CASE STUDIES

Water Balance on the Central Rift Valley

Jordi Pascual-Ferrer and Lucila Candela

PHOTO: Grazing the herd. Jordi Codony Gisbert.

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WATER BALANCE ON THE CENTRAL RIFT VALLEY

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1. INTRODUCTION

1.1. DISCIPLINE COVERED

The objective of this case study is to introduce the concept of the water balance on a basin as a mean to evaluate water resources and to be able to design development strategies according to the water resources available. Main goal focusses on the understanding of key concepts such as water balance, water deficit, water surplus or evapotranspiration and their role in water resources.

Moreover, through this exercise it is expected a full comprehension of the impacts that different development agendas may carry on water resources availability on a basin and, hence, on the downstream/upstream users and the environment.

1.2. LEARNING OUTCOMES

As a result of this exercise, students are expected to be able to:

- Understand the evapotranspiration process and learn how it can be estimated
- Conduct a basin water balance and understand the main information provided for the assessment of water resources and water uses in a basin
- Analyse the different proposed strategies while managing water resources and further implications

1.3. BRIEF PRESENTATION OF THE TWO ACTIVITIES

The class activity is focused on calculating the water balance in the basin, by estimating potential evapotranspiration through the Thornthwaite method in the first stage. The homework activity focuses on the water balance calculation in three selected sub-basins. The exercise includes current water use and demand estimation. Later, students will discuss different development strategies set on place and possible environmental impacts of these.

2. Description of the context

Water is crucial for humankind, not only as a means to sustain our life, but as a determining factor in many production activities (agriculture, industry, transport, etc.). Moreover, due to the high level of stress human development is putting on the environment and the services it provides, the concept of environmental water use has arisen. There is therefore a need to understand howwater interacts with the environment and with human activities in order to properly determine how to protect humankind from potentially devastating effects of mis-management, to optimize benefits that it can bring to development, etc. All these analysis shall be conducted at basin level, as explained below.

2.1. Water Balance:

Following the Dublin Statement on Water and Sustainable Development (1992), "the most appropriate geographical entity for the planning and management of water resources is the river basin, including surface and groundwater". Therefore, the work developed in the case study is based at the river basin scale. The river basin can be defined as the portion of land drained by a river and its tributaries, which may drain into the sea or into an endorheic lake. It is important to highlight that groundwater basins may not fully correspond to the surface catchment area or surface basin.

In order to devise a water budget within a basin, knowledge of the water balance is required. The water balance is a concept based on mass balance, and is calculated by counting all water inputs and outputs in the basin, as well as the variation in the water storage. According to the water cycle, this can be translated into the following expression:

Precipitation = Evapotranspiration + Water Surplus ± Water Storage variation

Precipitation (P) is the process which transforms water moisture either into rain (its liquid phase) or into ice or snow (its solid phase).

Evapotranspiration is the joint combination of evaporation and transpiration. The first term is the physical process in which water passes from liquid to gas, and may occur on (i) the soil and vegetation surfaces immediately after rainfall, (ii) from water surfaces (such as rivers, lakes and reservoirs), and (iii) from infiltrated water in the soil top layer (either recently infiltrated or moving back to the surface after a period in the sub-surface region). On the other hand, transpiration consists of the vaporization of liquid water contained in plant tissues and the movement of that vapour to the atmosphere (Edwards et al., 1983). Both evaporation and transpiration are quite difficult to measure separately, as they occur simultaneously and from a hydrological point of view only the amount of water returned to the atmosphere is of concern, therefore they are generally considered together under the term evapotranspiration.

Two terms are commonly used to represent evapotranspiration levels: Potential Evapotranspiration (PET) and Reference Evapotranspiration (RET), which is also called Actual Evapotranspiration. PET is the evapotranspiration that would occur if soil humidity and vegetation cover were always optimal and all available water could evaporate. Contrastingly, RET is the actual evapotranspiration occurring for a specific condition.

There are a range of different methods that may be used to estimate potential evapotranspiration, which may be accurate enough for a conducting a first assessment of basin hydrology. Table 1 summarizes some of the methods and the associated data required to estimate evapotranspiration.

Table 1. Data required for the application of selected evapotranspiration estimation methods. Source: (adapted from Sánchez San Román, 2011)

	Required data	**Other data**
Thornthwaite	Temperature	Theoretical sunshine hours at the site latitude
Jensen-Heise	Temperature (mean, max and min of the warmest month), altitude and solar radiation.	Theoretical sunshine hours Solar radiation maybe be estimated
Hargreaves	Temperature Solar radiation	Solar radiation maybe estimated through daily max and min temperature
Blanney-Criddle	Temperature	Theoretical sun hours Crop related coefficient
Turc	Temperature Real sun hours	From real sun hours global radiation is obtained through a formula
Penman	Temperature Real sunshine hours Wind speed Relative humidity	Through different tables all other required parameters can be calculated

Commonly these different methodologies are used to calculate evapotranspiration on a monthly basis using mean data collected over a perdiod of a number of years. However, for soil-plant-water balance, daily calculations are recommended.

Once precipitation data is known, calculation of the potential evapotranspiration and information regarding the field capacity (FC) of the soil in a basin allows the water balance calculation to be conducted. Usually the water balance in a surface basin is calculated on a monthly basis, and this allowsan estimation of the reference evapotranspiration, water deficit, water storage and water surplus to be obtained. The water deficit is the difference between potential evapotranspiration and reference evapotranspiration (PET - RET), while the water storage is water stored on the soil once potential and reference evapotranspiration are equal (RET = PET) and the field capacity is not achieved (P - PET < FC). Lastly, once the available water capacity is exceeded (P > PET + FC), it is named water surplus, which is water that cannot be retained by the soil and constitutes surface runoff or groundwater flow.

This water balance constitutes an initial assessment of available water resources, either for rain fed agriculture or for any other uses.

