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HYDROLOGICAL INVESTIGATION FOR CLIMATE CHANGE ADAPTATIONS IN THE KOU BASIN BURKINA FASO – A MINOR FIELD STUDY

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This study has been carried out within the framework of the Minor Field Studies Scholarship Programme, MFS, which is funded by the Swedish International Development Cooperation Agency, Sida.

The MFS Scholarship Programme offers Swedish university students an opportunity to carry out two months' field work, usually the student's final degree project, in a country in Africa, Asia or Latin America. The results of the work are presented in an MFS report which is also the student's Master of Science Thesis. Minor Field Studies are primarily conducted within subject areas of importance from a development perspective and in a country where Swedish international cooperation is ongoing.

The main purpose of the MFS Programme is to enhance Swedish university students' knowledge and understanding of these countries and their problems and opportunities. MFS should provide the student with initial experience of conditions in such a country. The overall goals are to widen the Swedish human resources cadre for engagement in international development cooperation as well as to promote scientific exchange between unversities, research institutes and similar authorities as well as NGOs in developing countries and in Sweden.

The International Relations Office at KTH the Royal Institute of Technology, Stockholm, Sweden, administers the MFS Programme within engineering and applied natural sciences.

Lennart Johansson

Programme Officer

MFS Programme, KTH International Relations Office

SUMMARY

The aim of this master thesis was to perform a hydrological investigation in the Kou Basin in Burkina Faso and with the help of this investigate how complementary irrigation could be used to avoid crop failure in the Burkinabe agricultural sector. Burkina Faso is a country suffering under the changing climate, the isohyets have moved between 100 and 150 kilometers to the south since the 1970s resulting in a substantial reduction of precipitation. Therefore the need for investments in adaptation techniques is urgent. Special focus has in this report been put on whether rainwater harvesting could be used as an infrastructural improvement to provide the water resources needed. Two years that is known for crop failure has been analyzed and compared to the crop growth stages, the crop water requirements and a year known for good harvest in attempt to establish a pattern. Potential dam sites have also been investigated to if possible strengthen the accessibility to water resources for complementary irrigation. The increased flood risks due to urbanization around Bobo-Dioulasso have also been investigated. The investigation has shown that the risk for increased floods due to this is low; the increase in runoff is approximately 14 %. Of the two dam sites investigated (Koumi and Badala) was Koumi found to be the most suitable; the topography was found to be crucial as the plain area around Badala would result in big evaporation losses due to a shallow reservoir with a big area. The use of rainwater harvesting in small-scale (one household) has its drawbacks in the limited storage capacity when it is held against the investment costs, a rainwater harvesting system for one household will therefore have difficulties to supply the water resources needed for complementary irrigation in this region. A more large-scale design (cooperative) has a great potential, especially in parts of Burkina Faso where there is no access to rivers or easy extractable groundwater. In this way farmers can get the supply of water for complementary irrigation at a smaller investment cost than for one household. A very crucial question in this topic is how the knowledge about this technique is enhanced so that there will be a future domestic expertise that knows about the needs and handles the ways of working in this area. The conclusion is therefore that with the help of a domestic expertise could the need and the importance of cooperatives be elucidated in a more effective way that would lead to greater acceptance and greater resistance towards crop failure among the Burkinabe farmers.

SUMMARY IN SWEDISH (SAMMANFATTNING)

Syftet med detta examensarbete var att genomföra en hydrologisk utredning i floden Kous avrinningsområde i Burkina Faso och med hjälp av detta undersöka hur kompletterande bevattning kan användas för att undvika missväxt i Burkina Fasos jordbrukssektor. Burkina Faso är ett land som lider under pågående klimatförändringar, isobarerna har förflyttats mellan 100 och 150 kilometer söderut sedan 1970-talet. Behovet för investeringar i anpassningstekniker för klimat-förändringar är därför brådskande. Speciellt fokus har lagts på huruvida regnvatten-insamling kan användas som en infrastrukturell investering för att ge tillgång till de vattenresurser som behövs. Två år som dokumenterat innebar missväxt har analyserats och jämförts med ett år känt för en god skörd samt grödors tillväxtstadier och vattenbehov för om möjligt kunna etablera ett mönster. Potentiella dammar som etableringsplatser har också blivit undersökta för att om möjligt kunna stärka tillgångarna för bevattning. Risken för ökade översvämningar på grund av urbaniseringen runt Bobo-Dioulasso har också undersökts. Undersökningen visar att risken för ökade översvämningar på grund av detta är låg, ökningen i avrinning var endast ca 14 %. Av de två i förslaget potentiella dammplatserna (Koumi och Badala) så fanns Koumi vara den mest lämpade. Topografin får ses som avgörande då det flacka området runt Badala skulle innebära stora avdunstningsförluster på grund av en utbredd och grund reservoar. Användandet av regnvatten-insamling i småskaligt utförande (för ett ensamt hushåll) har sin nackdel i form av den begränsade lagringskapaciteten ställt mot investeringskostnaderna, ett system för regnvatteninsamling för ett hushåll får därför svårt att tillgodose de mängder vatten som krävs för kompletterande bevattning i den här regionen. Ett mer storskaligt utförande (samfällighet) har dock stor potential och speciellt i regioner där det inte finns tillgång till floder eller lättillgängligt grundvatten. På detta sätt kan bönderna få tillgång till vatten för kompletterande bevattning till en lägre investeringskostnad än för ett hushåll ensamt. En mycket central fråga är hur kunskapen om denna teknik stärks så att det finns en inhemsk expertis som allmänt känner både behoven och behärskar arbetssätten. Därutöver via dessa inhemska experter kunna tydliggöra fördelarna i att arbetet sker i samfällighetsform. Acceptansen hos användarna när det är inhemska experter som ger råd och påtalar vikten av hur olika tekniker används är generellt hög. Slutsatsen blir alltså fortsatt att möjligheter finns att förbättra motståndskraften mot missväxt och på så sätt levnadsförhållandena för befolkningen i Burkina Faso.

SUMMARY IN FRENCH (SOMMAIRE)

L'objectif de cette thèse de master a été d'effectuer une recherche hydrologique dans le bassin du Kou au Burkina Faso et à l'aide de celle-ci étudier comment des systèmes complémentaires d´irrigation pourrait être utilisés pour éviter les mauvaises récoltes dans le secteur agricole burkinabè. Le Burkina Faso est un pays qui souffre d'un climat changeant, les isohyètes se sont déplacés entre 100 et 150 kilomètres au sud depuis les années 1970, ceci a entraîné une réduction substantielle des précipitations. Par conséquent, la nécessité d'investir dans des techniques d'adaptation est urgente. Dans ce rapport, Une attention particulière a été portée sur l'hypothèse qu'un système de récupération de l'eau pluviale pourrait être utilisé comme une amélioration des infrastructures afin de fournir les ressources en eau nécessaires. Deux années connues pour de mauvaises récoltes ont été analysées et comparées à stades de croissance des cultures, des besoins en eau des cultures et une année qui est connue pour de bonnes récoltes dans la tentative d'établir un modèle. Des sites de barrages potentiels ont également été étudiés pour, si possible, renforcer l'accessibilité à des ressources d'eau pour l'irrigation complémentaire. Les risques accrus d'inondation en raison de l'urbanisation autour de Bobo-Dioulasso ont également été étudiés. L'enquête a montré que le risque d'inondation accru en raison de ce développement est faible; l'augmentation du ruissellement est d'environ 14%. Sur les deux sites de barrages étudiés (Koumi et Badala) Koumi s'est révélé être le plus approprié; la topographie a été jugée cruciale étant donné que la zone de plaine autour de Badala entraînerait des pertes par évaporation, principalement à cause d'un réservoir peu profond sur une grande aire.

