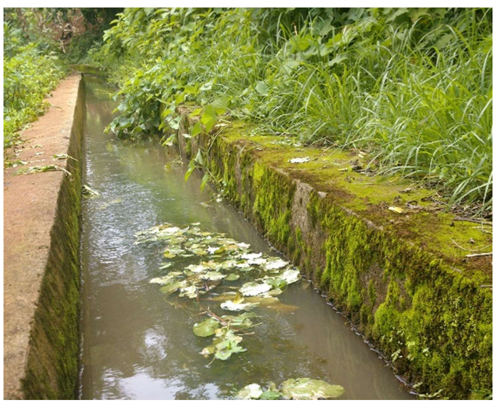
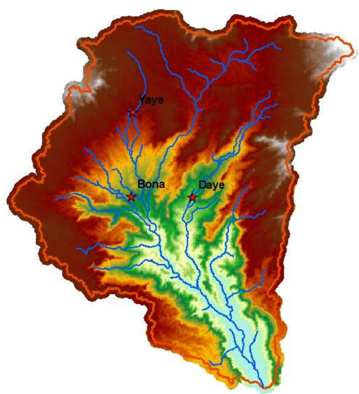
The impact of coffee-based agroforestry on the hydrology of the upper Genale River basin, Sidama Zone, Ethiopia.





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Abstract

Research was done in the upper part of the Genale River basin in the Sidama Zone, Ethiopia. The research focussed on answering the question whether coffee-based agroforestry could have an impact on the local hydrology. Discharge data, land use data and soil data was collected in the field and from literature and together put into a SWAT model to investigate the hydrological cycle of the basin. Several scenarios were created in which the amount of coffee in the area was altered. These scenarios were compared with each other to investigate the influence of coffee-based agroforestry on the hydrology. It appeared that altering the amount of coffee had a small influence on the hydrology, in particular on the discharge. When more coffee is present, the evapotranspiration increases, and both surface runoff and discharge decrease. After assessing the influence of coffee using the coffee scenarios, future scenarios were used to predict if there would be any noticeable changes in the future when land use changes. Land use changes are likely to affect the hydrology. The discharge could decrease with 47.500 cubic meters per day in a dry year, which is about 1% of the regular discharge. This could lead to a possible change in irrigation potential and in a possible decrease in drinking water resources.

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1. Introduction

Ethiopia is one of the largest producers and exporters of natural, unwashed arabica coffee (*coffea arabica*). In the past 55 years, the production increased from 1.69 million to 6.35 million 60 kg bags of coffee (*LMC, 2000; USDA, 2014*). During that same period, the export has grown substantially as well, increasing from just under a million in 1960 to almost 3.3 million bags today (Figure 1). The area under coffee production in 1980 was estimated at 350 thousand hectares. However, the ever increasing demand for coffee required extra space. In order to support the growth rate, an estimated area of almost 830 thousand hectares is in use nowadays (*LMC, 2000*).

In 2000, approximately 700.000 households, equalling 15 million people, were involved in coffee production. This implies that the livelihood of a quarter of the total population of Ethiopia is relying on the growth and production of coffee (*LMC, 2000*). However, even though many people are depending on the harvest of coffee, the yields are considered to be very low compared to other countries. According to the Federal Democratic Republic of Ethiopia (FDRE), less than 200 kg per hectare of forest coffee is harvested (*Petit, 2007*). These low yields are one of the main contributors to the paucity in Ethiopia. The fast growing population together with the low coffee yield, cause an almost permanent food shortage (*Clay et al., 1999*).

The dependency on the production of coffee became painfully visible in 1997, when the coffee market collapsed and export prices dropped from values around 45 US cents per kg to values as low as 18 US cents per kg (*Petit, 2007*). For the Ethiopian economy, this was a major setback, increasing the poverty in the country. After eight years, the coffee price finally increased again, resulting in a reduction of the poverty as well (*CIA World Factbook, 2011*).

To be able to improve food security, which results in a reduction of poverty, insight in coffee production is of great importance. One of the major aspects that determine coffee production is the availability of water. In Ethiopia, the single most important source of water is natural rainfall. Most coffee is cultivated in the sub-humid to humid, warm subtropical climatic zone (between 1500 and 2400 meter above sea level), which usually receives an annual rainfall of 1000-1600 mm, and has a temperature between 15 °C and 20 °C (*Abebe, 2013*). Note that the rainfall in Ethiopia is characterized by large spatial and temporal variability (*Gissila et al., 2004; Korecha and Barnston, 2007*).

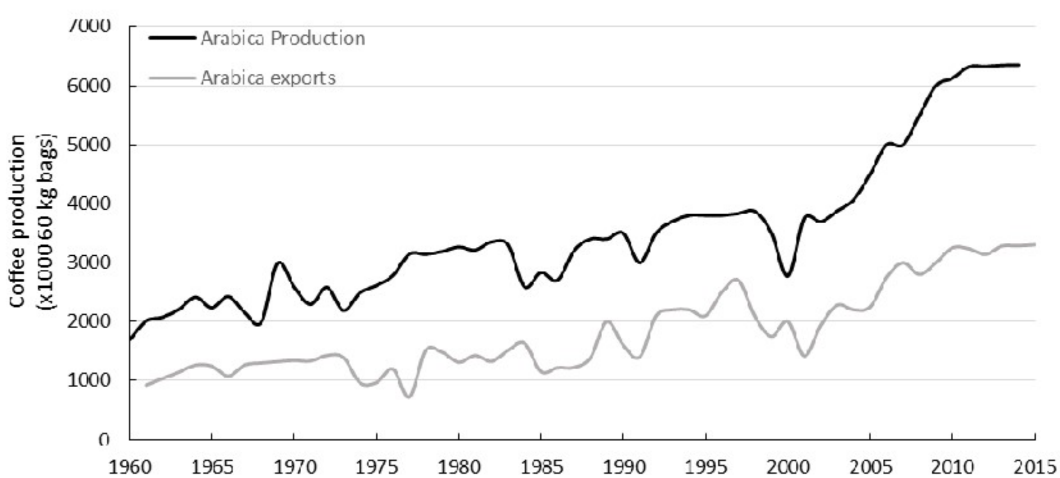

Figure 1: Coffee production and export rates in Ethiopia in the last 55 years. (Adapted from USDA, 2014).

Hydrological processes determine the growth of plants (*Baird and Wilby, 1999*), the amount and diversity of natural resources in the basin and along the course of a river and influence land degradation (*Morgan, 2005*). Land degradation usually occurs due to surface runoff, which could remove valuable soil from the site and thus hinder coffee growth by depleting the soil from its nutrients and organic matter. Given these facts, it is essential to have sufficient knowledge about the hydrological processes in an area, the more so as a large part of the agricultural potential is determined by these processes.

Not many studies have been conducted that investigate the impacts of changing land use on hydrology in Ethiopia. Woube (*1999*) showed that a change in land use led to an increase in flooding intensity in the Baro-Akobo River. Legesse et al. (*2003*) used a model to show that when arable land would be changed into forest, the discharge of the Ketar River would decrease due to increased evapotranspiration. Bewket and Sterk (*2005*) demonstrated that the expansion of agriculture had led to a decrease in discharge of the Chemoga River during the dry season, but that it had no impact on peak discharges. Apart from these three studies, there currently are, to the best of our knowledge, no other studies available concerning the impact of land use changes on hydrology.

Both land use change and climate change can affect hydrology. Land use changes can have an effect on processes on the land, such as evapotranspiration and surface runoff, whereas climate change could alter characteristic weather conditions. At present, there is insufficient knowledge available concerning the interaction between coffee cultivation and hydrological processes in Ethiopia. This knowledge gap could be filled by investigating the hydrological cycle for a particular area where coffee is cultivated. The information gained can then be used to implement improvements and necessary alterations in the current land use. The aim of this study therefore was to determine the influence of coffee on hydrological processes in a watershed where an abundance of coffee-based systems is found and predict the future hydrological solution for a number of land use change and climate scenarios. Three objectives were defined in order to be able to meet the main goal of this research:

- Determine the local hydrology of a watershed with an abundance of coffee-based systems.
- Model the influence of coffee on the hydrological processes within the basin.
- Predict the effects of climate change and land use changes on the hydrology and coffee production potential.

2. Site description

2.1 Research area

The area selected for this study is the upper basin of the Genale River catchment in the Sidama Zone, Ethiopia, where there is an abundance of coffee cultivation (Figure 2). The area of interest covers a region of 3179 km^2. The Genale River is a perennial river that receives most of its water from the Sidama and Bale Highlands. It starts its course on the southern side of the Great Rift Valley and runs towards the southern border with Somalia, having a length of 858 km and a basin area of about 172.000 km^2 (*CSA, 2012*) before it reaches the Indian Ocean. It is the fourth-largest river in Ethiopia. The head water source of this river covers several districts within the Sidama region, including Arbegona, Bensa and Bona Zuria. Further downstream it crosses the Borona region. After crossing the border with Somalia, it joins the Dawa River, together forming the Jubba River.

The three districts of Arbegona, Bensa and Bona Zuria form an area that is designated as research and development site by the International Livestock Research Institute (ILRI). ILRI collaborates with the International Water Management Institute (IWMI) in the Livestock and Irrigation Value Chains for Ethiopian Smallholders (LIVES) project that works on the improvement of food security and reduction of poverty on the site. In the past, not many studies have been conducted in this area. An inventory has been made concerning land management (*Yilma, 2013*). There are four main land use types present in the area: coffee-based systems, grazing land, agricultural crop land, and ensete (*Ensete ventricosum*), also known as false banana.