A number of codes are available for the study of hydrologic processes, with varying levels of complexity depending on the processes of the water cycle simulated. Some of the available codes are:

- HSPF (Hydrologic Simulation Program – FORTRAN), developed by the Environmental Protection Agency form the USA.
- SWAT (Soil and Water Assessment Tool), developed by the US Department of Agriculture.
- MIKE Basin, developed by the DHI.
- HEC-HMS (Hydrologic Modeling System), developed by the US Army Corps of Engineers.

2.2. Water Resources Management

For centuries, water within watersheds was not considered a scarce resource. However, continuous population growth combined with more recent climate and environmental changes threatens both quantity and quality of water resources, and thus the peaceful coexistence of human populations within a watershed and its ecosystems. As a result, water resources management has increased in its importance to solve increasing water conflicts.

Water governance is defined by the political, social, economic and administrative systems that are in place, and which directly or indirectly affect the use, development and management of water resources and water service delivery at different levels of society (UNDP, 2010). Appropriate water governance may solve most existing water-related problems.

In order to achieve good water governance globally, at the 2002 World Summit on Sustainable Development, which took place in Johannesburg, it was stated that all countries should develop Integrated Water Resources Management (IWRM) plans (United Nations, 1992). IWRM can be defined as a process that promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (Global Water Partnership, 2000).

In some regions, water has conventionally been managed within administrative rather than natural boundaries, in a fragmented rather than holistic manner, and in a technocratic rather than participatory way (Gourbesville, 2008). The IWRM approach uses the basin as the basic water management unit. Moreover, the basis of IWRM is that water uses are interdependent, which means that all uses should be considered together: land and water, surface and ground water hydrology, upstream and downstream activities and interests, etc. IWRM is a type of management approach that aims to establish a dialogue between all involved stakeholders. As such, IWRM should help create a transparent and accountable water regime in which competing claims can be moderated by well-informed participatory processes (Black and Hall, 2004).

All over the world, water used for irrigation accounts for approximately 70% of all water withdrawals (World Business Council for Sustainable Development, 2009). Yet globally, just the 19% of crops are irrigated. Some cross-country studies have determined that in areas where irrigation is used, poverty levels are a 20-30% lower than in areas where there is no irrigation.

Domestic water use comprises water used for drinking, sanitation, cooking, washing and gardening. These uses represent just 8% of overall water usage. But globally there are still 884 million people without access to an improved water source, 37% of whom live in Sub-Saharan Africa (WHO/UNICEF, 2010). Even some people who have access to water via an improved water point may have to spend a large amount of time fetching water (e.g. in Uganda 41% of the population who use an improved water point have their water point at more than 30 minutes walking distance).

Lastly, water is essential for ecosystems' survival, each of which requires a certain amount and quality of water to keep functioning. According to De Groot (1992), the functioning of natural processes is the basis for the existence ofhumankind on the earth, as natural ecosystems supply essential resources and raw materials. Environmental functions are 'the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly' (de Groot, 1992). These functions can be subdivided in four different groups (de Groot et al., 2002): (i) Regulation functions (capacity of natural and semi-natural ecosystems to regulate ecosystem processes, to maintain essential ecological processes and life support systems); (ii) Production functions (provision of ecosystem goods for human consumption); (iii) Habitat functions (natural ecosystems provide refuge and reproduction habitat to wild plants and animals) and (iv) Information functions (natural ecosystems may provide reflection, spiritual enrichment, cognitive development, recreation and aesthetic experience).

Water resources management may allow for the improvement of economic and social welfare, by establishing a dialogue between all involved stakeholders. Such a dialogue will not only prevent the deterioration of life of the poorest both today and tomorrow, but also help the the poorest to improve their livelihoods . If more equitable access to water is to be guaranteed, several social, economic, ecological and capacity obstacles will need to be faced (UNDP, 2004).;transparent and participatory water governance can help overcome these obstacles.

2.3. Ethiopia and the Central Rift Valley (CRV)

Ethiopia is the second most populated country in Africa with over 73.9 million people (Population Census Comission. F.D.R. Ethiopia, 2008). Its 1,100,000 km^2 ranks Ethiopia as the 10th largest African country. Addis Ababa is not only Ethiopia's capital but also hosts the African Union Commission.

The country is ranked in 171st position out of 182 in the Human Development Index ranking (PNUD, 2009). Agriculture is the backbone of the Ethiopian economy, providing 43.8% of the GDP (compared with 13.2% from industry and 43% from services) and is also the sector which employs most of the labor force, with 85% working in agriculture . The main export crop is coffee, although others such as qat, teff or cut flowers are also important for Ethiopian's economy. Ethiopia is one of the poorest countries in the world, and although it has a high rate of economic growth rate (8%), 38.7% of its population still lives below poverty line (Central Inelligence Agency, 2009). Although irrigation is growing all over the country, still droughts have a strong impact on the economic growth. The spatial and temporal variability of water resources limits development and constrains management and equitable distribution.

The Ethiopian Central Rift Valley (CRV) is a basin to the south of Addis Ababa (Ethiopia, Figure 1). There are globally significant freshwater ecosystems containing important areas of both terrestrial and aquatic biological diversity, and most are becoming degraded as a result of human activities (Lake Ziway and its influent rivers are used for irrigation, flower industry, soda abstraction, fish farming, domestic use and recreation) (Ayenew, 2007). Irrigation is growing across the country, including in the CRV, but still droughts, which occur periodically (FEG Business Development and Operations, 2009), have a strong impact on economic growth. The spatial and temporal variability of water resources limits development and constrains management and an equitable distribution. Nowadays, the main environmental problems in the basin are: water scarcity, poor water quality, deforestation, land degradation and biodiversity degradation (Codony Gisbert, 2010).

The studied basin is part of the East African Rift, which goes along East Africa from the Red Sea to Mozambique. The CRV is located between 38º15'E and 39º25'E and 7º10'N and 8º30'N, covering an area of approximately 10,000 km^2, and it ranges from around 1500m above sea level in the lowest parts of the valley up to more than 4000m at the eastern side of the valley. In 2007, the population living in the Central Rift Valley Basin was around 1.9 million people, of which 1,600,000 were living on rural areas (Population Census Commission. F.D.R. Ethiopia, 2008).