L'utilisation d'un système de récupération de l'eau pluviale à petite échelle (un ménage) a ses inconvénients dans la capacité de stockage limitée si on l'oppose aux coûts d'investissement, un système de collecte des eaux pluviales pour un ménage aura donc des difficultés à fournir les ressources en eau nécessaires à l'irrigation complémentaire dans cette région. Un design plus grande échelle (coopérative) a un grand potentiel, surtout dans certaines régions du Burkina Faso où il n'existe aucun accès aux rivières ou à une nappe phréatique facilement extractible. De cette manière, les agriculteurs peuvent obtenir l'approvisionnement en eau pour l'irrigation complémentaire à un coût d´investissement moindre que celui d'un ménage. La question primordiale est celle de la marche à suivre pour le renforcement des compétences techniques afin que soit mise en place d´une part une expertise locale ayant compétence en matière de définition des besoins et d´autre part le développement d´un savoir-faire en ce qui concerne la méthode. La conclusion est donc que, avec l'aide d'une expertise nationale pourrait la nécessité et l'importance des coopératives être élucidé d'une manière plus efficace, ce qui conduirait à une plus grande acceptation et une plus grande résistance aux mauvaises récoltes parmi les agriculteurs burkinabè.

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ABSTRACT

One of the biggest upcoming challenges to the international community is the problem of a changing climate. The earth's surface temperature is rising and associated impacts on physical and biological systems are increasingly being observed. Science tells us that climate change will bring about gradual changes, such as sea level rise, and shifts of climate zones due to increased temperatures and changes in precipitation patterns.

A changing climate affects the entire world but will strike hardest against the poorest as they are the ones most dependent on agriculture which is a sector that is very vulnerable to changes in temperature and precipitation patterns. One region that will be especially vulnerable and has experienced the problems of shifting climate zones before is the Sahel region that borders to the south end of the Sahara desert where problems of desertification have occurred before. This region will in large extent be affected if the Intergovernmental Panel on Climate Change's (IPCC) predictions of a rising temperature will become a reality. This is one of the reasons why I have chosen Burkina Faso, situated in the south end of the Sahel region, as the objective for my MFS. The question of rising temperatures will be especially important here as the region is very sensitive to differences in temperature. A crucial topic in this part of the world as well as the topic of this study is the process of adapting to the new climatic situation.

Key words: Kou Basin, Burkina Faso, Rainwater harvesting, hydrological investigation, climate change adaptation

1. INTRODUCTION

In terms of climate change there are two areas that are important when dealing with the subject. The two areas are mitigation and adaptation; Mitigation is about attacking the source of the greenhouse gases emitted and try to lower them. Adaptation is about importance to be aware of the effects of climate change in order to reduce the impacts of climate change that are happening now and increase the resilience to future impacts (The World Bank et al, 2003).

The present study will only deal with the question of adaptation, when the results of the hydrological investigation is achieved an attempt to try to predict the future changes in the chosen river catchment area with help of data from IPCC's climate predictions will be performed.

The relevance of this study becomes clear when taking part of Sida's "country fact sheet Burkina Faso, sector: Environment" where it is said under the point "prospects for the future" that "Funding to environment-related issues is likely to increase in countries like Burkina, considering the huge need for investments in climate change adaptation" (Sida, 2010).

The report will also contain a preliminary cost estimation of future investments, even though it could be highly uncertain.

1.1. Aim

The main aim of this study is to investigate the use of complementary irrigation as a tool to avoid crop failure during the rainy season and the infrastructural tools to provide water for this purpose. Special focus will be put on investigating the efficiency of rainwater harvesting techniques in this area. The study will also cover areas like the conditions for possible dam constructions within the catchment area and the question of changed run off conditions due to urbanization.

1.2. **Result**

The result of this report will be the outcome of the hydrological investigation; this will contain the calculations and discussions whether the most suitable place for a dam site is in the area of Koumi or in the area of Badala. Further the result will include an investigation of the suitability of rainwater harvesting in connection with complementary irrigation. The report will also contain an estimation of what a future climate could look like with help of the IPCC's climate change predictions.

2. BURKINA FASO

Burkina Faso (formerly Upper Volta) gained its independence from France in 1960. Repeated military coups in the 1970s and the 1980s were followed by multiparty elections in the early 1990s. Current president Blaise Campaoré came to power in a military coup in 1987 but has won every democratic election since then. Burkina Faso's limited natural resources and high population density result in poor economic prospects for the majority of the citizens. Recent unrest in Cote d'Ivoire and northern Ghana has hindered the ability of several hundreds of thousands Burkinabe farm workers to find employment in neighboring countries (CIA, 2011).

2.1. **Geography**

Burkina Faso is situated in the inner parts of West Africa, south of the Saharan desert border. It borders to Mali and Niger in the north and to Cote d'Ivoire, Ghana, Togo and Benin in the south (Fig. 1). The landscape is predominated by a plateau with a small slope towards the south. The terrain in southwest is mountainous and the southeast is covered by marshes. The north of the country is a desert like savannah while the grass plains in the south are covered with bushes and trees. The soil is often rocky and meager and not very suitable for agriculture. The plains in the north are almost turned into desert during the dry season.

The three most important rivers that flow through Burkina Faso are Mouhoun (black Volta), Nazinon(red Volta) and Nakambé (white Volta). Eventually they all join to form the Volta River that has its discharge in the Gulf of Guinea (Fig. 2). During the dry seasons these rivers might end up being completely dried out (Landguiden homepage, 2011).

2.2. **Climate**

Burkina Faso has a hot and dry climate; which gets hotter and dryer while moving further north in the country. There are two very distinct seasons, one dry and one rainy season. Annual rainfall varies from about 1000 mm in the south to 500 mm in the north. In the dry season the harmattan blows across the country; a hot dry wind from the Sahara. The climatic conditions changes with changing latitudes, the north has a desert like condition, while the south has a more tropical wet-dry climate. The rainy season lasts three to four months and occurs usually between April-June and September-October depending on where in the country (Atlas de l'Afrique, 2004).