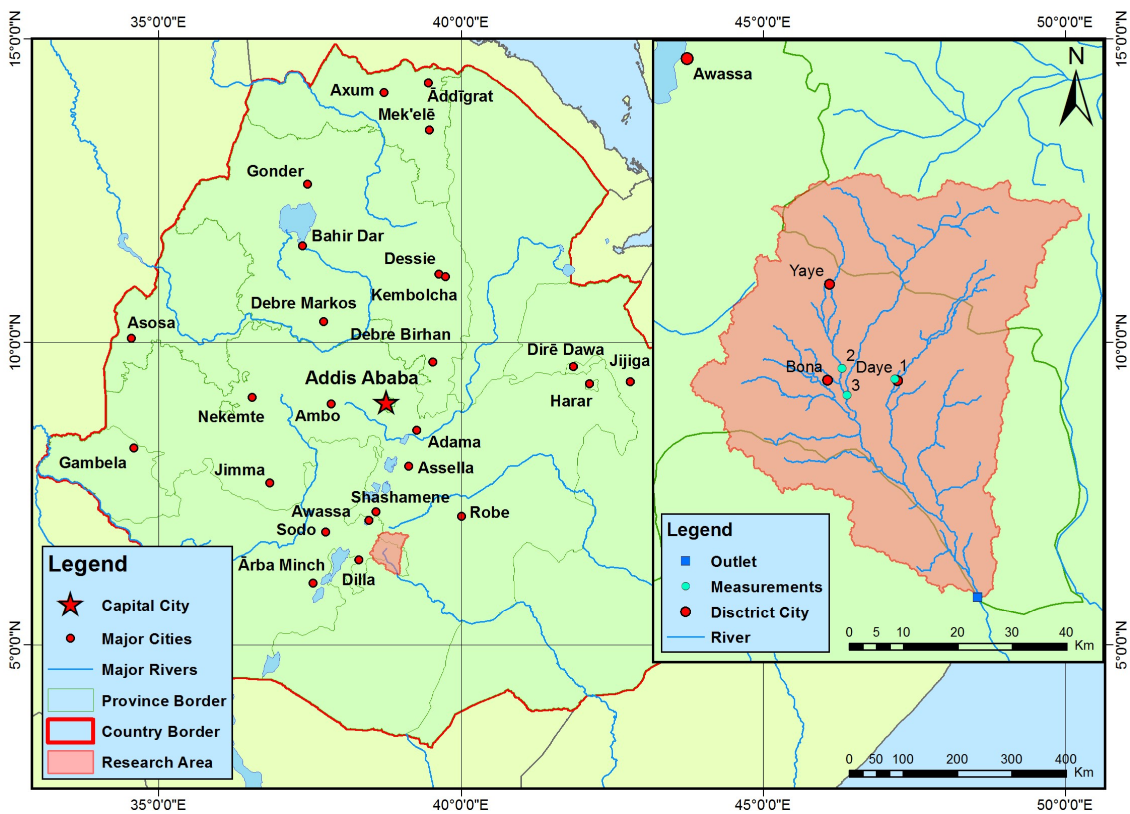

Figure 2: Research area of the Genale River basin, having an area of 3178.55 km². Close-up in the top right corner shows the detailed stream network in the catchment of the Genale River. Measurement locations are included.

Agricultural crop land can be further divided into cereals, vegetables, fruits and sugarcane. The highland areas (2200-3200 m) are dominated by grazing land, cereals and ensete. In the midlands (1600-2200 m) coffee-based agroforestry (Coffea arabica) is the main land use type (*Yilma, 2001*). Next to the coffee, there is also an abundance of ensete and agricultural land, including cereals, vegetables and sugarcane. Below 1600 m, the main land use type is agricultural land. With regard to the economy of the Sidama Zone, the coffee industry is of greatest importance.

2.2 Climate

The climate of the Sidama zone, being located in the highlands of Ethiopia, is predominately defined as tropical highland climate, having a generally dry winter season (*Osman and Sauerborn, 2002*). Ethiopia typically experiences four seasons: "Kiremt" (June-August), which is the main rainy season; "Tsedey" (September-November), the spring season; "Bega" (December-February), a dry and sunny season; and "Belg" (March-May), which usually brings light rains (*Yumbya et al., 2014*). The watershed of the Genale River has a mean yearly rainfall between 1246 mm and 1319 mm (*Yilma, 2013*). In Wondo Genet, a small town close to the watershed, temperatatures range between 10 and 25°C throughout the year. Since the watershed of the Genale River covers a large range in height, temperatures are also diverse in the area. Above 2500 meter, the yearly mean temperature is 12°C. At lower altitudes, between 1500 and 2000 meter, temperatures are roughly 7°C higher (*Yilma, 2013*). According to CSA (*2012*), the maximum monthly temperature of 25.1°C is reached in March. The minimum monthly temperature of 5.6°C occurs in January.

2.3 Coffee-based agroforestry and Ensete

Coffee grows best between the altitudes of 1600 and 2800 meter (*DaMatta et al., 2007*). However, coffee-based systems are usually found below 2400 meter, since the yields decrease above this altitude. The optimum yearly rainfall lies between 1200 and 1800 mm. Yields are highest when the yearly mean temperature lies between 18°C and 21°C (*Coste, 1992*) combined with a dry period of about two months per year (*Haarer, 1958*). These requirements make the Sidama Zone an ideal place for coffee-based systems. Most coffee-based systems in the Sidama Zone are coffee-based agroforestry systems, meaning that coffee bushes and trees are integrated. By implementing these types of systems, the destruction of natural vegetation that occurred in the past few decades is partly restored (*Teketay and Tegineh, 1991*). Next to the restoration, the main reason for agroforestry systems is that the trees provide shade for the coffee bushes, which is needed to maintain and enhance the crop production. Furthermore, it also provides the farmer with both wood and non-wood products. An important aspect of agroforestry is that all used crops and plants are native species. This ensures that all plants and crops can flourish and can have abundant yield. The diversity of trees and shrubs in these agricultural systems add to the provision of diverse products. For trees, commonly used species are avocado and ensete.

Ensete (*Ensete ventricosum*) is a large, non-woody, single-stemmed banana-like plant, having a bundle of leaf sheaths that form at the beginning of the stem (*Yilma, 2001*). It reaches heights of about six meter with leaves of about five meters length, and a width of about a meter. The fruits of the plant are similar to the domestic banana and are edible but lack flavour and have hard, black, rounded seeds. The root of the plant is the main edible portion and can give 40 kg of food after four or five years of maturing. Ropes, twine, baskets and general weaving can be obtained from the leaves (*Tsegaye and Westphal, 2002*). Ensete is a staple food for about 15 million people in

South and South-west Ethiopia. Since the Sidama region itself is one of the most densely populated areas of Ethiopia, having a population density of more than 249 persons per square kilometre and more than 500 persons per hectare of arable land (*WBISPP, 1997*), a large part of the crop yield is used for local use.

Coffee bushes can grow up to a height of 3.5 meter and produce so-called cherries that look reddish or purple. Within these cherries, usually two coffee beans are found. After three to five years, the bushes will grow its fruits and will produce for about fifty or sixty years. In contrast to ensete, coffee is one of the main export products of Ethiopia. It is used as the main cash source in the area (*Yilma, 2001*). However, the recently introduced drug called khat (*Qatha edulis*) has become a very popular cash income in recent years (*Getahun and Krikorian, 1973, Tefera et al., 2003*). Nowadays, khat is mainly produced without affecting the coffee plantations, but the rapid increase of the drug could lead to a neglect of coffee plantations.

3. Methodology

First, a field study was conducted in the research area. Data from the fieldwork and from literature concerning plant and soil properties were put into a hydrological model, after which was calibration and validation were applied. After application, the model was checked for reliability using statistics. Next, the model was set up using a DEM, land use map and soil map. A slope map was also created using the DEM. The DEM, slope map and soil map were kept unchanged for all scenarios, whereas the land use map was adapted to investigate the influences of land use changes. In total, 10 land use maps were put into the model. These include a map from 1985, 2015, four scenarios containing land use maps with adapted amounts of coffee, and four future scenarios. A more detailed description is given below.

3.1 Modelling

3.1.1 SWAT

The model that was used in this study is the Soil and Water Assessment Tool (SWAT). SWAT is a continuous time, physics based, and spatially distributed public domain hydrological model, developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large, complex watersheds (*Abraham et al., 2007*). More general, it describes hydrological processes within a watershed. A watershed is a geographical area that drains into a river or reservoir (*Hendriks, 2010*). Dingman (*2002*) defines the watershed as "the area that appears on the basis of topography to contribute all the water that passes through a given cross section of a stream". The boundary that delimits the watershed is called the water divide. A watershed can be made up of smaller subbasins if several smaller streams come together to form a larger stream. In this case, the subbasins are also defined by their own water divides, within the larger water divide of the main basin. SWAT has been used in several studies in Ethiopia, and generally gave reliable results for the simulation of watershed hydrological processes (*e.g. Abraham et al., 2007; Easton et al., 2010*).

The basic principle behind the SWAT model is that a basin can be divided into several subbasins, in which only one main stream exists. Next to the stream, other information that is put into the model is divided into several categories: climate, hydrologic response units (HRU's), ponds and wetlands, and groundwater. HRU's are lumped land areas within the basin that have unique land use and soil properties (*Neitsch et al., 2011*). In general, HRU maps can be obtained by combining a land use map, a soil map and a slope map.

The hydrological processes within SWAT are based on several well-known hydrologic equations, using a general water balance equation as its basis. Here, the most important equations used by the model are given, which are derived from the SWAT manual (*Neitsch et al, 2011*).

The hydrologic cycle as used in SWAT is based on water balance equations for three distinct layers within the subsurface: the unsaturated zone, the shallow aquifer, and the confined aquifer. The three balance equations are comparable. Here, the water balance for the unsaturated zone is given by

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day,i} - Q_{surf,i} - E_{a,i} - w_{seep,i} - Q_{lat,i}) \qquad (1)$$

where SW_t is the final soil water content, SW_0 is the initial soil water content on day i, R_{day} is the amount of precipitation on day i, Q_{surf} is the amount of surface runoff on day i, E_a is the amount of evapotranspiration on day i, w_{seep} is the amount of percolation on day i, and Q_{lat} is the amount of lateral flow on day i. All parameters have the unit mm.

3.1.2 Evapotranspiration

For evapotranspiration, the Penman-Monteith equation is used, since daily meteorological data is available. The Penman-Monteith equation combines components that account for energy needed to sustain evaporation, the energy required to remove the water vapour, and aerodynamic and surface resistance terms. The equation for potential evapotranspiration is defined as

$$\lambda E = \frac{\Delta \cdot (H_{net} - G) + \rho_{air} \cdot c_p \cdot [e_z^0 - e_z]/r_a}{\Delta + \gamma \cdot (1 + r_c/r_a)} \tag{2}$$

Here, λE is the latent heat flux density ($MJ\, m^{-2}\, d^{-1}$), E is the evapotranspiration ($mm\, day^{-1}$), Δ is the slope of the saturation vapour pressure-temperature curve (kPa $°\text{C}^{-1}$), H_{net} is the net radiation ($MJ\, m^{-2}\, d^{-1}$), G is the heat flux density to the ground ($MJ\, m^{-2}\, d^{-1}$), ρ_{air} is the air density ($kg\, m^{-3}$), c_p is the specific heat of air at constant pressure ($1.013 \times 10 - 3\ \text{MJ kg}^{-1}\, °\text{C}^{-1}$), e_z^0 is the saturation vapour pressure of air at height z (kPa), e_z is the water vapour pressure of air at height z (kPa), γ is the psychometric constant ($\approx 0.067\ \text{kPa}\ °\text{C}^{-1}$) (*Hendriks, 2010*), r_c is the plant canopy resistance ($s\, m^{-1}$), and r_a is the aerodynamic resistance ($s\, m^{-1}$).