According to Jansen et al. (2007) an estimate of water use in the CRV is as shown in Table 2. From the figures it is clear that there are several competing uses of water on the CRV, and nowadays it is mainly the environment that is experiencing the negative effects of this.

Table 2. Water use in the CRV. Source: Jansen et al.(2007)

Water Use	Annual water use (hm3)
Irrigation	150-200
Livestock	8
Domestic	7.3
Industrial use	1

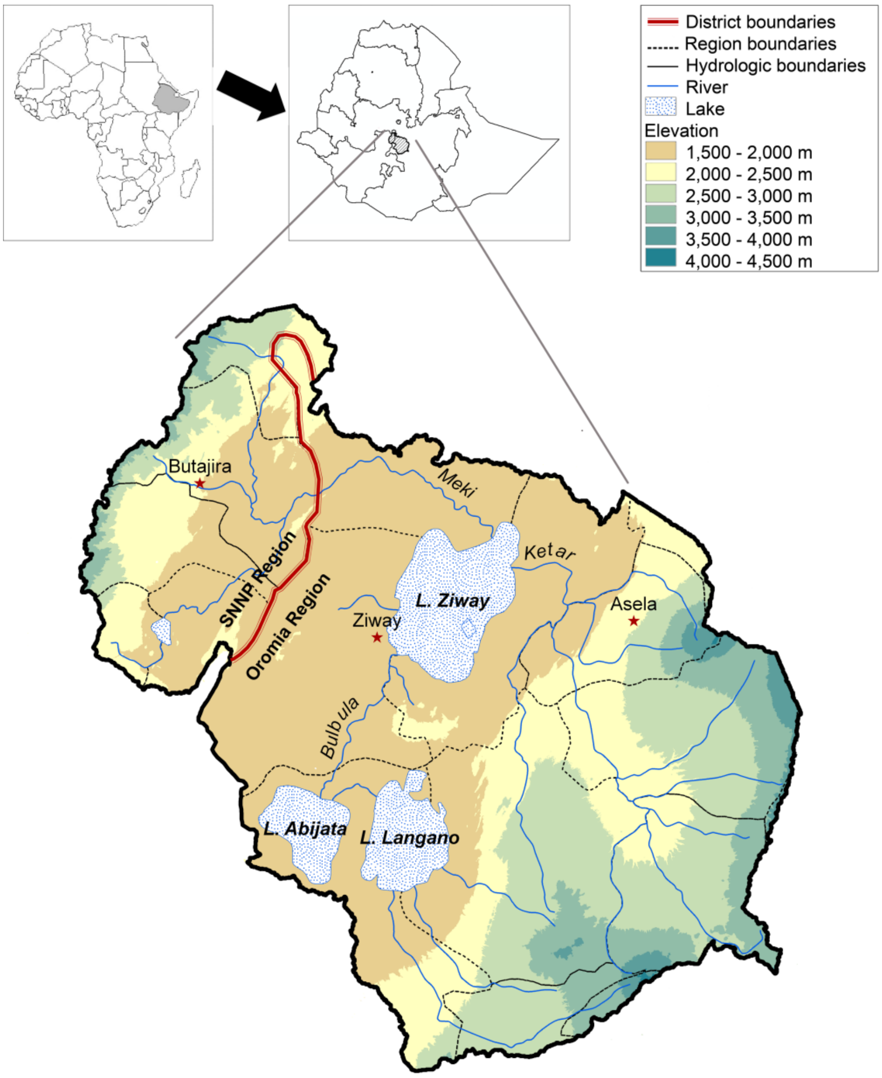

Figure 1. Location map of the Central Rift Valley

Most of the natural vegetation consists of woodland and savannas. Afro-montane forests are mainly in the highlands, while cultivated land is located in the valley areas. The land cover comprises 10.9% of woodlands and 76.8% under agricultural management, of which 1.3% is irrigated land (Jansen et al., 2007). Irrigation water is mainly sourced from surface water, either by river diversion (44%) or from lake Ziway (31%), and only 25% of the land is irrigated using groundwater through existing wells (Rodriguez de Francisco, 2008).

Agricultural production and its related activities is the main pillar that sustains the CRV economy. According to the Master Plan Study Project on Integrated Resources Development (2007) about 67% of the CRV's GDP is from the agricultural sector (i.e. crops, livestock, fisheries and forestry), while industry and service sectors account for 10% and 24% respectively. The regional GDP per capita is about 910 Birr per capita (or 105US$

using 2005 exchange rate), which is a low GDP per capita even compared to Ethiopian standards.

The amin water management problems can be exposed as: (i) an overexploitation of water resources, hindering ecosystems survival and rising competition of uses between subsistence farming, industrial farming and tourism promotion; (ii) poor water quality, endangering both irrigation and drinking water provision; and (iii) high dependency of population on water resources to sustain their livelihoods.

2.4. CRV: Water Quality and Quantity

The average level of Lake Ziway has decreased by around 0.5 m since 2002 (Jansen et al., 2007), and hence the level of the Bulbula river outflow has also decreased. Due to this, Lake Abyata (the outermost lake of the basin located in the Abyata-Shala National Park) has been suffering from a drastic decrease of water input, endangering the rich biodiversity of the area (Oromia Environmental Protection Office, 2005). Lake Abyata's recent decrease has added to the rapid changes in lake extension and volume suffered during the last forty years (Ayenew, 2007).

In Ethiopia, between 150,000 and 200,000 ha/yr of forest cover are being lost either because it is changed into new agricultural land, or because it is used for charcoal production or construction (Ayenew, 2007). The CRV itself has suffered deforestation and land use maps based on satellite interpretation (from LANDSAT MSS and ASTER images) (Jansen et al., 2007) show that during the period 1986-2006 forest cover in the region decreased by almost 50%. Irrigation has also shown a great increase in the region. Large-scale irrigation started in the 1970s in the Lake Ziway catchment, and it experienced great development during the 1980s (Legesse and Ayenew, 2006). It was also in the 1980s that water demanding industry (a soda ash factory) started operating at Lake Abyata's shore and the greatest decrease of the lake level started (Alemayehu et al., 2006). Since then, irrigation has kept growing. As an example, during the period 2007-2013 Adami Tulu Jido Kombolocha and Dugda woredas (Ethiopian districts), both situated on the western shore of Lake Ziway, have had an increase in irrigated land of around 70%.