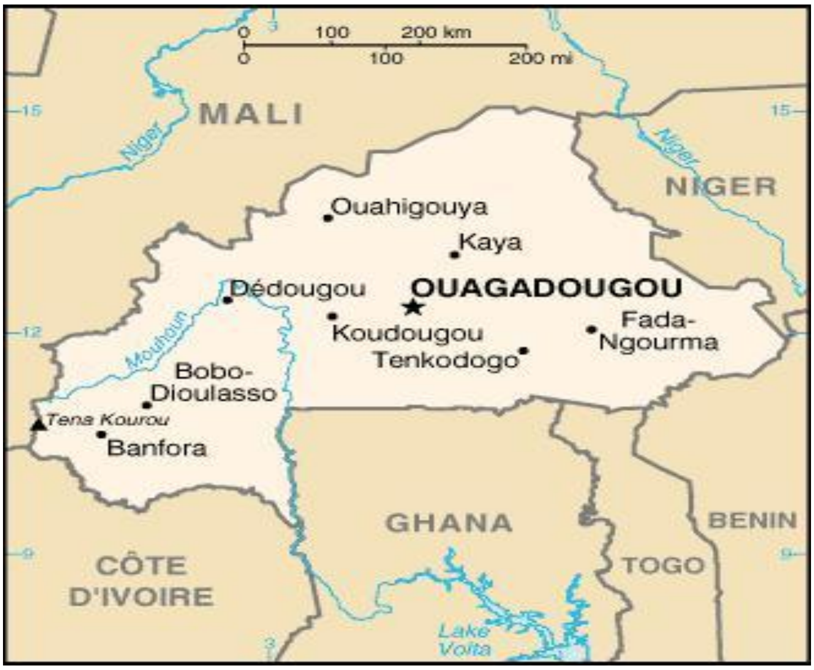


Figure 1 Map of Burkina Faso (Wikipedia, 2011)

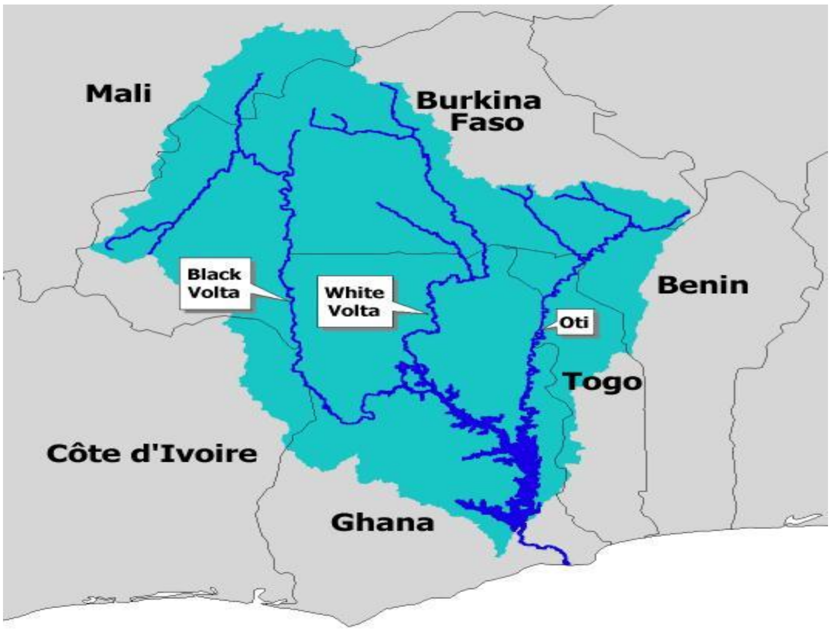


Figure 2 Map of the Volta Basin (Delft University of technology, 2005)

2.3. Agriculture

Even though limited amounts of natural resources the country's economy depends on it. The economy is dominated by agriculture. It employs 86 % of the country's population. Grain production for the country's own need is the base. Cotton is partly produced for exportation abroad (provides 50 % of export income); animals are also breaded and sold. 40 % of GDP (gross domestic product) comes from agriculture (crops 25 %, livestock 12 % and 3 % from forestry and fishing).

Figure 3 Picture of shrub savannah, Kou Basin

Figure 4 Pictures from inside and just outside forêtclassée du Kou

Cereal growing takes up 88 % of the cultivated areas and constitutes the staple diet for the Burkinabe population. The Burkinabe climate and natural environment is harsh and the rainfall is low and influenced by strong inter-annual and space-time variability. These two conditions affect directly the agro-pastoral production. Present aridity in the north is causing the crop-growing season to shorten with 20 – 30 days. The soils are generally not very deep and therefore the water retention time and the organic matter content are low. Traditional farming methods and population growth enhances the degradation from year to year. This is especially critical close to the urban areas. These physical constraints make the Burkinabe agriculture sector very sensitive to a changing climate. Poor diversification of incomes and the sensitivity to a changing climate are two of the big reasons why economic and food insecurity persists in the rural households.

To establish a working private sector the traditional sectors within agriculture and forestry need to be reformed to, in a sustainable way, give higher productivity. This will also result in higher incomes to the rapidly growing population (SIDA, 2004, CEEPA, 2006).

2.4. The Kou River

The chosen catchment area for the study is the one of the Kou River in the western parts of Burkina Faso (Fig. 1). The area stretches from the north of Banfora in the south to the streams of river Mouhoun (black volta) in the north where Kou adds to the main catchment area of Mouhoun (see appendix 1 for a more a detailed map of the Kou Basin). As the river flows northwards it follows a small slope that gets even smaller in the northern part of the catchment area; where marsh areas are found in the close surroundings of the river. The river starts under the name Kiéné and the name is changed into Kou when the river of Farakoba flows into it. Most of the river plain of Kou is covered by shrub savannah (Fig. 3) and the conditions are dry.

The river Kou has an all-year round flow, this is because the river is fed with groundwater from a natural spring in the area around the village Nasso(Compaoré, P, 2011). This also creates areas with different types of vegetation from the predominant savannah; areas that are common in more humid conditions. This area has been classed as a natural reserve to protect the special environment (this area is called forêt classée du Kou, see map in appendix 1), the distinction in this reserve between the green haven of the natural reserve and the dry forest just a couple of hundred meters from the riverbed is astonishing (Fig. 4).

The large urban area of Bobo-Dioulasso is situated within the catchment area of Kou and from this area the sub catchment of the river Wé leads the water northward to finally join Kou northeast of Badala(see map in appendix 1).

3. BACKGROUND

3.1. Complementary Irrigation

If nothing else is mentioned the facts in this section are taken from discussions with Albert Compaoré, national program officer for natural resources and climate change at the Swedish embassy in Ouagadougou and from the observations in the field study.

Irrigation is an old technique that has been used within agriculture for thousands of years. The definition of irrigation is according to the oxford American dictionaries "supply water to land or crops to help growth, typically by means of channels." Another definition supplied by the website wordIQ.com says: "Irrigation is the replacement or supplementation of rainfall with water from another source in order to grow crops. In contrast agriculture that relies only on direct rainfall is sometimes referred to as dryland farming."

The last definition is interesting, not due to that the source is the most reliable or that it is more correct than the first one, instead it is the fact of it describing irrigation as either the replacement or the supplementation of rainfall. To better understand the situation in Burkina Faso and the scope of this thesis, things need to be made clear about the difference between these two.

When the rainfall is replaced by irrigation, normally this is only called irrigation. This is due to the fact that the essential part of the water that is used to water the crops is taken from an external source. This technique is not very common in Burkina Faso, there are some areas in the Kou basin where this technique is used to grow rice but in Burkina Faso as a whole this is a rare technique.

The other part described in the second definition is the supplementation of rainfall; this could also be called the complementation of the rainfall, therefore the term complementary irrigation. This part describes the adding of water to the dryland farming to enhance the crop growth or to avoid crop failure.

Complementary irrigation has different purposes during different seasons; during the dry season it serves as the possibility of adding extra harvest to the total annual harvest. This possibility can mean the difference of sending kids to school or not for some farmers (Compaoré, P, 2011).

The other purpose and the most important for this thesis is the use during the rainy season, this is not widely used in Burkina Faso. Investigations are made to find out if complementary irrigation could be used during the rainy season to avoid crop failure i.e. as a supplementation of rainfall when a long period of drought might cause crop failure. As 80 % of the Burkinabe farmers rely on dryland farming and as much as two out of five harvests (Johansson, I, 2011) fail the avoidance of crop failure due to complementary irrigation might have a major impact in terms of poverty reduction.