The slope of the saturation vapour pressure-temperature curve is obtained using the following equation:

$$\Delta = \frac{4098 \cdot e^0}{(\bar{T}_{av} + 237.3)^2} \tag{3}$$

where e^0 is the saturation vapour pressure on a given day (kPa) and $\bar{T}_{av}$ is the mean daily air temperature (°C). e^0 can be calculated using

$$e^0 = \exp\left[\frac{16.78 \cdot \bar{T}_{av} - 116.9}{\bar{T}_{av} + 237.3}\right] \tag{4}$$

The water vapour pressure of air is calculated using the relative humidity. Relative humidity is the ratio of an air volume's actual vapour pressure to its saturation vapour pressure,

$$R_h = \frac{e}{e_0} \tag{5}$$

where R_h is the relative humidity on a given day, e is the actual vapour pressure on a given day (kPa), and e^0 is the saturation vapour pressure on a given day (kPa). To determine the actual evapotranspiration, SWAT first evaporates the rainfall that is intercepted by the plant canopy. Then it calculates the maximum amount of transpiration and soil evaporation, using equations from Neitsch et al. (*2011*).

The net radiation is calculated adding the net shortwave radiation and net longwave radiation together. Both these parameters are calculated using the solar radiation. The net shortwave radiation includes the soil albedo in its calculation, whereas the longwave radiation includes temperature and actual vapour pressure (*Neitsch et al., 2011*). The heat flux density to the ground is assumed to be zero within the SWAT model, since the heat stored when the soil warms early in the day is lost when the soil cools late in the day or at night. Surface resistance and aerodynamic resistance are both dependent on land use. For most land use types, a standard value is given in literature that is determined by plant height, roughness, etc. (e.g. *Hendriks, 2010*).

3.1.3 Surface runoff

Another important feature that needs to be calculated is the surface runoff within the basin. The SWAT model uses the Soil Conservation Service (SCS) curve number (CN) method to model this process. One of the advantages of the SCS-CN method is that it uses only one parameter, the curve number CN. It is a function of the most important components that produce runoff. The equation equals

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \quad (6)$$

where Q_{surf} is the surface runoff, R_{day} is the daily rainfall in mm, I_a is the total initial abstraction including interception, surface storage and infiltration, and where S is the retention parameter. The initial subtractions I_a are usually assumed to be equal to $0.2 \cdot S$ (*Neitsch et al., 2011*). The retention parameter S is defined as

$$S = 25.4 \cdot \left(\frac{1000}{CN} + 10\right) \quad (7)$$

with CN being the curve number for a given soil and land use combination. It is a function of the soil's permeability, land use and antecedent soil water conditions. There are three antecedent soil moisture conditions determined, being 'dry but above wilting point', 'average', and 'near saturation' (*Dingman,* 2010). Furthermore, there are four hydrologic soil groups, classified on the basis of their infiltration capacity. Hydrologic condition is qualified as either 'good' or 'poor' per soil. Another major feature in determining the SCS curve number is the land use. For this parameter, a user can create his own classes or use predefined classes, which are available in SWAT. In this study, predefined classes were used.

3.1.4 Data input

In order to run the model successfully, data concerning topography, soils, hydrology, climate, land use and plant properties were needed. During a field study from March 6th to May 22nd 2015, river discharge, plant properties and soil properties were measured. Next to the fieldwork, a DEM was provided by Utrecht University, a soil map was obtained from the Food and Agriculture Organization (FAO), available discharge data was received from the Ministry of Natural Resources in Ethiopia (MNRE), and climatological data was downloaded from the National Centers for Environmental Prediction (NCEP) online database, supplemented with data from the LIVES project. An overview of the data is given in Table 1.

Table 1: Data needed for modelling the hydrology of the Genale River basin. The location where the data was retrieved is given.

Data	Location
DEM	Database Utrecht University
Climatic variables	Datasets from NCEP and extra meteo-stations of LIVES
Land use maps	Literature (*Van den Bout, 2015*)
Land use properties	Fieldwork and literature (*e.g. Dingman, 2002; Neitsch et al, 2011*)
Rooting depth	SWAT database and fieldwork
Soil map	FAO Database
Soil properties	Literature (*BZW, 2013*), SWAT database and fieldwork
River discharge	Fieldwork

3.1.5 Model application

Calibration of the SWAT model was done using the discharge data from the MNRE. The first five years of the dataset were used as calibration values. Before calibration was done, a sensitivity analysis was done. SWAT-cup is part of the SWAT model which allows to find sensitive parameters in the model and to conduct sensitivity analyses. The eight most sensitive parameters were selected and given a value range in SWAT-cup. During calibration, the software defines the best fitting scenario using the observed values.

To determine whether a model performs acceptable, different statistics were calculated. The Nash-Sutcliffe simulation efficiency (E_{ns}), and the root mean square error (RMSE) were used.

The E_{ns} indicates how well the plot of observed versus simulated values fits the 1:1 line (*Nash and Sutcliffe, 1970*). E_{ns} ranges from 1 to -∞, with 1 being a perfect fit. E_{ns} is defined as

$$E_{ns} = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2} \quad (8)$$

The RMSE indicates the error between observed and simulated values (*Alansi et al., 2009*). A value of 0 indicates a perfect fit. The larger the RMSE gets, the larger the error is. It has the same unit as the data to which it is applied. Its equation is given by

$$RMSE = \sqrt{\frac{\sum(\hat{y}_i - y_i)^2}{n}} \quad (9)$$

where y_i is the observed discharge on day i, $\hat{y}_i$ the modelled discharge on day i, $\bar{y}$ the mean of the observed discharge, and n is the number of observations.

Apart from gaining insight in the current situation, the model was also applied to run various scenarios. The scenarios that were used were divided into two categories. In the first category, the land use map of 2015 was adapted to see the influence of coffee. The scenarios were based on the land use map of 2015, in which the area under coffee was multiplied by 0.8, 0.9, 1.1 and 1.2 to see how this would affect the hydrological cycle. In the second category, scenarios were made that represent land use changes in the future.

3.2 Data collection and analysis

3.2.1 Topography

Topographical data was available as a digital elevation model (DEM). To define the boundaries of the watershed and its subbasins, the DEM was analysed in a GIS environment. The DEM that was used is based on the ASTER GDEM (ASTER GDEM is a product of Ministry of Economy, Trade and Industry and NASA), kindly provided by Utrecht University. It has a grid size of one arcsecond, which corresponds to approximately 30 meters.

Several locations were chosen where discharge will be measured in the Genale River, and, using these locations, the corresponding watersheds draining to this point were determined. A requirement for the location of measurements was that there was an abundance of coffee-based agroforestry within the subbasin.

3.2.2 Climatological data

Weather data was downloaded from NCEP. This database uses data from the Climate Forecasting System Reanalysis (CFSR). It contains global meteorological data for each day between 1979 and 2014 in a 38-km grid (*Fuka et al., 2013*). It includes precipitation, maximum temperature, relative humidity, solar radiation and wind speed. CFSR was created and used as a global, high-resolution coupled atmosphere-ocean-land surface-sea ice system in order to give the best estimation of the state of these three domains. To provide more accuracy in predictions, data assimilation was incorporated (*Saha et al., 2010*). Daily data from 16 grid points (appendix A) was downloaded to cover the whole catchment.

Extra data on precipitation was received from the LIVES project. In Yaye, the district town of Arbegona, a rain gauge was placed in April 2014 and is recording since. At the moment, this is the only accessible rain gauge within the catchment. The overlapping 10-month period of the online database and the rain gauge were used to validate the correctness of the NCEP database.

3.2.3 Hydrological data

Discharge data was available from MNRE who have measured daily discharges at location 3 (Figure 2) from 1997 until 2006. Only in 2005, four months were missing. The area that was covered by the drainage point where the measurements were done has an approximate size of 719 km^2. The dataset was evenly split in two parts and one part was used for calibration and the other for validation of the model.

On two other locations within the catchment (Figure 2, locations 1 and 2), extra discharge data was obtained. At these locations, an area of respectively 315.3 km^2 and 44.3 km^2 drains to these points. In the period between March 6th and May 22nd, the discharge was measured several times using a SENSA RC2 Water Velocity Meter. The SENSA uses the Faraday principle of electro-magnetic induction. It is exceptionally sensitive, making it ideal for slow and shallow flows in both clean and dirty water. Furthermore, it has a reading accuracy of ± 0.5% (*HSL, 2010*). Unfortunately, due to lack of rainfall during the fieldwork, only the base flow was measured.

3.2.4 Land use data

Satellite images with 30 m resolution from the Landsat satellite database were used to determine land use. These images were processed by Van den Bout (*2015*), providing four land use classifications from the years 1985, 1993, 2003 and 2015. The land use maps of 1985 and 2015 were used in this report to represent past and present. All four years together were used to determine land use changes in the past. The observed trends were then extrapolated into the future. The land use map of 2015 was used as the starting point for all created scenarios.

In this study, seven classes were defined for land use: rangeland, forest, grazing land, ensete, agricultural land, coffee and residential areas. There are no significant water bodies in the basin. For all types of land use, plant properties were recorded to implement in the SWAT database. These properties include plant height, canopy cover, leaf area index, rooting depth and growth patterns. This data was collected using several 4 m diameter circles per land use along five transects with a length of 2 km long transects. Data that was not measurable in the field was derived from literature. These properties include plant canopy resistance and aerodynamic resistance amongst others. Hendriks (*2010*) provides several values for the resistances based on a general classification. For different land use types, typical curve numbers are listed in both Dingman (*2002*) and Neitsch et al. (*2011*). These values were also put into the SWAT database.

3.2.5 Soil data

A soil map was derived from the Food and Agriculture Organization (FAO). This map contains the extent of all soil types in a 900 m grid, containing basic values for all soils. The soil data provided by Yilma (*2013*) was used to gain extra precision, combined with several soil cores in the catchment and a soil core from BZW (*2013*).

Soil properties that were needed per soil class were soil depth, moist bulk density, available water capacity, saturated hydraulic conductivity, erodibility, organic matter, texture, and the soil hydrologic group (A, B, C or D), which determines the infiltration rate. These values were already provided in the SWAT database. The available soil cores were used to compare with the given values.

4. Results and discussion

The four maps that were produced as input for the SWAT model are shown in Figure 3. From the DEM it appeared that the lowest point in the area, the drainage point, is located at 1356m above sea level, whereas the highest point lies at 3670m above sea level. Most of the area, 61%, has slopes gentler than 10°. Only 1.7% of the slopes were steeper than 30°. The dominant soil types in the catchment were Luvisols (30.9%), Phaeozems (15.0%), Vertisols (13.3%), and Andosols (10.3%).