Public perception and acceptance of decreasing water resources is clear. However, the public seems to be reluctant to accept that upstream water abstraction is currently detrimental to downstream users and ecosystems. Although there has been no substantial reduction of precipitation during the last 50 years (Ayenew, 2004), people still perceive rainfall reduction as the real cause of lack of water in the region (Codony Gisbert, 2010).

Both man-made and non-anthropogenic factors are affecting water quality in the area. Most of the CRV is covered by volcanic rocks, mainly ignimbrites, basalts and rhyolites, which cause great levels of fluoride in the groundwater (Chernet et al., 2001). Flouride levels reach up to 200 mg/l in the floor of the rift, although its concentration decreases in the highlands, where it can be less than 1 mg/l (except in some points where confined thermal springs can be found) (Ayenew, 2008). In some areas the population is drinking this contaminated water, which results in dental and skeletal fluorosis (Ayenew, 2008, Raventós Vilalta, 2010). Moreover, the alkaline and sodic characteristics of this water is damaging the agricultural potential of the soil where it is used for irrigation (Chernet et al., 2001). In terms of anthropogenic factors, deforestation and loss of vegetation cover is causing sediment and nutrients to be washed away. This material then reaches the terminal lakes and causes eutrophication, which is killing fish and other microorganisms, as seen in Lake Abyata (Ayenew, 2007). Although clear results on water quality are not available, the use of agrochemicals and pesticides in the area in order to improve land productivity may be endangering water quality.

2.5. CRV: Socio-economic aspects

Environmental degradation intensifies inequality through the adverse impacts it has on already disadvantaged people, but conversely, inequalities in human development may amplify environmental degradation (HDR, 2011). A household survey conducted by Master Plan consultants (Halcrow and GIRD, 2007) has shown that the main sources of income of the population are both crop production and livestock rearing, as can be seen in Figure 2.

As a result of land productivity, which appears to be quite low in some areas of the basin, and the small size of the plots cultivated by farmers, farming is primarily subsistence based, and certain areas of the CRV are considered as food deficit zones (FEG Business Development and Operations, 2009).

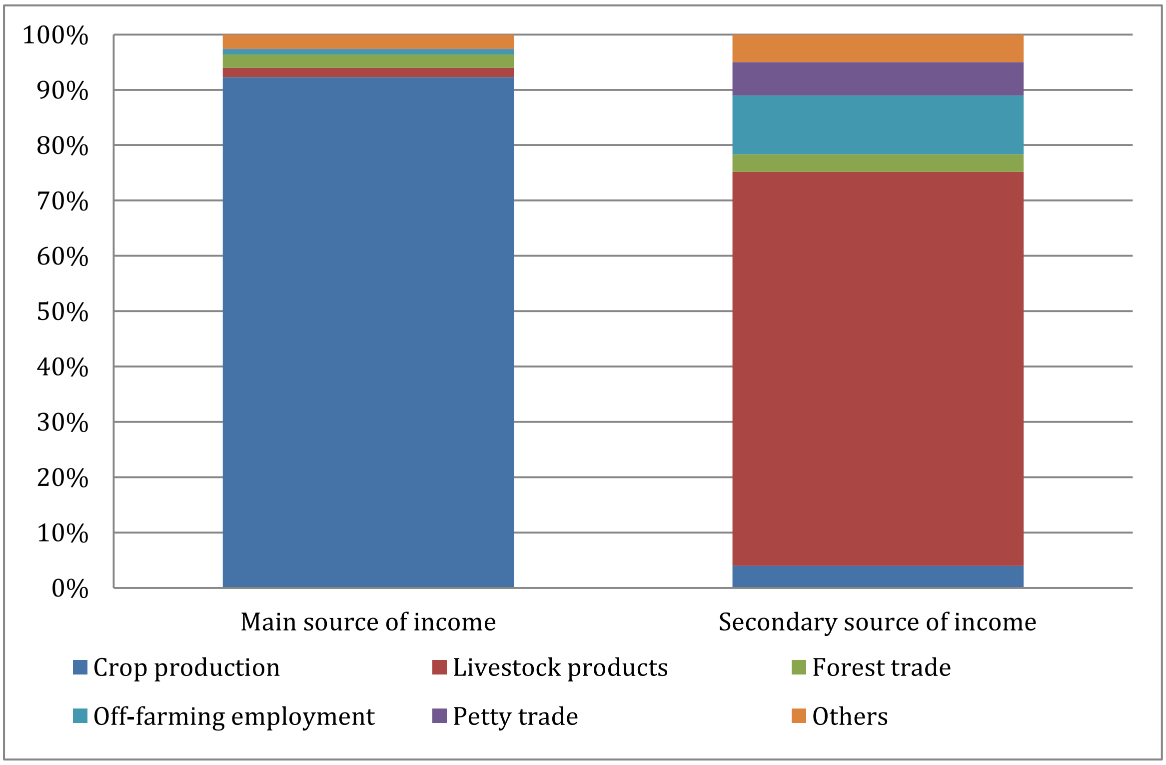

Figure 2. Principal and secondary source of income according to a household survey done in the Ethiopian Rift Valley. Source: Halcrow and GIRD (2007)

One of the reasons why land productivity is low is because of land degradation, which is primarily caused by improper agricultural practices and poor tillage systems (Sissay, 2003). Moreover, increasing irrigation of farms using salty water combined with furrow irrigation systems (the most common in the area), is causing salinization of the soil. This problem is causing farmers to abandon fields where productivity is decreasing (Shimelis, 2008) and an increase on the rate of deforestation as farmers clear land tostart farming new areas (Sissay, 2003). Recent country wide strategies aim to improve the productivity of agriculture by increasing the area of irrigated land (both with ground and surface water), increasing the use of chemical fertilizers and improved seeds, selecting appropriate crops according to soil characteristics and introducing soil conservation practices (MoFED, 2010).