3.2. Rainwater harvesting

Rainwater harvesting is a technique that collects water from roofs or larger catchment areas. The water collected can be used as drinking source but also for other means of usage. This technique is especially useful in areas where there is no direct access to water sources or where the groundwater is polluted or too deep to economically be able to extract it.

The rainwater may be collected in different ways, either through roof catchment or ground catchment. The first one collects the water falling on a roof and conducts it to cisterns through gutters. The second one uses the principle of catching runoff from hard ground during heavy rains. This runoff may be lead in lined pits or may be diverted into a bore well as to artificially recharging a groundwater aquifer. In addition, dams might be constructed to retain flowing water in gullies or valleys (Unicef, 1999).

3.3. Run off in Bobo-Dioulasso, flood risks

Within the Kou catchment area is the urban area of Bobo-Dioulasso situated, this urban area with almost 500 000 inhabitants has been growing tremendously during the last twenty years(Atlas de l'afrique, 2004). This is not a trend unique for Burkina Faso or even Africa as the urbanization is a growing problem in most parts of the world. When a city is growing, in terms of hydrology, there are certain features that changes; land that used to be savannah or forest are turned into to residential, commercial and industrial areas, all these are interconnected with a network of roads, both asphalted and graveled. When this happens the runoff is affected as the different areas have different runoff properties. What often happens is that more impervious surfaces renders a larger runoff than the savannah or forest that used to be there; this creates larger flows of water on the streets of the city than before. The problem with this is that sometimes the urbanization goes out of control and the government has not the time to develop a sewer system in the same speed as the urbanization, this is often a problem in the cities of the developing countries. When this happens the runoff is increased but there is no way for the water to flow away and large floods could occur, like the one in Ouagadougou September 2009 (DN, 2009).

The urban area of Bobo-Dioulasso is situated in a sub catchment area of the river Kou called Wé. This river does not have water flowing in it all year round and flows northward from Bobo-Dioulasso in the south to the village Sourkoudougou where it joins the stream of Bingbélé (see map in appendix 1).

4. METHODS

In a hydrological investigation an area of investigation needs to be chosen, this could be a rivers catchment area or sub catchment area in a larger system. As described above the Kou River catchment area has been chosen for the investigation. Two sites along the river have been chosen for the investigation of the suitability of a dam construction. The hydrological investigation will be performed as follows:

Defining a catchment area

1. When an area has been selected for the hydrological investigation, a catchment area will be defined. This catchment area will then be the study area. Which catchment area that is chosen and why depends on what purpose the hydrological investigation has. To determine average precipitation the whole catchment area is used and if the investigation deals with dam sites the sub catchments that provides water to the site are defined

Collection of existing data

2. The fieldwork will largely be composed of the job of finding existing data, like flow data, radiation, temperature and collection of map material that could be helpful in the investigation. Large effort needs to be put in to finding as much data as possible, because without data it will hard to draw any conclusions. The database of the Food and Agriculture Organization of the United Nations (FAO) will be helpful in the search for data dealing with water demand for a certain land use or for different kinds of crops.

Analysis

3. When the data is collected the work of analyzing the data follows. This part will be composed of estimating the water flow in the area as well as the water use. An estimation of future influences to the area due to the impact of climate change will also be performed (described below).

4.1. Theoretical background

4.1.1. *Water balance*

The water balance is an accounting of the inputs and outputs of water i.e. how much water there is in the area and where it goes. Water enters the catchment area through precipitation and then leaves as either evapotranspiration or runoff. Included are also the storage changes in the catchment area in form of lakes and groundwater reservoirs. The water balance of a place, whether it is an agricultural field or a continent, can be determined by calculating the input, output and storage changes of water at the Earth's surface (Ritter, 2006).

The water balance (per year) is described by the following equation:

$$P = ET + R + \Delta S \quad (1)$$

Where:

P= Precipitation (mm)

ET = Evapotranspiration (mm)

R= Runoff (mm)

ΔS= Storage (mm)

4.1.2. ***Evaporation***

Ven Te Chow states in "Applied hydrology that: "The two main factors influencing evaporation from an open water surface are the supply of energy to provide the latent heat of vaporization and the ability to transport the vapor away from the evaporative surface". When energy supply is not limiting the best method to calculate the evaporation is the aerodynamic method and when vapor transport is not limiting the best approach is the energy balance method. However, normally both of the factors are limiting therefore a combination of these two is needed; the combination method.

Energy balance method

$$E_r = 0{,}0353R_n \text{(mm/day)} \qquad (2)$$

Where:

R_n=Net radiation (W/m²)

Aerodynamic method

$$E_a = B(e_{as} - e_a) \text{(mm/day)} \qquad (3)$$

Where the vapor transfer coefficient B is:

$$B = \frac{0{,}622k^2\rho_a u_2}{p\delta w\left[\ln\left(z_2/z_0\right)\right]^2} \qquad (4)$$

Where:

k (kappa) = 0,4

ρ_a = Density of air (kg/m³)

u_2 = Wind speed (m/s at height 2 m)

z_2 = Height above water surface (m)

z_0 = Roughness height (m)

p = Air pressure (kPa)

δ_w = Density of water (kg/m³)

The combination method:

$$E = \frac{\Delta}{\Delta+\gamma}E_r + \frac{\gamma}{\Delta+\gamma}E_a \qquad (5)$$

Where:

γ = The psychrometric constant

Δ = The gradient of the saturated vapor pressure curve at air temperature T_a

For further details: (Chow, V.T., 1988p.86-90)

4.1.3. ***Thiessen method***

The Thiessen method is used to determine areal average rainfall, it assumes that "at any point in the watershed the rainfall is the same as that at the nearest gage so the depth recorded at a given gage is applied out to a distance halfway to the next station in any direction." The relative weights for each measuring point are determined from the areas in a Thiessen polygon network. The areal average precipitation ($\overline{P}$) for the watershed is:

$$\overline{P} = \frac{1}{A}\sum_{j=1}^{J} A_j P_j \qquad (6)$$

Where the area A is:

$$A = \sum_{j=1}^{J} A_j \qquad (7)$$

4.1.4. ***SCS method for abstractions***

The Soil Conservation Service has developed a method that is used to compute the abstractions of storm rainfall. The depth of excess precipitation or direct runoff P_e is always less than or equal to the depth of precipitation P. The calculations are based on the following equations:

$$CN = \frac{1000}{10 + S} \qquad (8)$$

Where:

S = Maximum potential retention

CN = A dimensionless curve number

To find out the excess precipitation or direct runoff (P_e) the following equation is used:

$$P_e = \frac{(P - 0{,}2S)^2}{P + 0{,}8S} \qquad (9)$$

For further details: (Chow, V.T., 1988,p. 147-152)

4.1.5. ***Rippel diagram***

The Rippel diagram is the name for the mass curve used to estimate how big a reservoir could be based on the driest 24-month period available. The accumulated inflow during the 24-month period is shown in the diagram and with help of this the maximum constant release can be found using the two peak values when the reservoir is full (Wanielista, M., Kersten, R., Eaglin, R. 1997).