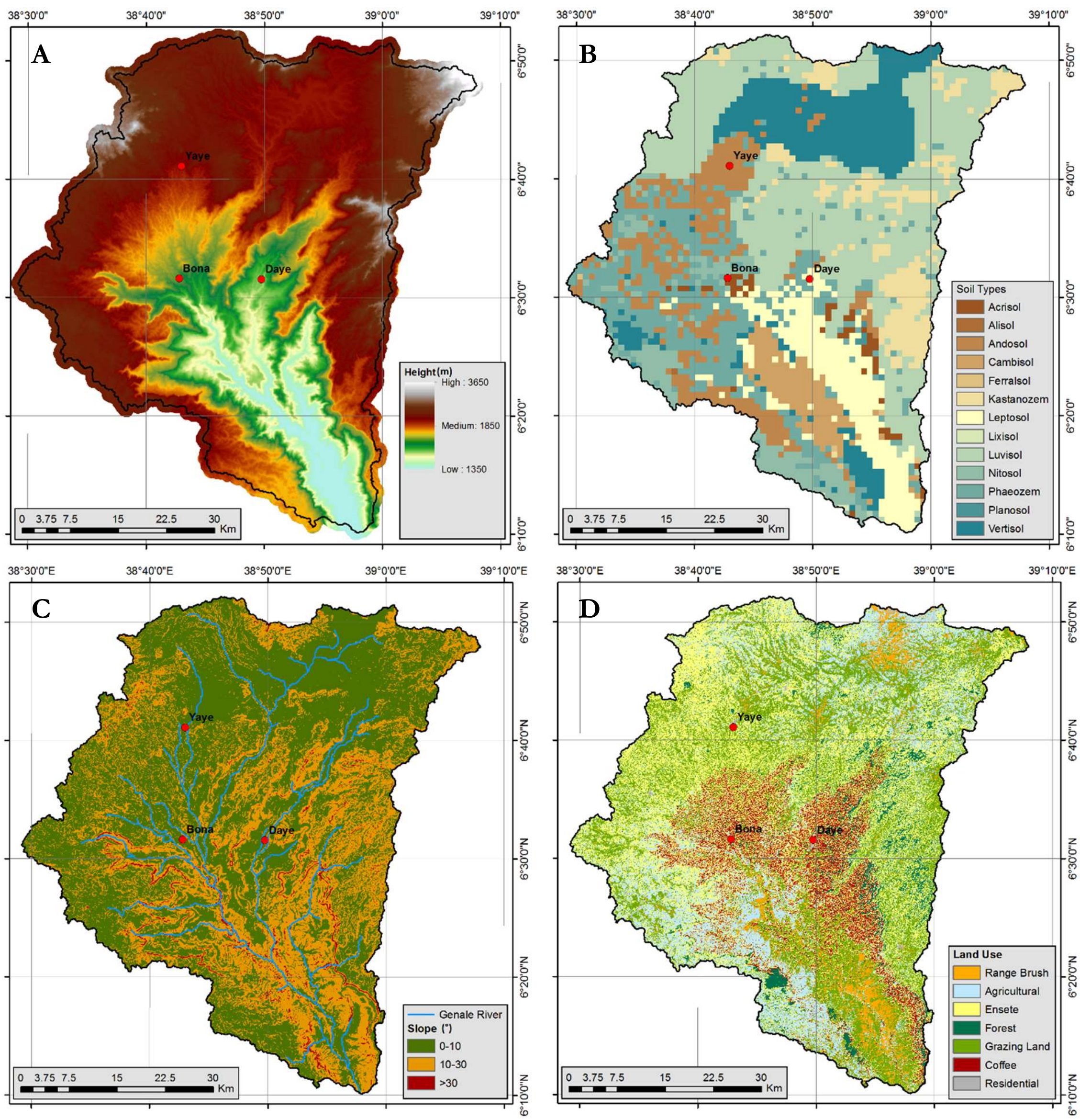

Figure 3: Characteristics of the Genale River basin in the Sidama Zone, Ethiopia. A: DEM. B: Soil map. C: Slope map. D: Land use map of 2015.

4.1 Calibration and validation

Weather and discharge data for the model calibration run from April 1997 until December 2001, and for validation from January 2002 until December 2006. Between the 19th of June and the 15th

of October in 2005, no discharge data was available. Using these datasets, the model was run with the land use map that represents the situation between 1997 and 2006 best, that is, the land use map of 2003. SWAT-cup was used for the calibration of the model. Five simulations of 500 runs each were applied. The first simulation used wide ranges for the eight most sensitive parameters in the model that were defined by SWAT-cup (Table 2). In the next simulation, the ranges were reduced, until the final values for all parameters were calculated. With these values, validation was also performed. The outcome of the calibration and validation process is shown in Figure 4. In Table 3 the results from the statistical measurement techniques that were used to verify the model performance are shown.

Table 2: Eight parameters from SWAT that appeared most sensitive during the sensitivity analysis. The given ranges are used during the first model run.

Parameter	Description	Range
GW_REVAP	Water evaporation coefficient from groundwater (-)	0.1 - 0.3
SOL_AWC	Available water capacity in soil layer (mm mm^{-1})	± 40%
ALPHA_BF	Base flow recession constant (days)	0 - 1
SOL_K	Soil conductivity (mm hour^{-1})	+- 80%
SURLAG	Surface runoff lag coefficient (-)	0 - 10
GWQMN	Threshold water depth in the shallow aquifer for base flow (mm)	0 - 3000
GW_DELAY	Groundwater delay time (days)	± 80%
CN2	Initial SCS CN value (-)	± 30%

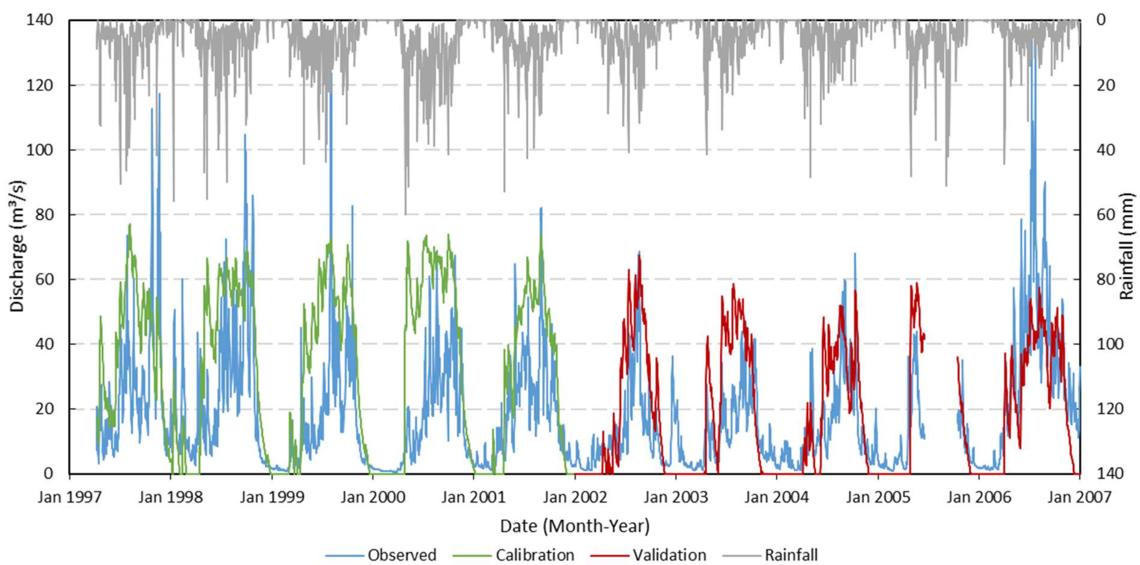

Figure 4: Calibration and validation model outcome visualized, together with the observed discharge. In grey, rainfall data from the NCEP is given. Statistics are given underneath the graph.

Table 3: Statistical analysis of the model calibration and validation.

Function	period	RMSE	E_{ns}
Calibration	Apr 1997 – Dec 2001	23.15	-0.59
Validation	Jan 2002 – Dec 2006	15.06	0.23

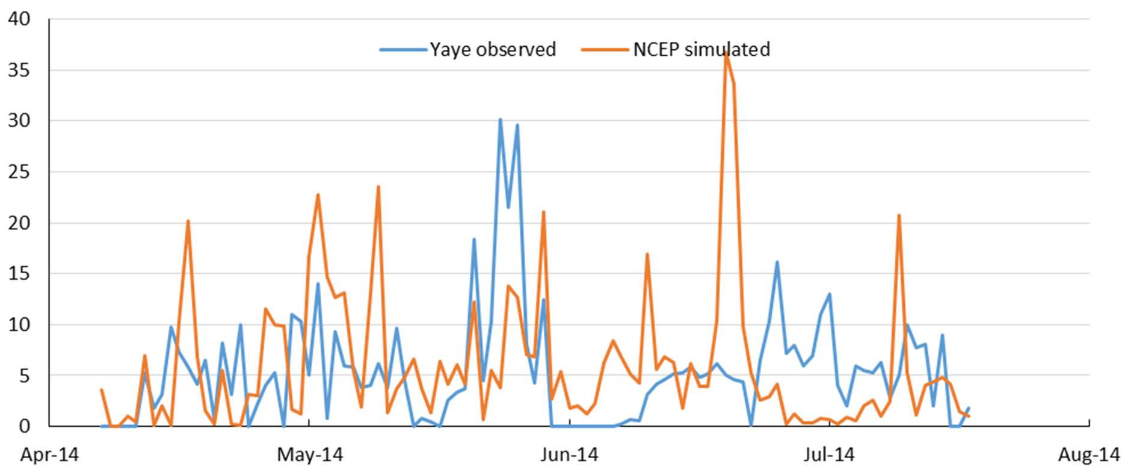

Figure 5: Comparison between observed rainfall (blue) in Yaye, Arbegona, and NCEP simulated rainfall (orange).

It appears that the calibrated discharges in the model are too high at the beginning of the rainy season in comparison to real discharges. This is most obvious in 2000. Large rainfall events seem to be not well represented in the data of the NCEP, as can be seen for example in November 1997, June 1999 and June 2006. Furthermore, the base flow regularly reduces to 0 m^3/s in the dry season. The observed discharges vary from 0.5 to 5 m^3/s in the dry season.