Article 40 of the 1995 Ethiopian constitution states that ownership of land is exclusively vested in the state and the peoples of Ethiopia, establishing that land is a common property, and that peasants have the right to obtain land without payment for grazing and cultivation purposes (GoE, 1994). In disagreement with the Government's position, some argue that the main constraint to achieving higher land productivity is the common property of land and the insecure land tenure system it develops; increasing productivity needs greater investment in farms which would require peasants to own the land upon which they farm (Halcrow and GIRD, 2007). However, probably the biggest barrier to overcome in increasing agricultural production in the CRV is the small size of landholdings, as they currently average 0.85 ha per farm (Raventós Vilalta, 2010). Oromia regional government has established a minimum plot size per household of 0,5 Ha for annual crops and 0,25 Ha for perennial crops, as well as a maximum of 0,5 Ha of irrigated land (ONRS, 2007).The SNNPR regional government has established a minimum 0,5 Ha per plot without differentiating the type of crop, and also a plot of 0,5 Ha for irrigation systems (SNNPRS, 2007). As plots of this size are insufficient to support a family, farmers remain in a cycle of poverty, as they cannot afford the required investments to improve their productivity. Fragmented land tenure together with a lack of capacities not only hinders productivity but also leads to an overexploitation of land, an intensive use of agrochemicals and, where irrigation is available, a high competition for and abuse of water. Moreover, as the population is growing, the threat of deforestation on the forests that still exist in the area is increasing. Lately, regional legislation has allowed farmers to rent plots (in almost half of the region of Oromia(ONRS, 2007)), although the lack of other livelihood means does not seem to facilitate concentration processes.

Agricultueis not the only practice overexploiting land, livestock farming is also doing so and there are clear evidences of overgrazing (Jansen et al., 2007). Livestock is part of the farming system in the highland areas, where animals are grown for meat and milk production. They are also used as draft animalsand therefore make an important contribution to the income of households. In the drier southern lowlands of the Rift Valley, livestock production is based on semi-nomadic pastoral systems and is seen as the main source of wealth.

Additional income is obtained from charcoal production, which further compounds deforestation and the disappearance of acacia forests is causing a reduction in the habitat and food source of migratory birds (Shimelis, 2008). New legislation on forest management has toughened penalties on unlicensed forest exploitation (GoE, 2007b), but a lack of capacity to enforce the legislation may hinder its immediate impact.

2.6. CRV: Water management

In line with the country’s overall decentralization scheme, the water sector has also gone through the process of decentralization. The Federal Government, through the Ministry of Water and Energy (MoWE, previously called Ministry of Water Resources) is in charge of policy and strategy development at central level (Wube et al., 2009), and provision of technical support to regional water bureaus and offices (Ministry of Water & Energy, 2010). Under the umbrella of the MoWE there are the River Basin Organizations (RBO), which have the overall objective of promoting and monitoring the integrated water resources management process, namely: (i) providing policy guidance and planning oversight; (ii) preparing river basin master plans; (iii) deciding on major water works and water allocation; (iv) proposing water rates and (v) managing water use disputes between Regional States in the basin (GoE, 2007a). The first RBO was developed for the Abbay Basin (or Blue Nile Basin), and current legislation has been written based on experience in that basin (Raventós Vilalta, 2010). Since the first RBO, few other RBOs have been established, although on of those that has is the Rift Valley Lakes Basin RBO. This RBO is composed by different sub-basins within it, among which is the CRV basin.

Despite the presence of the RBO, problems have arisen in water resources management in the basin. The ability to manage water effectively is diminished by: lack of capacityand ignorance on laws, regulations and procedures by regional and local governments (Raventós Vilalta, 2010); lack of coordination among different involved stakeholders (Codony Gisbert, 2010); and a lack of a proper monitoring network and an updated national database on water resources and use. Moreover, despite policy guidelines that establish stakeholder participation and decentralization, the Federal Government still exerts the greatest influence in the region (Raventós Vilalta, 2010).

Water policy in Ethiopia tries to combine aspects of both social equity and economic efficiency. Consistentwith Government laws and international conventions, every Ethiopian citizen has the fundamental right to have access to sufficient water of acceptable quality, to satisfy basic human needs (MoWR, 1999). On the other hand, public and private agencies and persons applying for water use permits and certification of their technical and professional competence have the full right to use any water resources, provided they fulfill requirements set by the supervising body (either the Federal or the Regional Government) (GoE, 2000). Environmental policy states that rural water supply systems require an environmental impact assessment, although there are several exceptions: surface and ground water fed irrigation projects covering less than 50 ha; all small scale agricultural activities; and the rearing of cattle (<50 heads), pigs (<100 heads), or poultry (<500 heads) (EPA, 2003). As a result of these policies, more facilities are able to use water for productive activities than for domestic purposes.

As the Ethiopian water policy establishes that all water resources are common property of the people of Ethiopia and the state, irrigation water is common property rather than private, therefore no one is being held responsible for the mismanagement of water irrigation can cause (Raventós Vilalta, 2010).

3. Class assignment procedure:

This activity is conceived for a two-hour classroom session. Students are grouped into pairs for problem solving. After an hour and a half, once the exercise has been solved by the students, the lecturer will demonstrate how to solve it, together with addressing doubts and questions that may be arisen by the students.

3.1. Statement

The exercise will focus on the Ketar basin, a sub-basin of the CRV system. The Ketar river is a tributary of Lake Ziway, on the eastern side of the lake, which provides the greatest proportion of water to the lake (see Figure 3).

To assess water dynamics and water resources in the basin, a first stage estimation of the hydro-meteorological parameters and a soil-plant-water balance has to be conducted for the basin.