4.1.6. ***Frequency analysis***

The 100- and the 1000 years floods can be found with frequency analysis based on measured values of yearly max floods. Two methods are used in this study, the graphical and the analytical method. A flood with a certain return period, for example 100 or 1000 years can be determined with frequency analysis.

The graphical method: In the graphical method the logarithms for the measured flow data are assumed to be normal distributed, when plotted into a log normal distribution diagram they form a straight line that with extrapolation can be followed to read the100- and the 1000 years flood. They are plotted in the diagram and each value is assigned the plotting position probability according to the Weibull formula (there are several plotting formulas but in this case the Weibull formula is used).

The Weibull formula:

$$P(X \geq \chi_m) = \frac{m}{n+1} \qquad (10)$$

The analytical method: To get an as correct result as possible the graphical method is compared with analytical method. If the line in the graphical method is close to straight then the data follow the normal distribution and can be assumed to be correct. The analytical method considers a skew coefficient that gives a more correct result if the line is curved. The flood Q_T with the return period T (years) = 1/p (probability of exceeding Q_T) is estimated from the equation:

$$\log Q_T = \log Q + s * K_T \qquad (11)$$

LogQ = average of logarithms of floods

s = standard deviation of logarithms of floods

K_T = Frequency factor corresponding to the return period T and depending on the skew coefficient

For a normal distribution the frequency factor can be expressed as a standard normal variable z, this variable is calculated through the approximation that:

$$z = w - \frac{2{,}515517 + 0{,}802853 + 0{,}010328w^2}{1 + 1{,}432788w + 0{,}189269w^2 + 0{,}001308w^3} \qquad (12)$$

where:

$$w = \left[\ln\left(\frac{1}{p^2}\right)\right]^{1/2} \quad (0 < p \le 0{,}5) \qquad (13)$$

For further details: (Chow, V.T., 1988p.389-398)

4.1.7. ***Calculation of runoff in a sub catchment area***

It can be assumed that the area in one sub catchment area of a larger catchment area and the area of the large one are proportional to the runoff in the two catchment areas. This gives the opportunity to, from the data of one point in a river, estimate the runoff in any other point in the catchment area. Therefore the following assumption can be made:

$$\frac{A_1}{A_2} = \frac{Q_1}{Q_2}$$

Based on the water balance equation:

The runoff in one catchment area is as the following equation:

$P – E = R_1$ (storage equals zero)

And in a sub catchment area the runoff is as follows:

$P – E = R_2$

These two multiplied with the area of the catchment area gives the flow out of the areas Q_1 and Q_2:

$A_1(P - E) = Q_1$ -> $P – E = Q_1/A_1$

$A_2(P – E) = Q_2$ -> $P – E = Q_2/A_2$

So if the precipitation and the evaporation remains approximately the same in the catchment area as well as in the sub catchment area the assumption above is true, this assumption is however not always reliable. If the evaporation is much higher in the sub catchment area than in the measuring point. This could be verified with the water balance equation and the average precipitation value for the sub catchment area.

4.1.8. ***Transfer of flood values in a sub catchment area***

In terms of frequency analysis the relation between catchment and sub catchment areas is not the same as the above described. In this case the

100 and 1000 years flood relates to each other as the following assumption:

$$HHQ = k * q_s A^{\alpha} \text{ (m}^3\text{/s)} \qquad (14)$$

where:

k = constant depending on the topography, the infiltration rate and other factors in the catchment area.

q_s = specific yearly average water flow ($m^3/s*km^2$)

A = the area of the catchment area(km^2)

α = Constant dependent on the shape of the catchment area. α = 0,4 for long and narrow areas and α = 0,8 for round areas. Here α = 0,5 is assumed.

$$\frac{HHq_1}{HHq_2} = \sqrt{\frac{A_1}{A_2}} \qquad (15)$$

4.1.9. ***Crop water requirement***

When designing a water harvesting system, it is necessary to determine the water requirement of the crop intended to be grown. There are several good methods to estimate this. It should, however, be noted that equations, which give high accuracy, also require a high accuracy of measured data which in most places where water harvesting is practiced will not be available. In this case it is often adequate to use estimates of water requirements for common crops.

When calculating the crop water requirement, two methods will be used. The basic formula reads as follows:

$$ET_{crop} = K_c * ET_o \qquad (16)$$

Where:

ET_{crop} = The water requirement of a given crop in mm per unit of time e.g. mm/day, mm/month or mm/season.

K_c = Crop factor (table 1)

ET_o = The "reference crop evapotranspiration" in mm per unit of time e.g. mm/day, mm/month or mm/season.

The reference crop evapotranspiration is defined as the rate of evapotranspiration from a large area covered by green grass that grows actively, completely shades the ground and which is not short of water. An approximation can be calculated for this value with the Blaney-Criddle formula; which could be inaccurate in extreme conditions.

The ETo value was calculated with theBlaney-Criddle formula:

$$ET_o = p(0,46T_{mean} + 8) \qquad (17)$$

Where:

ET_o = Reference crop Evapotranspiration (mm/day)

T_{mean} = Mean daily temperature (°C)

p = mean daily percentage of annual daytime hours.

The evaporation can also be based on estimations of the evaporation rate from an open water surface. This evaporation can be estimated through measurements like the pan evaporation method or calculated with the combination method described above. The results of the calculations are multiplied with a "pan coefficient". If the precise pan coefficient is not known, the average value 0,70 can be used as an approximation, thus:

ETo = Epan*Kpan (18)

(Critchley, W., Siegert, K., 1991)

4.1.10. *Rainwater harvesting*

To determine how much water that can be collected during a season a simple formula is used. The supply is determined by the amount of rain falling in the area, the area of the roof and the runoff coefficient of the roof.

Supply = P*A*C (19)

Where:

P = precipitation (m/year)

A = Area (m^2)

C = Runoff coefficient (Overflow, leakage, evaporation losses≈20% ➔C=0,8)

Where the runoff coefficient is around 80 % due to overflow, leakage and evaporation losses.

5. Field Study

This chapter describes the different sites that I have visited during my stay in Burkina Faso. Not all of the visits are from the Kou Basin but the irrigation techniques used are the same. All of the sites described can be found on the map in appendix 1 except Fô that is situated close to the Mali border, northwest from the Kou Basin.

5.1. Local irrigation techniques

In my search for contacts in the Mouhoun catchment area I got in contact with Bertil and Ingrid Johansson who have been working as missionaries in Burkina Faso in the 1970s. 1978 they started a combined pastor and agricultural school in the village Banankélédaga outside Bobo-Dioulasso; which is situated in the catchment area of Kou. (Johansson, 2003)With this contact I got the possibility to rent a house on the area and from there I have had the best of chances to investigate the area and the different agricultural techniques that are used here. They also put me in contact with an agronomist, Pingwindi Compaoré, who did his studies at the school and now works in Bama. He and his friend Julien Sama, who works at the institute for agricultural research in Bama, have been helping me to answer my questions about the area, show me around and to take me to the right persons if they could not answer my questions.

Table 1 Crop factors, number of days of crop stage and general sensitivity of major crops in Burkina Faso (Critchley, W., Siegert, K. 1991).