In Figure 5, the observed rainfall in the district of Arbegona is compared to the simulated rainfall data of the NCEP. The measurements in Arbegona only started in April 2014, leaving no possibility to compare the rainfall data during the period of calibration. The comparison shows that the timing of rainfall events is accurate, but the amounts of rain differ widely. The simulated rainfall sometimes underestimates the rainfall, for example during the end of May, but also overestimates rain, for example during the month of June. This could be an indication that the rainfall data of the NCEP cause a small error in the model, although there is no possibility to verify this.

An explanation for the disappearing base flow could be ascribed to the small groundwater reservoirs simulated in the model. There is very little recharge in the reservoir, which indicates that as soon as the rain season ends, the reservoir does not have enough water to sustain the river during the whole dry season. From the observed values (figure 4), it is visible that at the end of the dry season, the base flow can decrease to very small values of about 0.5 m^3/s. This is for example visible in 1999 and 2000. This could mean that if the dry season would last longer, the discharge could indeed decrease to 0 m^3/s. Increasing the size of the reservoirs resulted in decreased model performance.

Comparing the calibration and the validation, the statistics show that the model performs better in the validation period. The RMSE has decreased with almost 35% and E_{ns} gets considerably closer to one (Table 3). Despite the errors in the model results, it was assumed that the model reasonably simulates the hydrology of the catchment.

4.2 Coffee-based agroforestry in 2015

The area under coffee production in 2015 was 251.3 km^2. This is almost 8% of the total area of the catchment, which has a size of 3178.6 km^2. The coffee was mainly located between 1600m and 2500m above sea level, since this area has the best weather conditions for coffee growth. Coffee plantations were mostly located on Luvisols (63.0 km^2), Phaeozems (61.6 km^2), and Leptosols (57.8 km^2). Coffee plantations were seldom planted on steeper slopes than 30°. The total area of coffee on these slopes was 7.4 km^2. Areas with slopes between 0° and 10° and between 10° and 30° have 128.0 km^2 and 115.9 km^2 coffee, respectively.

There is no clear relation between soils and land use in the catchment (Table 4). This is mainly so because farmers usually do not use soil types for certain land uses. The location different land use types are mostly dependent on their position and slope, and not so much on soil type. There are some minor relations to be seen between land cover and soils. The reason behind this is that some soils are found only at certain heights or locations. Vertisols are mostly found above 2400m, and are logically rare on coffee fields. Grazing land is mostly found on Luvisols and Vertisols since these soils dominate the highlands. Leptosols are mostly found along the main stream of the Genale River. Here, a lot of coffee and rangeland is found.

A relationship between slope and land use is more easily seen (table 5). Because steep slopes cover a small area of the total catchment, the percentages are much smaller in this class than the other two classes. Nevertheless, it is clear that there is relatively more forest on steeper slopes than for other land cover. Next to forest, coffee is also found on steeper slopes. This finds its origin in the fact that while deforesting an area, usually some trees were left to function as shade trees for coffee plantations. Most residential areas are found on the gentle slopes. In Table 6, values are given per land use class. Ensete and grazing land dominate most slope classes, but in this Table it becomes more visible that agricultural lands have a large share in the gentle sloped areas. The steepest slopes are, next to ensete and grazing land, mostly dominated by forests and coffee plantations.

Table 4: Land use of 2015 in percentages in the Genale River basin for different soil types.

Land cover	Andosol	Leptosol	Luvisol	Phaeozem	Vertisol	Other
Agriculture	9.9	6.2	27.5	17.4	20.7	18.2
Coffee	8.5	23.0	25.1	24.5	0.9	18.0
Ensete	13.3	6.9	35.7	17.6	7.4	19.1
Forest	12.9	5.4	33.2	9.2	2.7	36.7
Grazing land	9.0	9.3	30.5	11.6	20.5	19.2
Rangeland	1.7	26.0	13.0	3.9	35.9	19.4
Residential	16.6	11.6	10.8	27.3	17.0	16.8

Table 5: Land use of 2015 in percentages in the Genale River basin for different slope classes.

Land cover	0-10°	10-30°	30-45°
Agriculture	70.22	28.93	0.85
Coffee	50.94	46.12	2.94
Ensete	59.08	39.29	1.63
Forest	36.26	58.29	5.45
Grazing land	65.28	33.35	1.37
Rangeland	64.79	34.17	1.04
Residential	89.06	10.94	0.00

Table 6: Percentages of land use classes in 2015 per slope class.

Slope class	Agriculture	Coffee	Ensete	Forest	Grazing land	Rangeland	Residential
0-10°	21.61	6.58	34.81	3.43	28.52	4.84	0.21
10-30°	14.68	9.83	38.16	9.09	24.01	4.20	0.04
30-45°	9.42	13.58	34.35	18.45	21.44	2.77	0.00

Table 7: Size of hydrologic components shown for all found land use types in the Upper Genale River basin. Percentages are based on the amount of rainfall.

Land cover	Precipitation		Groundwater recharge		Evapo-transpiration		Surface runoff		Lateral flow	
	mm	%	mm	%	mm	%	mm	%	mm	%
Agriculture	1688.34	100.0	293.00	17.4	608.50	36.0	734.80	43.5	52.17	3.1
Coffee	1684.61	100.0	513.30	30.5	664.98	39.5	429.93	25.5	76.48	4.5
Ensete	1692.78	100.0	521.14	30.8	687.24	40.6	411.03	24.3	73.30	4.3
Forest	1694.28	100.0	653.00	38.5	618.48	36.5	330.70	19.5	92.17	5.4
Grazing land	1691.44	100.0	453.03	26.8	603.57	35.7	556.23	32.9	78.65	4.7
Rangeland	1686.77	100.0	180.78	10.7	547.32	32.5	916.86	54.4	41.66	2.5
Residential	1711.44	100.0	315.59	18.4	680.14	39.7	643.18	37.6	72.57	4.2

Table 8: Size of hydrologic components in coffee plantations per different soil type. Percentages are based on the amount of rainfall.

Soils	Precipitation		Groundwater recharge		Evapo-transpiration		Surface runoff		lateral flow	
	mm	%	mm	%	mm	%	mm	%	mm	%
Leptosols	1695.91	100.0	737.35	43.5	648.99	38.3	193.60	11.4	115.97	6.8
Luvisols	1699.66	100.0	568.40	33.4	681.54	40.1	372.57	21.9	77.13	4.5
Phaeozems	1698.07	100.0	295.43	17.4	681.10	40.1	660.36	38.9	61.19	3.6
Other	1675.51	100.0	499.65	29.8	643.36	38.4	478.82	28.6	53.68	3.2

Compared to the other land uses in the area, coffee has a relatively high evapotranspiration (Table 7). Only ensete and residential areas have a comparable evapotranspiration. A reason for this could be that the large area of roofs and broad ensete leafs give high evaporation rates. Surface runoff is low on coffee plantations compared to the other land uses. Only forest and ensete have a smaller runoff. This could be explained by the higher density of trees and plants that restrict the runoff. Land uses with low surface runoff generally have a higher groundwater recharge. The surface runoff, however, is next to land cover largely dependent on the soil type, as can be seen in Table 8, where the hydrologic components are shown for coffee plantations on different soils.

Table 7 shows that an increase in coffee could cause a change in the hydrology, although the changes will not be extreme, especially since ensete seems to have higher evapotranspiration and lower surface runoff. Only grazing land, rangeland and agricultural land have a much lower evapotranspiration. The same trend is visible for surface runoff, only grazing land, rangeland and agricultural land have a much higher surface runoff compared to coffee. This would imply that if these land uses are replaced by coffee, a change in hydrology might be visible. Otherwise, the differences are likely to be very small.

Not many studies have been conducted that investigate the influence of coffee-based agroforestry on the local hydrology. Legesse et al. (*2003*) showed that the discharge of the Ketar basin in Ethiopia would decrease with 8% when the present day dominantly grazing land would be converted to woodland, which would include coffee-based agroforestry. Verbist et al. (*2005*) on the other hand, drew the conclusion that changing the forested areas of Lampung, Sumatra to coffee-based systems would lead to a very small increase in the discharge-rainfall ratio. Both studies are in accordance to what is visible in Table 4. In order to check the trends seen in this Table, four coffee scenarios were created.

4.3 Coffee scenarios

Four scenarios, each having a different area covered with coffee-based agroforestry were implemented in the model. The situation of 2015 was used as the basis for these scenarios. In the first scenario (M20), the amount of coffee plantations was decreased by 20%. The second scenario (M10) has a coffee reduction of 10%, whereas the third (P10) and fourth (P20) scenarios had an increase of respectively 10% and 20% (Table 9). Apart from the area of coffee, other land use classes have changed slightly as well due to the coffee reduction and expansion. The change in coffee in the four scenarios is further shown in Table 10.

The difference in all the components of the hydrologic cycle is given for the extreme scenarios of M20 and P20 (Table 11). The values given in this Table are averaged values for a period of 32 years, between 1982 and 2013. The differences between the scenarios seem very small. Nevertheless, the difference in discharge between the situation in 2015 and the M20 scenario is 239.48 $m^3/hour$ and between 2015 and P20 the difference is -740.21 $m^3/hour$.

Table 9: Land use in percentages in the Genale River basin for all four coffee scenarios, including the land use in 2015.

Land cover (in %)	M20	M10	2015	P10	P20
Agriculture	18.98	18.82	18.98	18.58	18.43
Coffee	6.42	7.17	7.87	8.61	9.33
Ensete	36.97	36.69	35.95	36.09	35.81
Forest	5.85	5.80	5.77	5.71	5.67
Grazing land	27.00	26.79	26.68	26.33	26.10
Rangeland	4.64	4.59	4.60	4.54	4.52
Residential	0.14	0.14	0.15	0.14	0.14

Table 10: Changes in coffee area in the basin in hectares and percentages in all four scenarios. The changes are relative to the situation in 2015.

Scenario	Coffee area		Coffee changes	
	ha ($\times 10^3$)	%	Ha ($\times 10^3$)	%
M20	20.41	6.42	-4.61	-18.43
M10	22.79	7.17	-2.23	-8.91
2015	25.02	7.87	0.00	0.00
P10	27.37	8.61	+2.35	+9.39
P20	29.66	9.33	+4.64	+18.55

Table 11: Influence of the different scenarios on the hydrologic components in the basin. Difference is shown in percentages relative to the situation in 2015. Values are averaged over a period of 32 years between 1982 and 2013.

Component	M20		2015	P20	
	mm	%	mm	mm	%
Precipitation	1699.70	+0.00	1699.70	1699.70	+0.00
Surface runoff	565.49	+0.25	564.07	558.68	-0.96
Lateral flow	118.73	-0.15	118.91	119.42	+0.43
Return flow	281.02	-0.20	281.58	284.25	+0.95
Discharge	983.08	+0.07	982.42	980.38	-0.21
Evapotranspiration	654.40	-0.09	655.00	656.90	+0.29
Revap. from shallow aquifer	60.31	-0.03	60.33	60.55	+0.36
Percolation	359.30	-0.17	359.90	362.96	+0.85
Recharge to deep aquifer	17.96	-0.22	18.00	18.15	+0.83

Table 12: Discharge values for the Genale River in the Sidama zone. Discharges are given for three different weather situations and three different coffee scenarios.

