B42, MPEG and CFSR with ground-observed data for the Lake Tana basin in Ethiopia. Hydrology and Earth System Sciences 18(12):4871-4881.

Worqlul AW, Yen H, Collick AS, Tilahun SA, Langan S, Steenhuis TS (2017). Evaluation of CFSR, TMPA 3B42 and ground-based rainfall data as input for hydrological models, in data-scarce regions: The upper Blue Nile basin, Ethiopia. Catena 152:242-251.