Crop	Maize	Sorghum	millet	groundnut
Initial stage	0,40	0,35	0,35	0,45
(days)	20	15	20	25
Crop dev. Stage	0,80	0,75	0,70	0,75
(days)	35	30	25	35
Midseason stage	1,15	1,10	1,10	1,05
(days)	40	40	40	45
Late season	0,70	0,65	0,65	0,70
(days)	30	30	25	25
Season average	0,82	0,78	0,79	0,79
total number of days	125	120	115	130
General sensitivity to drought	Group four (high sensitivity)	Group two	Group two	Group one (low sensitivity)

5.1.1. *The agriculture school in Banankélédaga*

During one afternoon I was shown around on the school's properties where the students are taught how to cultivate and maintain farmland in a sustainable way. The school focuses also on the importance of planting trees to avoid desertification; which was a big problem in Burkina Faso during the 1980s (Fries, J., 1991). The school has around 34 hectares of land and is using complementary irrigation to water parts of the fields during the dry season (approximately 3 hectares). The water is pumped from the groundwater, with the help of three pumps, into a reservoir, from there the water is then lead through underground pipes to different areas around the school properties where water extraction points (Fig. 5) are placed so that water can be taken from here. To divert the water to the wanted part of the field plastic pipes are used (Fig. 5).

The irrigation techniques here are of the simplest kind. There are no concrete channels that lead the water and there is no system for controlling the water flow or the diversion of water. Instead channels are dug in the soil and mud serves as hatches.

The channels are dug in the soil with simple shovels. When enough water has been diverted to a certain lot some mud from the water channel is put in the opening of the lot to stop the flow (Fig. 7).

To divert water to an adjacent channel there are no hatches that could decide the exact amount that are going to pass instead rocks are used as the hatch and in this way one have with simple means created a hatch. The main flow, however, (Fig. 7) still continues in the direction of the main channel and a smaller amount is diverted towards the adjacent channel (field visit, Ilboudou, J, Compaoré, P, 2011).

5.1.2. *Irrigation techniques in Bama*

My contact in Burkina Faso mister Pingwindi Compaoré lives in Bama where he also has his farmland. He has approximately 2 hectare where he use complementary irrigation during the dry season. To do this he uses pumps that pump water from holes dug down to the groundwater level (Fig. 7).

Then to spread the water across the fields the same technique is used as on the agriculture school in Banankélédaga i.e. through the means of plastic pipes, shovels and canals dug into the soil. Mister Compaoré has two pumps, one big and one small, that when the investments were made did cost 900 000 F CFA (around 12 000 SEK) for the big one and 200 000 F CFA (around 2600 SEK) for the small one. At that time both were new (Field visit, Compaoré, P &Sama, J 2011).

5.1.3. *Irrigation techniques in Fô*

A field visit was also made in the village of Fô towards the Mali border. There the simplest complementary irrigation technique was studied; the one using watering cans to spread the water across the fields (Fig. 6). In this area there is a long band that stretches 15-20 kilometers where the groundwater is very close to the surface, the area covers approximately 100 hectares.

This gives the possibility to take advantage of this and to use complementary irrigation. Holes are dug all over the area so that groundwater can flow into them and to give close access to water.

The watering cans are heavy and when carrying two at a time, also considering the heat, the distance you will be able to walk is not that long. Compared to the use of pumps this technique is of course much heavier and not at all as effective, but the investment cost is far less as the only thing needed are the watering cans and a shovel to dig the holes with. However this is hard labor and the area that one person could irrigate during one day is small. The fields must be irrigated approximately every third day and to be able to irrigate a bigger area the farmer divide his time between three places ending up doing that every day. When using the pump system, irrigation every third day is also needed but in between that, other things could be done (Field visit, Compaoré, P &Sama, J 2011).

5.2. The dam at Samandéni

There is a project in the Mouhoun river catchment area to construct a major dam that is going to be the third biggest in the country with a volume of 1050 000 000 m^3. The site is not in the catchment area of the river Kou but this dam will still have large impact on the water resources in the Kou catchment area (see map in appendix 1).

First and foremost it will produce electricity for the whole region of which the Kou catchment area is just a small part of it. Secondly the dam will also create a 153 km^2 large lake that will provide the region with water for irrigation. So writing about the water resources in the Kou catchment area and not mentioning the dam is just not possible.

The dam is financed by the Abu Dhabi funds, the Islamic development bank and Burkina Faso itself and is to be finished around 2013. It will measure 22,6 m high and 2760 m long and it will produce 750 000 tons/year in the agricultural sector, 1 200 tons of fish/ year in traditional fishing, 5000 tons in aquaculture and 16 GWh/year (PDIS, 2007).

5.3. Hydrological observations

According to the maps of direction meteorology nationale there are four stations for meteorological measurements in the catchment area (Appendix 14, marked with a circle) one synoptic station, which is where the most information is collected and with the highest frequency. These are used at airports and this one is situated at the international airport of Bobo-Dioulasso. There are also two agricultural stations; used in especially dense agricultural areas (like Vallée du Kou and Farakoba) and finally one precipitation station, these only measure the precipitation for the meteorological institute (The precipitation data from the four stations are found in appendix 2).

The runoff from the catchment area feeds the rivers that flow north towards the joining with Mouhoun, the flow is irregular as it follows the rainy and the dry season. The highest measures are therefore found in August and September right after the peak of the wet season. The flow of Kou is measured at a hydrological station in Badala(see map in appendix 1). The measurement series stretches from 1984 to 2008 (Fig. 8, The whole measurement series is found in appendix 3) with a couple of breaks. The yearly average flow in Badala can be seen in figure 10.

5.4. Crop water requirement

To find out how much water certain crops that are planted in Burkina Faso statistic (Table 2) were gathered from a FAO report:

Figure 5 Upper left: One of the extraction points placed around the school area. Upper right and lower Left: The pipe system used to lead the water. Lower right: The reservoir

Figure 6 Picture of a man irrigating his field with a watering can

Figure 7 Upper left: A mud "gate", upper right: A water diverting point, lower left: Mr Sama, Mr Compaoré and the diesel pump, lower right: The hole dug down to the groundwater level

6. CLIMATE CHANGE

6.1. Present situation

The question of climate change has during the last couple of years always been a dark cloud that hangs over the future of the planet and especially the dry areas in Africa. It is a fact that the precipitation patterns in this region have changed over the last eighty years. According to the Atlas de l'afrique has the isohyets moved between 100 and 150 km to the south across the Burkinabe plains (Fig. 9).

The mean precipitation in Bobo-Dioulasso has been 1089 mm during the years 1930-2004. The precipitation time period that is used in this report stretches from 1959 to 2010 for Bobo-Dioulasso Airport. The yearly precipitation could therefore be put in comparison with the mean value of the whole area to try to find out if there is a trend (Fig. 10 and 11).

The red line shows a mean value on 5 years of surplus and deficits; this shows the trend of a somewhat dryer climate. However if the precipitation data is compared to the mean value described above between 1930 and 2004, the picture is a lot darker and here a clear trend of a dryer climate is visible (Fig. 11).

6.2. Future situation

A lot of work has lately been put into trying to predict how the future climate will be. The IPCC has established country profiles with their calculations on how the future climate will be changed compared to the present. There is no country profile for Burkina Faso, but there is one for Ghana and this profile cover the area of the Kou Basin as well.

The report states that the mean annual temperature has risen over the region with 1,0°C since 1960 and that in terms of precipitation the "annual rainfall in Ghana is highly variable on inter-annual and inter-decadal timescales.

This last picture confirms the moving of the isohyets towards south as the red trend line rarely leaves the minus 100-line compared to the mean value.