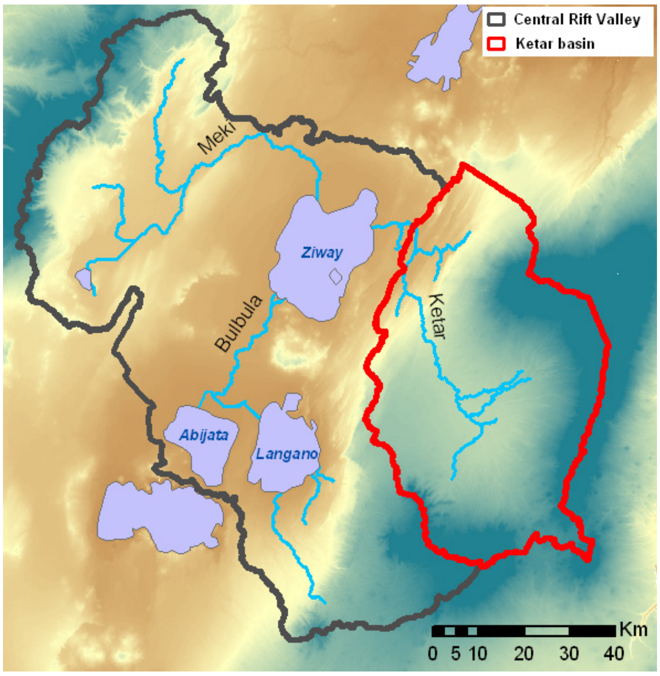

Figure 3. Central Rift Valley and Ketar basin

For this purpose, meteorological data from the Sagure station (N7°46'12"; E39°8'60") has been selected as the most representative of the Ketar basin. Mean monthly temperature and mean monthly rainfall for more than 25 years is presented in Table 3. For the sake of simplicity, the hydrological year is considered as starting at the beginning of January

Table 3. Mean monthly rainfall (P) and temperature (T) at Sagure meteorological station.

	J	F	M	A	M	J	J	A	S	O	N	D
P (mm)	14.4	25.2	60.1	75.7	82.5	95.2	155.4	147.5	77.5	36.5	8.4	5.5
T (ºC)	13.8	14.2	15.5	15.3	16.0	15.1	14.0	14.3	14.6	15.1	14.7	13.6

The theoretical sunshine hours (Sun) for the same latitude can be considered as presented in Table 4.

Table 4. Theoretical sunshine hours at Sagure meteorological station

	J	F	M	A	M	J	J	A	S	O	N	D
Sun (h)	13.2	14.2	14.9	15.1	14.7	14.5	14.7	14.8	14.9	14.3	13.5	12.9

The field capacity (FC) of the soil can be assumed as 80mm.

Students are requested to: i) Estimate the monthly Potential Evapotranspiration (PET) through the Thornthwaite method using the available data, and ii) Calculate the water balance for the basin on a monthly basis.

Appendix 1 presents guidelines on how to apply the Thornthwaite Method. For extra information you may access: http://onlinecalc.sdsu.edu/onlinethornthwaite.php

3.2. Solution

The Monthly Thorthwaite Heat Index calculated for the given data is:

Table 5. Monthly Thornthwaite Heat Index (i) for the Sagure meteorological station

	J	F	M	A	M	J	J	A	S	O	N	D
i	4.63	4.88	5.55	5.43	5.81	5.35	4.76	4.92	5.09	5.31	5.14	4.54

The Annual Heat Index (I) is I=61.40 for the monthly temperature at the site of interest. The α parameter used for calculating the non-corrected PET is a=1.458. The Potential Evapotranspiration estimation for each month, considered as 30 days long with 12 hours of theoretical sun per day, are:

Table 6. Non corrected Potential Evapotranspiration (PET) for the Sagure meteorological station

	J	F	M	A	M	J	J	A	S	O	N	D
$PET_{non\ corrected}$	51.9	54.5	61.8	60.5	64.5	59.6	53.3	55.0	56.8	59.2	57.3	50.9

The corrected PET with the theoretical sunshine hours for each month (and considering February as 28.3 days long) is:

Table 7. Potential Evapotranspiration (PET) for the Sagure meteorological station

	J	F	M	A	M	J	J	A	S	O	N	D
PET	59.0	60.9	79.3	76.2	81.7	72.0	67.5	70.1	70.5	72.9	64.5	56.5

Once the PET has been calculated the soil hydrological balance can be estimated, considering January as the beggining of the hydrological year. In order to solve the basin water balance:

- If the amount of precipitation is lower than Potential Evapotranspiration (P<PET), the Reference Evapotranspiration is the sum of precipitation and part of the existing soil storage, until the sum of both equals Potential Evapotranspiration. But if there is not enough storage in the soil, then Reference Evapotranspiration is lower than the potential, and the difference is called water deficit, which does not accumulate from month to month. (If water storage from previous month are zero, then Reference Evapotranspiration equals precipitation)
- If precipitation is higher than Potential Evapotranspiration (P>PET), then the Reference Evapotranspiration equals the Potential (RET = PET), and the remaining water fills up the water storage, which does accumulate from month to month. If precipitation is large enough, water storage may reach the field capacity (P>PET+FC), then exceeding water is called water surplus.

In January, February, March and April, as precipitation is lower than Potential Evapotranspiration, Reference Evapotranspiration equals precipitation, and there is a water deficit. In May and June, as precipitation is larger than Potential Evapotranspiration, Reference Evapotranspiration equals Potential Evapotranspiration, and water storage starts to fill, but without reaching the maximum value of 80mm and, hence, without water surplus. Those that can be found in July, August and September, when Reference Evapotranspiration equals Potential Evapotranspiration and water storage reaches 80mm. In October precipitation is once again lower than Potential Evapotranspiration, but as there is still water stored in the soil. Hence, Reference Evapotranspiration equals the Potential, although the water storage continues to fall there is not yet a water deficit. Finally, in November and December, the Reference Evapotranspiration equals precipitation and the rest of water storage, which does not reach Reference Evapotranspiration, and hence there is once again a water deficit.

Results can be found in Table 8 and Figure 4.