Scenario	Discharge					
	Dry year		Average year		Wet year	
	m³/sec	%	m³/sec	%	m³/sec	%
M20	50.20	+0.19	80.54	+0.11	177.22	+0.04
2015	50.11	0.00	80.45	0.00	177.14	0.00
P20	49.93	-0.37	80.20	-0.32	176.74	-0.22

Table 13: Evapotranspiration values for the Genale River basin in the Sidama zone. Evapotranspiration is given for three different weather situations and three different coffee scenarios.

Scenario	Evapotranspiration					
	Dry year		Average year		Wet year	
	mm	%	mm	%	mm	%
M20	685.15	-0.12	679.49	-0.13	649.42	-0.12
2015	686.00	0.00	680.40	0.00	650.20	0.00
P20	688.47	+0.36	684.24	+0.56	653.86	+0.56

Table 14: Surface runoff values for the Genale River basin in the Sidama zone. Surface runoff is given for three different weather situations and three different coffee scenarios.

Scenario	Surface runoff					
	Dry year		Average year		Wet year	
	mm	%	mm	%	mm	%
M20	280.49	+0.43	477.71	+0.29	1067.57	+0.21
2015	279.30	0.00	476.32	0.00	1065.38	0.00
P20	271.77	-2.70	466.41	-2.08	1052.50	-1.21

Next to the average values in the past 32 years, six years have been chosen based on the amount of rainfall to represent extreme weather conditions. The years were divided into two wet years, two average years, and two dry years. Most of the years were chosen within the calibration and validation period (Figure 6). For each specific weather condition (wet, average and dry), the monthly rainfall was averaged using the two years to remove any extremities in rainfall. The three situations were then used to investigate for three important aspects of the hydrological cycle, specifically actual evapotranspiration, surface runoff and discharge. The effect of land use changes on these components is presented in Table 12 to 14. The values in Table 12 show that in a situation with more coffee-based agroforestry, the discharge decreases slightly.

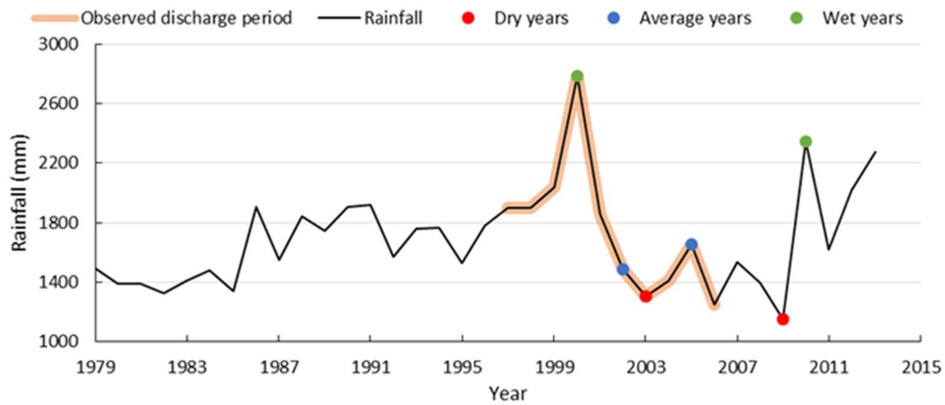

Figure 6: Yearly rainfall in the Sidama Zone. The orange line shows the period in which discharges are measured in the Genale River. The years that are used for the different weather situation are mostly chosen during this period.

The actual evapotranspiration is higher when there is more coffee, although the differences are small. For the M20 scenario, the difference in percentages is equal for all three weather conditions. For P20 however, there is a dissimilarity. During a dry year, the increase is smaller than for an average or wet year. When looking at the surface runoff, it appears that less coffee leads to an increase in surface runoff. During a wet year, the difference seems smaller than during a dry year.

Since coffee-based agroforestry includes several layers of vegetation, being undergrowth, coffee bushes and shade trees, it follows that having more coffee plantations will lead to a higher evapotranspiration than during the previous period in which there was more grazing land, ensete and agricultural land. The thicker vegetation layer holds more water, and has more leaf surface area from which the water is then evaporated. Less water can reach the surface, and thus the surface runoff decreases. More water is taken up from the soil, and less water reaches the streams and rivers because of decreased return flow and discharge logically decreases. The difference in discharge between 2015 and the P20 scenario is almost 18 thousand cubic meters per day. The difference between 2015 and the M20 scenario equals almost 6 thousand cubic meters per day.

The difference in discharge between M20 and 2015 and between P20 and 2015 is small. Adding more coffee does have a much larger influence on discharge than removing coffee. This could be explained by the way coffee is replaced with other land use when the area under coffee production is reduced. There was no controlling mechanism used to check for this process. The accuracy could be improved by running the model using more scenarios with for example a change of 30 or 40% coffee.

The decrease in discharge for the Genale River implies that when there is more coffee in a basin, there is less irrigation potential, which in turn decreases the potential crop yield of irrigated crops. This will prove to be a downside when coffee-based agroforestry increases. Next to the decrease in irrigation potential, less drinking water can be extracted from the river and smaller brooks. A third downside is the increased potential of droughts. During years with insufficient rainfall, relatively more water will be used by coffee plantations, leaving even less water in the soil for other uses. Even so, the differences are small, and only a large shift in land use could lead to potentially problematic situations.

4.4 Land use changes

Between 1985 and 2015, the land use in the catchment has changed considerably. Back in 1985, the two most dominant land use types were grazing land and forest, covering 49% and 40% of the total area respectively. With just over 5% of the total area, ensete was the largest cultivated land use. Nowadays, grass and forest cover 27% and 6% respectively, mostly at the expense of the growth in ensete, coffee and agricultural land. This indicates that grazing land and forest have declined in a fast pace during the past 30 years (Figure 7, Table 15). On the other hand, ensete, agricultural land and coffee are increasing rapidly to keep up with the population growth.

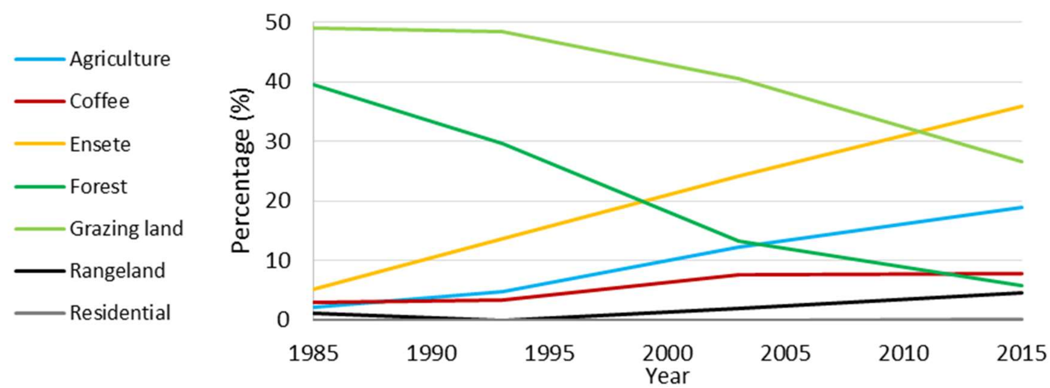

Figure 7: Land use changes shown in the past 30 years in the Upper Genale River basin, Sidama Zone.

Table 15: Land use changes in the past 30 years in the Upper Genale River basin, Sidama Zone in percentages.

Land cover (in %)	1985	1993	2003	2015
Agriculture	2.26	4.80	12.23	18.98
Coffee	2.89	3.43	4.56	7.87
Ensete	5.19	13.64	24.20	35.95
Forest	39.54	29.64	13.31	5.77
Grazing land	48.89	48.44	40.59	26.68
Rangeland	1.21	0.01	2.07	4.60
Residential	0.02	0.04	0.05	0.15

Based on the clear trends from the past, predicting what the future will look like can be done. There are however some aspects that should be taken into account. The government of Ethiopia is trying to stop the deforestation in the country. Although there is still considerable deforestation, the rate in which it occurs is declining fast. This would mean that in the future, there will only be a few hectares of forest left in the catchment. Next to the decline in forest, grazing land will also decrease at the expense of agricultural land and ensete. Although there is still a lot of livestock, it is being fed with ensete leaves with increasing regularity.

Since Ethiopia currently has one of the fastest growing populations in the world, the staple food ensete is due to increase further in the region. The clear linear trend in growth will most likely continue in the future. Agricultural land is likely to develop faster in the future than Figure 7 shows. The increase in coffee can only be speculated about, as it is greatly depending on the coffee market.

Apart from the increase in size for certain land use, there are also changes within the separate classes. This is especially true for agricultural land. Chat, a common drugs in Ethiopia and surrounding countries, is becoming a popular cash crop, and takes up space at the expense of other crops. Next to chat, vegetables and fruits are introduced and add up to the diversity of the land use. This is the main reason for the expected growth in agricultural land.

Concerning coffee-based agroforestry, it has becomes apparent that there is an increase in using extra undergrowth as a soil protection measure. Elephant grasses (*Pennisetum purpureum*) in particular are commonly used. This will, obviously, alter the preferential paths of surface runoff, and more water is potentially taken up within the plots where these measurements are implemented.

4.5 Future scenarios

Now that it is assessed that coffee-based agroforestry does have a small influence on the local hydrology, it is important to see how the hydrology might be altered in the future. There are several things to be taken into account when the future is concerned. As stated previously, the land use is not only changing in area, but in composition as well, such as changing crop types and integrated cropping systems, like elephant grass in coffee-based agroforestry. The trends seen in land use changes were implemented in SWAT for the future scenarios, although it is difficult to predict how the alterations will impact hydrology. Because of the uncertainty in coffee growth, four scenarios were created for the year 2050. In these scenarios, the land use classes vary in size.

In all created scenarios, rangeland area increases with a few hectares to compensate for the more extreme weather conditions. Both drought and flooding can cause more strain on plants that grow on difficult spots, such as steep sloping hills, and locations with insufficient soil depth. Forest decreases in all cases, although it does not disappear. Grazing land is about to halve in 2050. Livestock will mostly be fed with ensete leaves. Ensete will increase further along the linear trend that was visible in the past thirty years. This has mainly to do with the increasing population in the catchment. Agricultural land will almost double, because of the introduction of new vegetables and fruits, along with the seemingly unstoppable growth in chat. The residential area will remain comparably small, but does increase. Finally, coffee seems highly variable when it comes to predicting the future.