This means that long term trends are difficult to identify". The report further states that rainfall over this region was particularly high in the 1960s, a fact that could be observed (Fig. 10 and 11) and that the shift between the 1970s and the 1980s received particularly low levels of rainfall. This causes the trend to be decreasing over the period 1960 to 2006 with an average of 2,3 mm per month and decade.

The projections of future climate in the report deal with temperature and precipitation. The temperature will, according to the projections, increase by 1,0°C to 3,0°C by 2060s and 1,5°C to 5,2°C by the 2090s. An important statement in the report considering that the Kou basin is situated in the north is "the projected rate of warming is most rapid in the northern inland regions of Ghana than the coastal regions."

The projections of future precipitation patterns are a lot more uncertain, the report states that: "projections of mean annual rainfall averaged over the country from different models in the ensemble project a wide range of changes in precipitation for Ghana, with around half the models projecting increases and half projecting decreases."

Table 2 The distribution of different land types before urbanization

Land types	% (B)	CN (B)	Product (B)	% (C)	CN (C)	Product (C)
Cultivated land Without conservation technology (WCT)	3,3	64	211,2	8,2	76	623,2
Savannah	52,3	37	1935,1	26,2	51	1336,2
Residential areas				7	79	553
Industrial districts				1	81	81
Commercial areas				0,2	87	17,4
Roads				1,8	79	142,2
Sum	55,6		2146,2	44,3		2753

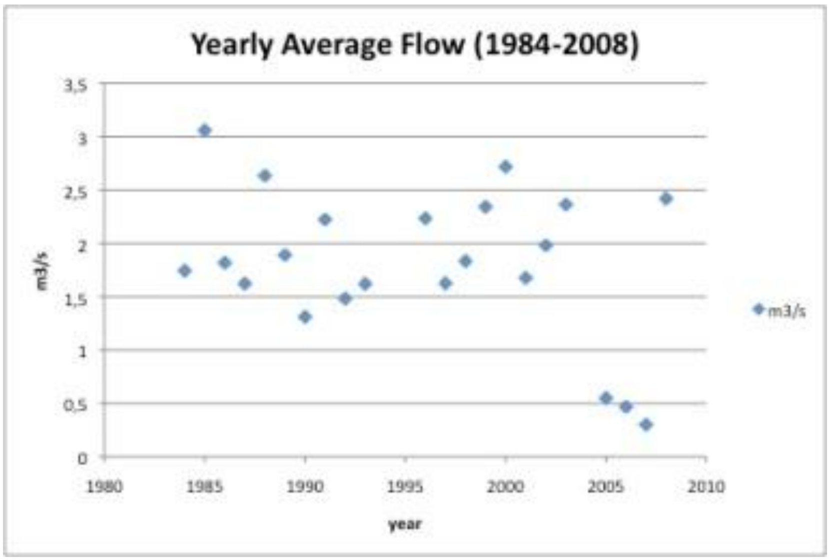


***Figure 8** The yearly average flow in Badala 1984-2008 (Ministère de l'agriculture, de l'hydraulique et des ressources halieutiques, 2011)*

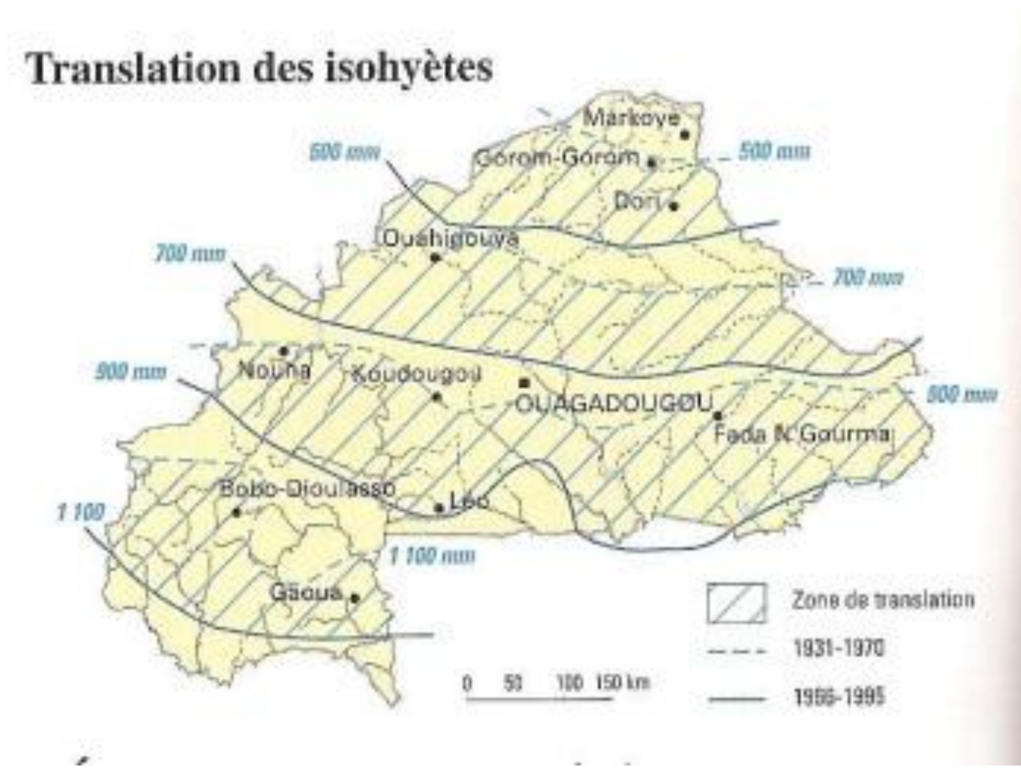


***Figure 9** Movement of isohyets from north to south in Burkina Faso (Atlas de l'Afrique)*

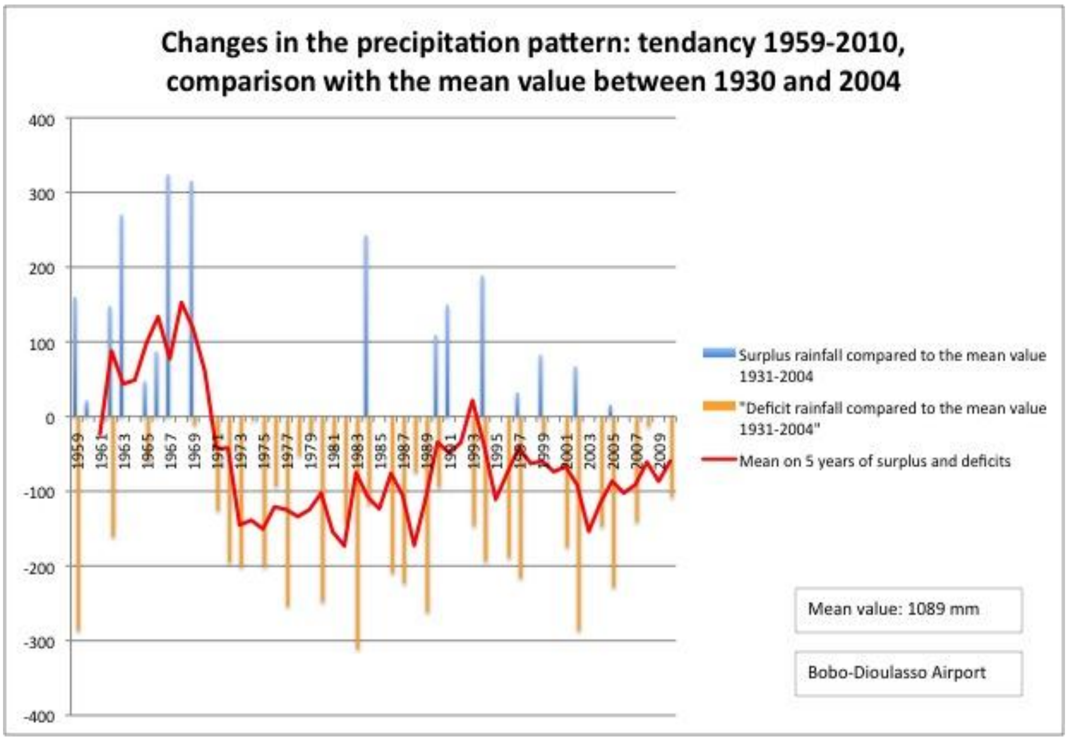


Figure 10 Changes in the precipitation pattern, comparison with the mean value between 1959 and 2010