Table 8. Results of the Ketar water balance

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Annual*
PET	59.0	60.9	79.3	76.2	81.7	72.0	67.5	70.1	70.5	72.9	64.5	56.5	831.3
RET	14.4	25.2	60.1	75.7	81.7	72.0	67.5	70.1	70.5	72.9	51.9	5.5	667.6
Deficit	44.6	35.7	19.3	0.5	0.0	0.0	0.0	0.0	0.0	0.0	12.6	51.0	163.6
Storage	0.0	0.0	0.0	0.0	0.8	24.0	80.0	80.0	80.0	43.6	0.0	0.0	
Surplus	0.0	0.0	0.0	0.0	0.0	0.0	31.9	77.3	7.0	0.0	0.0	0.0	116.2

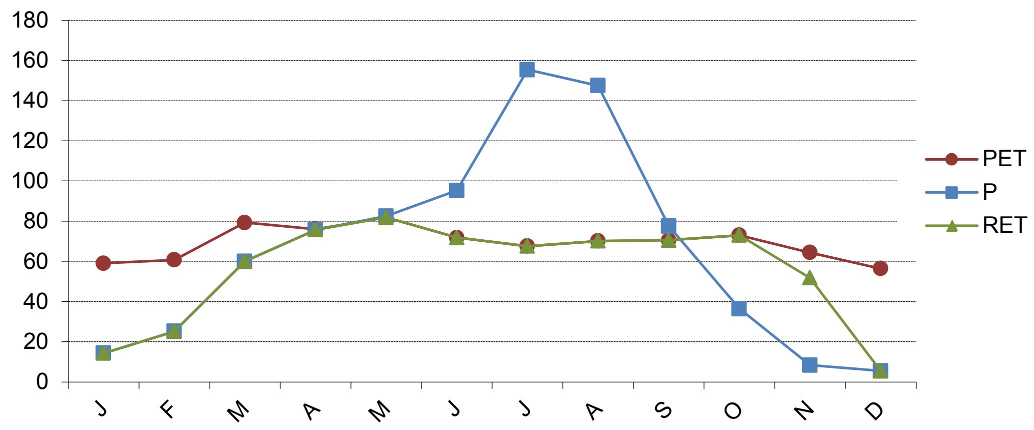

Figure 4. Graphical representation of the water balance for the Ketar basin

4. HOMEWORK

4.1. METHODOLOGY

This exercise is planned to be carried out in pairs. The idea is to conduct a water balance of the basin using data from different meteorological stations and once the water balance has been conducted, to suggest different water management strategies for the basin and evaluate their potential positive and negative impacts.

Data is provided below, but students also require information in Appendix 2, as there the local context is also defined.

4.2. PROPOSED STATEMENT

A small NGO is willing to start a project on the Ketar basin aiming to improve livelihoods of the population on the basin. They are aware of water problems in the basin and are willing to investigate what would be the best development strategy according to the availability of water resources.

Having this objective in mind, they request you to complete a short report (less than 1000 words) analyzing the different development strategies for the basin's water resources, including pros and cons related to: rain-fed agriculture, irrigated agriculture and livestock farming.

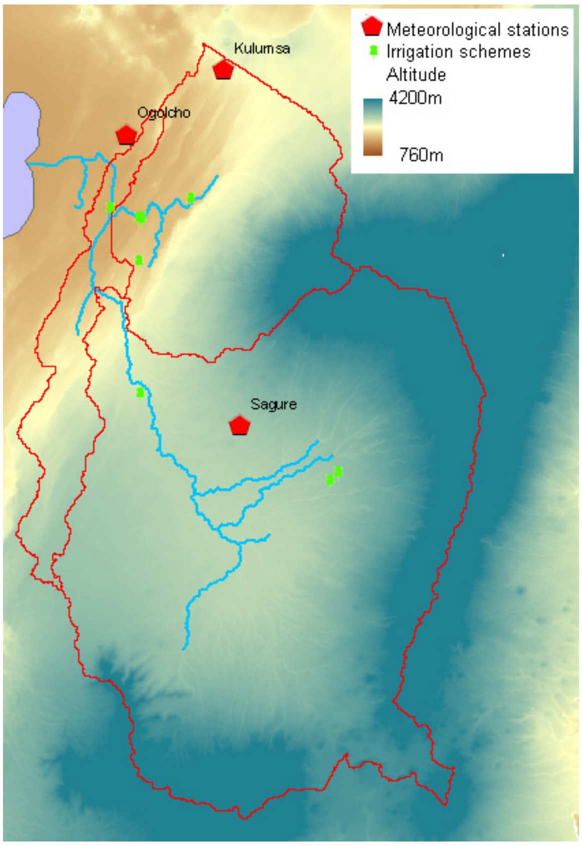

Figure 5. Ketar Basin

The NGO is also considering the best location for the planned activities, and also if impacts on water resources can be minimized based on the site selected. According to available data, the basin has been divided into three different sub-basins named Sagure, Ogolcho and Kulumsa (see Figure 5), considered homogeneous in terms of soil water reserve and climatic conditions for the sake of simplicity. They also request the analysis of impacts associated with each type of development activity and area if differences in sustainability are observed.

The data available in order to conduct the analysis are listed below:

- Meteorological data from the three different sub-basins: Sagure (7.77ºN, 39.15ºE), Ogolcho (8.07ºN, 39.03ºE) and Kulumsa (8.13ºN, 39.13ºE). The hydrological year starts at the beginning of January.

Table 9. Monthly mean precipitation and temperature for the meteorological stations of Kulumsa, Ogolcho and Sagure.