In the first scenario, F1, the market price of coffee has reduced, and thus there will be less coffee produced. In scenario F2, the amount of coffee stays roughly the same. The coffee market is still stable, and no new coffee producing countries have entered the market. The last two scenarios, being F3 and F4, have a considerable increase in coffee production. Especially F4 shows a large increase. This could for instance be due to an increasing crop yield and increasing popularity of Ethiopian coffee on the coffee market. In Table 16, the percentages of land use are shown per scenario, including the percentages of 2015 for comparison.

Table 16: land use in the basin for future scenarios. 2015 is added for comparison. Value are given in percentages.

Land cover (in %)	2015	F1	F2	F3	F4
Agriculture	18.98	34.00	33.58	33.05	32.46
Coffee	7.87	5.68	7.94	11.49	13.94
Ensete	35.95	41.57	40.64	38.49	37.40
Forest	5.77	1.56	1.47	1.45	1.45
Grazing land	26.68	11.49	10.81	10.08	9.46
Rangeland	4.60	5.48	5.36	5.24	5.08
Residential	0.15	0.22	0.21	0.21	0.21

Table 17: Influence of the different scenarios on the hydrologic components in the basin. Difference is shown in percentages relative to the situation in 2015.

Component	2015	F1		F2		F3		F4	
	mm	mm	%	mm	%	mm	%	mm	%
Precipitation	1699.7	1699.7	+0.0	1699.7	+0.0	1699.7	+0.0	1699.7	+0.0
Surface runoff	564.1	600.9	+6.5	598.7	+6.1	596.3	+5.7	593.4	+5.2
Lateral flow	118.9	111.6	-6.2	111.9	-5.9	112.1	-5.7	112.5	-5.4
Return flow	281.6	253.7	-9.9	254.8	-9.5	256.2	-9.0	257.8	-8.5
Total water yield	982.4	982.3	-0.0	981.6	-0.1	981.0	-0.1	980.1	-0.2
Evapotranspiration	655.0	659.2	+0.6	659.9	+0.7	660.4	+0.8	661.1	+0.9
Revap. from shallow aq.	60.3	56.2	-6.8	56.3	-6.6	56.5	-6.4	56.7	-6.1
Percolation	359.9	326.3	-9.3	327.6	-9.0	329.2	-8.5	331.0	-8.0
Recharge deep aquifer	18.0	16.3	-9.4	16.4	-9.1	16.5	-8.6	16.6	-8.1

Next to land use, the future climate also needs to be assessed. It appears from the IPCC report that the precipitation in Ethiopia is likely to increase, although it is expected that the overall rainfall in the northwest of Africa is to decrease (*Niang et al., 2014*). In Figure 6 however, it appears that precipitation in the Sidama Zone is not so much increasing or decreasing, but rather getting more extreme. Dry years get very dry, and wet years are likely to become even wetter. It is therefore decided to assess the same wet, average and dry years as was done for the coffee scenarios.

The amount of water for each different hydrological component, averaged for the years between 1982 and 2013 is given in Table 17, and shows again a trend in decreasing discharge when there is more coffee present, even though the amount of agriculture is increasing as well. In the F4 scenario, the discharge will decrease with 20.000 cubic meters per day. The increased agricultural fields cause higher surface runoff, but lateral flow and return flow decrease considerably, eventually causing a lower discharge nonetheless. This shows that the water uptake of coffee-based systems is larger than for agricultural land. The values of scenarios F2 and F3 confirm these trends.

Figure 8 shows the difference in discharge, evapotranspiration and surface runoff for the three weather conditions, all in comparison to the situation of 2015. Tables 18 to 20 show the yearly averaged values of three important components. It is clear that the discharge of the Genale River will most likely show a small decrease in the near future due to land use changes, especially during the rainy season the difference is clear. Apart from the period July to September, evapotranspiration increases throughout the year. Surface runoff will increase throughout the year, most likely because of the increasing amount of agricultural land. This is also confirmed in Figure 9, where the yearly averaged discharge is shown. From this figure, it is evident that there are more factors present next to coffee-based agroforestry that cause the decrease in discharge, since scenario F2 reveals that the discharge decreases as well when the coffee plantations are not extended, even though it is not as extreme as for scenarios F3 and F4. The latter two show that increasing the area under coffee production does have an impact on the discharge in the catchment. It is evident that there are other factors that influence the discharge in the future. These factors are not included in this report, since they were not determined in this study. Apart from that, it is also unclear how agricultural fields will develop in the future. Will the introduction of new fruits and vegetables continue? Will chat indeed increase as much as here anticipated? How will farmers react to the market and the changing land use around them? These questions all influence the quality of the scenarios predictions.

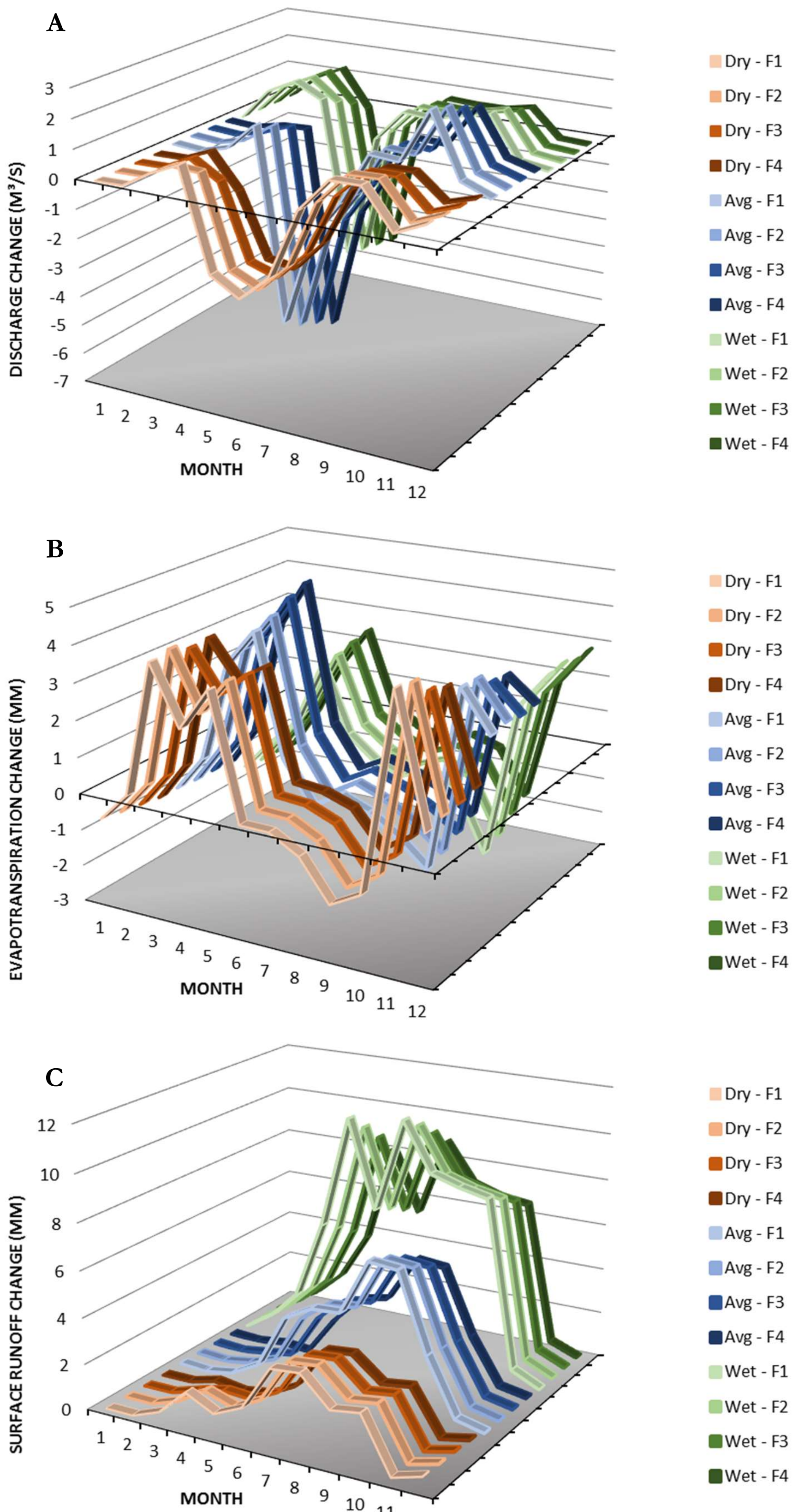

Figure 8: Differences in discharge (A), evapotranspiration (B), and surface runoff (C) between 2015 and different combinations of future scenarios and weather conditions. Values of the situation of 2015 are subtracted from the future situation. The different colours show weather conditions and intensity shows different scenarios.

Table 18: Discharge values for the Genale River in the Sidama zone. Discharges are given for three different weather situations and three different future scenarios.

Scenario	Discharge					
	Dry year		Average year		Wet year	
	m³/sec	%	m³/sec	%	m³/sec	%
2015	50.11	0.00	80.45	0.00	177.14	0.00
F1	49.90	-0.42	80.20	-0.32	177.37	0.13
F4	49.56	-1.09	79.88	-0.71	177.02	-0.07

Table 19: Evapotranspiration values for the Genale River basin in the Sidama zone. Evapotranspiration is given for three different weather situations and three different coffee scenarios.

Scenario	Evapotranspiration					
	Dry year		Average year		Wet year	
	mm	%	mm	%	mm	%
2015	686.00	0.00	680.40	0.00	650.20	0.00
F1	696.62	+1.55	687.86	+1.10	649.89	-0.05
F4	698.19	+1.78	690.53	+1.49	653.42	+0.49

Table 20: Surface runoff values for the Genale River basin in the Sidama zone. Surface runoff is given for three different weather situations and three different coffee scenarios.

Scenario	Surface runoff					
	Dry year		Average year		Wet year	
	mm	%	mm	%	mm	%
2015	279.30	0.00	476.32	0.00	1065.38	0.00
F1	296.73	+6.24	504.85	+5.99	1127.13	+5.80
F4	291.37	+4.32	497.86	+4.52	1114.93	+4.65

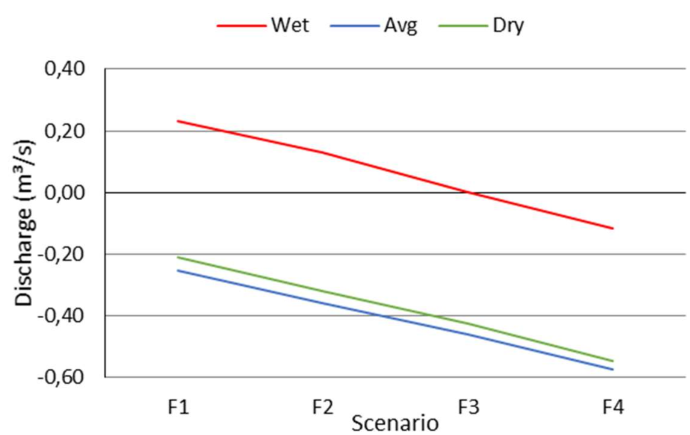

Figure 9: Differences in discharge between the situation in 2015 and the future scenarios. The discharge of the 2015 situation is subtracted from the discharge in the given scenarios. The differences are shown for all three weather conditions.

Given the prospects of decreasing discharge, it is most likely that irrigation potential decreases and droughts are more likely to occur in the future. At the same time, the smaller discharge compared with the shrinking percolation and recharge to the deep aquifer leads to less drinking water that can be extracted.

Next to the discharge, another aspect that should be kept in mind is that there are more factors to be reckoned with besides the discharge. Erosion and crop yield for example need to be researched as well. Applying elephant grasses will decrease river discharge even further since it is mostly likely to decrease surface runoff, but it will simultaneously reduce the risk of massive soil erosion as well. Likewise, there is also a dilemma when it comes to crop yield. If the demand for coffee increases, the question remains whether this should be restrained only because of a decrease in discharge, irrespective of the consequences.

5. Conclusions and recommendations

The land use changes in the past 30 years have led to a decrease in percentage of the discharge in the Genale River. These changes occurred due to expansion of agricultural fields, ensete and coffee-based agroforestry, mostly at the expense of grazing lands and forests.

Coffee-based agroforestry includes several layers of vegetation, leading to a large amount of water interception and water uptake. This in turn leads to a higher evapotranspiration and a decrease in surface runoff. The smaller surface runoff combined with a decreased return flow leads to less river discharge. In comparison to the situation in 2015, the future scenarios show a decrease in discharge of about 1%. Although this leads to a large volume of water (up to 47.500 m^3/day), it is a relatively minor change. This could be due to the small area under coffee production. Even in the far future, it is not anticipated that the increase of coffee will be larger than approximated in this study. The exact decrease is difficult to assess since base flow is underestimated in the model.

Looking closer at the future scenarios, it appears that in most scenarios, the discharge of the Genale River will become smaller due to decreasing lateral flow and return flow. Surface runoff is likely to increase, probably causing more erosion. The increase in surface runoff is most likely due to the increase in agricultural lands in the scenarios. The decreasing discharge has a small negative effect on the irrigation potential and drinking water availability, and it could potentially lead to a higher risk in terms of droughts.

Since the water availability of the Genale River determines to a large extent the wellbeing of the population in the catchment, it is important that the discharge is kept as high as reasonably possible. The development of the area should therefore be focussed on vegetables and fruits, and not so much on coffee, since coffee will use relatively much water. Furthermore, the decrease in grazing land should be stopped as well. The expansion of agricultural fields could partly be stopped by intensifying the harvest of existing fields. Harvesting during the Belg season, and not only during the Kiremt season could prove a sustainable way of increasing crop yield without further altering the natural environment. Knowing that agricultural lands can increase soil erosion potential, preventive measures should be taken. These measurements could for example include grass pathways for drainage and the already commonly used cactus-like (*Euphorbia Candelabrum*) hedges.

The results of this study could be improved by applying data assimilation to the data. Calibration is now applied to the whole dataset, whereas data assimilation uses the results of the previous data points in the calculation of the next data point. This could lead to a more accurate description of the reality in the catchment, which in turn would provide a more accurate model.

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Appendix A – Weather stations

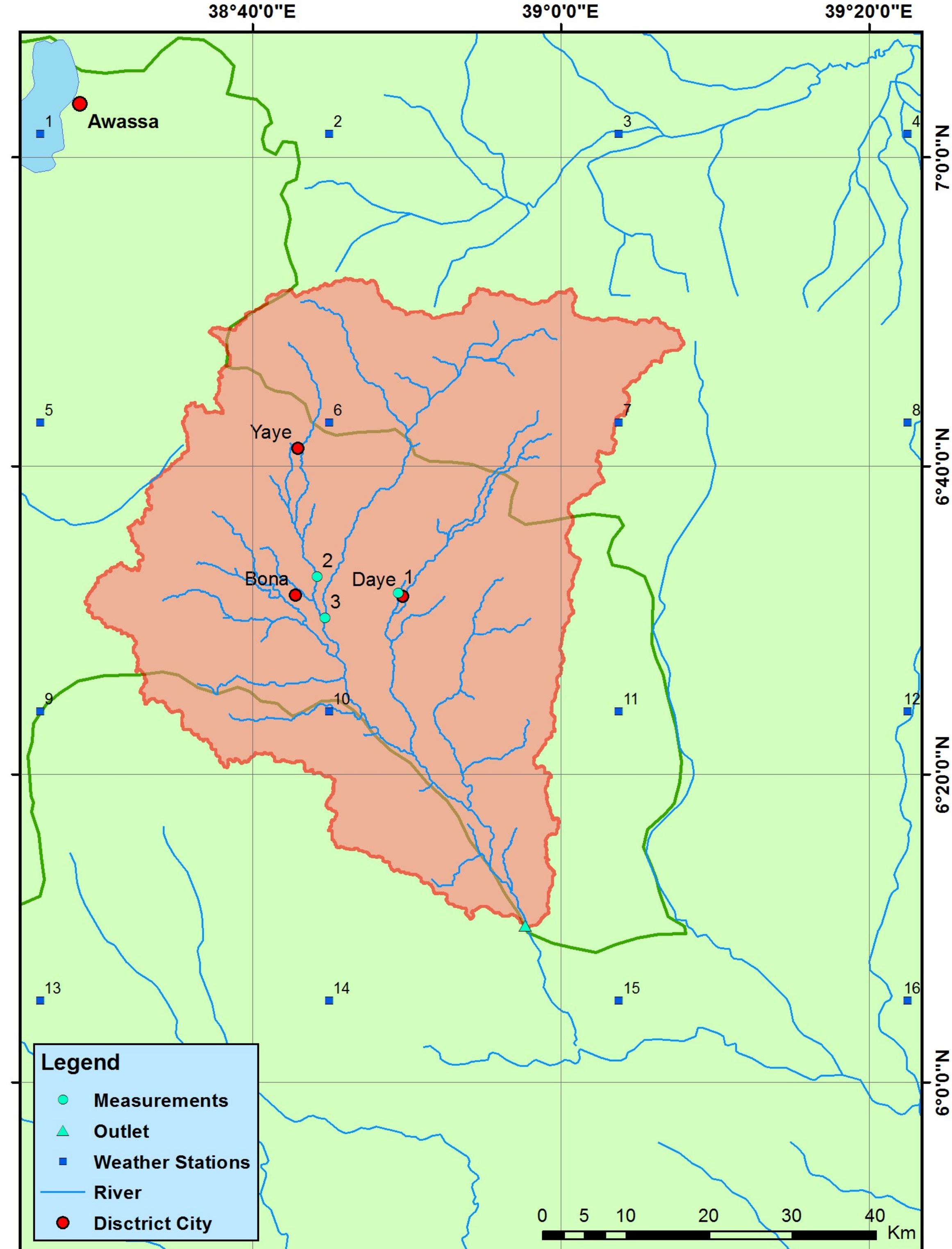

Figure 1: Locations of weather stations in the upper basin of the Genale River. Locations retrieved from the NCEP.

Appendix B – Scenario results

Table 1: Averaged long term results for all water cycle components for coffee scenarios. All values are given in mm.

Component	M20	M10	2015	P10	P20
Precipitation	1699.70	1699.70	1699.70	1699.70	1699.70
Surface runoff	565.49	564.08	564.07	561.03	558.68
Lateral flow	118.73	118.78	118.91	119.17	119.42
Return flow	281.02	281.66	281.58	283.08	284.25
Total water yield	983.08	982.39	982.42	981.25	980.38
Evapotranspiration	654.40	655.1	655.00	656.1	656.90
Revap. from shallow aquifer	60.31	60.30	60.33	60.45	60.55
Percolation	359.30	359.96	359.90	361.62	362.96
Recharge to deep aquifer	17.96	18.00	18.00	18.08	18.15

Table 2: Averaged long term results for all water cycle components for future scenarios. All values are given in mm.

Component	2015	F1	F2	F3	F4
Precipitation	1699.70	1699.70	1699.70	1699.70	1699.70
Surface runoff	564.07	600.85	598.70	596.29	593.38
Lateral flow	118.91	111.59	111.92	112.10	112.53
Return flow	281.58	253.74	254.75	256.24	257.78
Total water yield	982.42	982.38	981.62	980.97	980.12
Evapotranspiration	655.00	659.20	659.90	660.40	661.10
Revap. from shallow aquifer	60.33	56.23	56.33	56.49	56.65
Percolation	359.90	326.29	327.45	329.19	330.98
Recharge to deep aquifer	18.00	16.31	16.37	16.46	16.55

Table 3: Model results for discharge, evapotranspiration and surface runoff per weather condition for coffee scenarios.

Scenario	Discharge (m^3/s)			Evapotranspiration (mm)			Surface runoff (mm)		
	Dry	Av	Wet	Dry	Avg	Wet	Dry	Avg	Wet
M20	50.20	80.54	177.22	685.15	679.49	649.42	279.30	476.32	1065.38
M10	50.11	80.45	177.16	686.19	680.42	650.06	279.29	476.36	1065.51
2015	50.11	80.45	177.14	686.00	680.40	650.20	279.30	476.32	1065.38
P10	50.10	80.44	177.12	685.91	680.45	650.47	278.68	475.57	1064.28
P20	49.93	80.20	176.75	688.48	684.24	653.87	271.76	466.41	1052.51

Table 4: Model results for discharge, evapotranspiration and surface runoff per weather condition for future scenarios.

Scenario	Discharge (m^3/s)			Evapotranspiration (mm)			Surface runoff (mm)		
	Dry	Avg	Wet	Dry	Avg	Wet	Dry	Avg	Wet
2015	50.11	80.45	177.14	686.00	680.40	650.20	279.30	476.32	1065.38
F1	49.90	80.20	177.37	696.62	687.86	649.90	296.73	504.84	1127.13
F2	49.79	80.09	177.27	697.32	688.80	650.95	295.13	502.82	1123.66
F3	49.69	79.99	177.14	697.52	689.58	652.26	293.45	500.54	1119.55
F4	49.57	79.88	177.03	698.19	690.53	653.42	291.36	497.86	1114.93