		J	F	M	A	M	J	J	A	S	O	N	D
Kulumsa	P	22.0	41.8	83.8	80.4	85.7	95.6	123.2	131.8	100.9	38.6	13.2	8.9
	T	15.4	16.1	17.0	17.5	18.1	17.4	16.1	15.9	16.1	16.5	16.6	15.7
Ogolcho	P	12.3	30.9	68.3	66.9	65.7	83.1	154.3	104.8	95.2	32.9	8.3	3.6
	T	20.1	20.6	21.0	21.6	21.9	21.2	20.2	19.9	20.2	20.8	20.7	20.4
Sagure	P	14.4	25.2	60.1	75.7	82.5	95.2	155.4	147.5	77.5	36.5	8.4	5.5
	T	13.8	14.2	15.5	15.3	16.0	15.1	14.0	14.3	14.6	15.1	14.7	13.6

- The surface area and field capacity for each of the three sub-basins is:

Table 10. Area and soil water reserve of the three sub-basins

	Area (km^2)	Soil water reserve
Kulumsa	654.1	115
Ogolcho	254.6	80
Sagure	2181.0	80

- Population in the basin is estimated at around 475,000 inhabitants, with an average water consumption of 30 l/inhab/day

- Livestock can be estimated at 370,000 Tropical Livestock Units (TLU). TLU is a standard unit used to compare different animal species, which uses the following conversion factors: Cattle=0.7 TLU, sheep/goat = 0.1 TLU, horse 0.8 TLU, donkey = 0.65 TLU, mule = 0.7 TLU, pig = 0.2 TLU, chicken = 0.01 TLU. Mean annual consumption of water by TLU is 25l/(day·TLU).

- A list of different irrigation systems in the basin is also provided. According to estimates water consumption is around 5500 m^3/ha/year (considering an irrigation period of 5 months)

Table 11. Irrigation systems in the basin

Woreda	Source	Area (ha)	Sub-basin	Beneficiaries (inhab)
Lemuna Bilbilo	River	500	Sagure	3200
Degeluna Tijo	River	500	Sagure	3400
Tiyo	River	615	Sagure	995
Ziway Dugda	River	130	Kulumsa	313
Ziway Dugda	River	158	Kulumsa	358
Ziway Dugda	River	40	Kulumsa	100
Ziway Dugda	Groundwater	139	Kulumsa	160
Ziway Dugda	River	65	Kulumsa	149
Ziway Dugda	River	372	Ogolcho	350

- Finally, in Appendix 2. The description of the CRV can be found for the homework exercise. This contains information that may help define pros and cons for the different development strategies to be implemented.

4.3. Solution

In order to conduct the assessment, first the water balance shall be independently calculated at each of the three sub-basins, which also includes the evapotranspiration estimation. Results are shown in the following table:

Table 12. Water balance for each of the areas (mm)

		J	F	M	A	M	J	J	A	S	O	N	D	Total
SAGURE	PET	59.0	60.9	79.3	76.2	81.7	72.0	67.5	70.1	70.5	72.9	64.5	56.5	831.3
	RET	14.4	25.2	60.1	75.7	81.7	72.0	67.5	70.1	70.5	72.9	51.9	5.5	667.6
	Deficit	44.6	35.7	19.3	0.5	0.0	0.0	0.0	0.0	0.0	0.0	12.6	51.0	163.6
	Storage	0.0	0.0	0.0	0.0	0.8	24.0	80.0	80.0	80.0	43.6	0.0	0.0	
	Surplus	0.0	0.0	0.0	0.0	0.0	0.0	31.9	77.3	7.0	0.0	0.0	0.0	116.2
OGOLCHO	PET	82.4	85.3	102.7	107.1	111.0	99.0	92.6	89.8	90.3	95.9	86.8	82.7	1125.6
	RET	12.3	30.9	68.3	66.9	65.7	83.1	92.6	89.8	90.3	92.9	8.3	3.6	704.8
	Deficit	70.0	54.4	34.4	40.2	45.3	15.9	0.0	0.0	0.0	3.0	78.4	79.1	420.8
	Storage	0.0	0.0	0.0	0.0	0.0	0.0	60.0	60.0	60.0	0.0	0.0	0.0	
	Surplus	0.0	0.0	0.0	0.0	0.0	0.0	1.7	15.0	4.9	0.0	0.0	0.0	21.6
KULUMSA	PET	62.3	65.7	82.7	85.4	90.3	81.2	74.2	73.4	73.0	75.6	69.5	62.7	896.1
	RET	22.0	41.8	82.7	81.6	85.7	81.2	74.2	73.4	73.0	75.6	69.5	60.6	821.2
	Deficit	40.4	23.9	0.0	3.9	4.6	0.0	0.0	0.0	0.0	0.0	0.0	2.2	74.9
	Storage	0.0	0.0	1.1	0.0	0.0	14.3	63.4	121.9	145.0	108.0	51.7	0.0	
	Surplus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.7	0.0	0.0	0.0	4.7

At basin level, the global balance is obtained by multiplying the results for each zone by the area of each zone. Hence, the global balance would be (remembering: 1mm=1 l/m^2 and hm^3 = cubic hecometre = $1x10^6$ m^3):

Precipitation	788.0 mm	2434.8 hm^3/year
RET	704.9 mm	2177.8 hm^3/year
Deficit	164.4 mm	508.0 hm^3/year
Surplus	83.2 mm	257.0 hm^3/year

Domestic water consumption can be estimated by multiplying the population by the mean consumption: 475,000 pers. x 30 l/inhab/day. This gives an annual water consumption of around 5.20 hm^3.

On the other hand, irrigation consumption can be estimated at 13.85 hm^3, after considering 2519 ha of irrigated land in the basin, and a mean irrigation dose of 5500m^3 per year per hectare. Livestock consumption can be estimated at 3.38 hm^3 per year.

For the report evaluation, it is important that: i) results are based on the calculated water balance for each of the areas and the whole basin and ii) water resource use/demand prior to the new proposed management is known in order to fully understand the impact that different uses may have on the basin. The test should observe pros and cons of each strategy, considering aspects such as those listed below:

- Reduction of water available may hinder downstream users: impacts on Lake Ziway
- Irrigated agriculture has larger economic benefits than rain-fed agriculture
- Kulumsa sub-basin appears to be best for rain-fed irrigation due to lower water deficit
- The use of irrigation may cause soil erosion
- Use of agrochemicals may hinder water quality and favor eutrophication
- Use of groundwater for irrigation may damage soil for water use due to its alkaline and sodic characteristics
- The increase of cattle number may also impact water quality

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