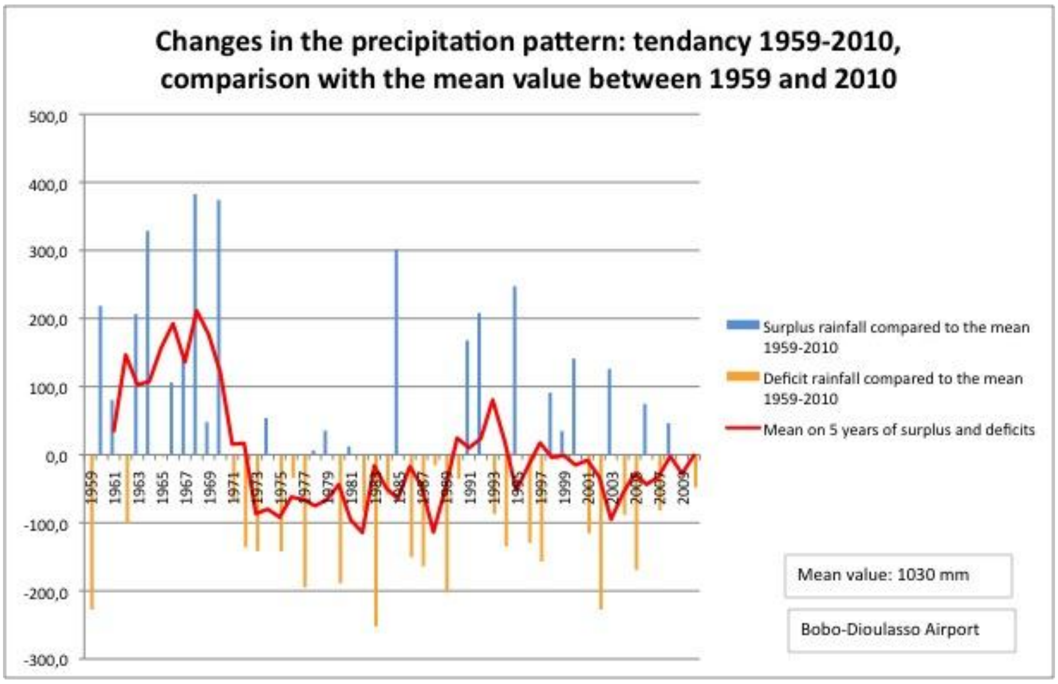


Figure 11 Changes in the precipitation pattern, comparison with the mean value between 1930 and 2004

7. RESULTS

7.1. Complementary irrigation

If nothing else is mentioned are the facts from this section taken from discussions with Albert Compaoré, national program officer for natural resources and climate change at the Swedish embassy in Ouagadougou and from the observations in the field study.

7.1.1. *The importance of complementary irrigation*

The question must be asked whether the use of complementary irrigation makes a difference or not? The traditional farming methods with the hope of a good year of rain, gives the farmer what he needs and sometimes more if the conditions are good. Maybe the rain does not come when expected, the harvest might fail, two out of five is a high ratio (as described above),and with a changing climate these events are likely to increase and as said in the chapter “climate change” the future climate will be warmer and more unpredictable so to enhance the resilience towards these events the complementary irrigation is crucial; it gives the possibility to avoid crop failure during the rainy season but it also gives the opportunity to cultivate the land in the middle of the dry season when the normal conditions does not allow it. The scheme that I have made below (Fig. 12) tries to describe the actions present in the process:

The two circles describe the cyclical way of agriculture where the harvest can end up being successful or end up in crop failure; with the later one leading to poverty. With the intervention of complementary irrigation most of the crop failures could be avoided and a successful harvest leads to surplus which could be invested in education, healthcare but most important in the beginning, own investments in complementary

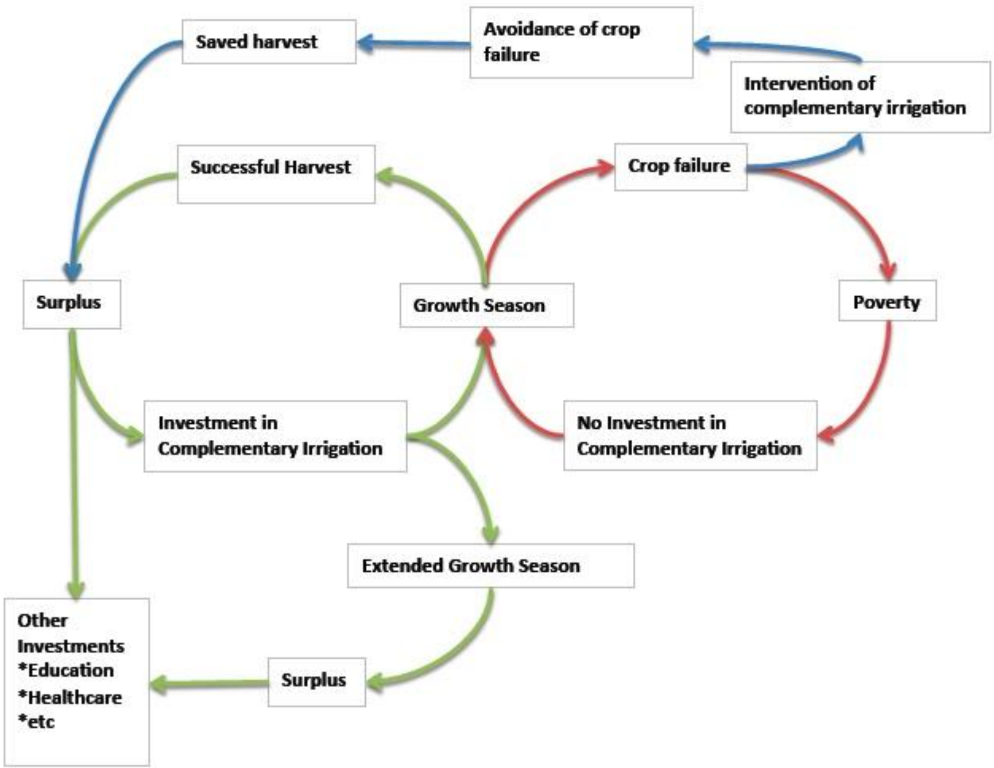


Figure 12 Description of the actions involved in the process around complementary irrigation

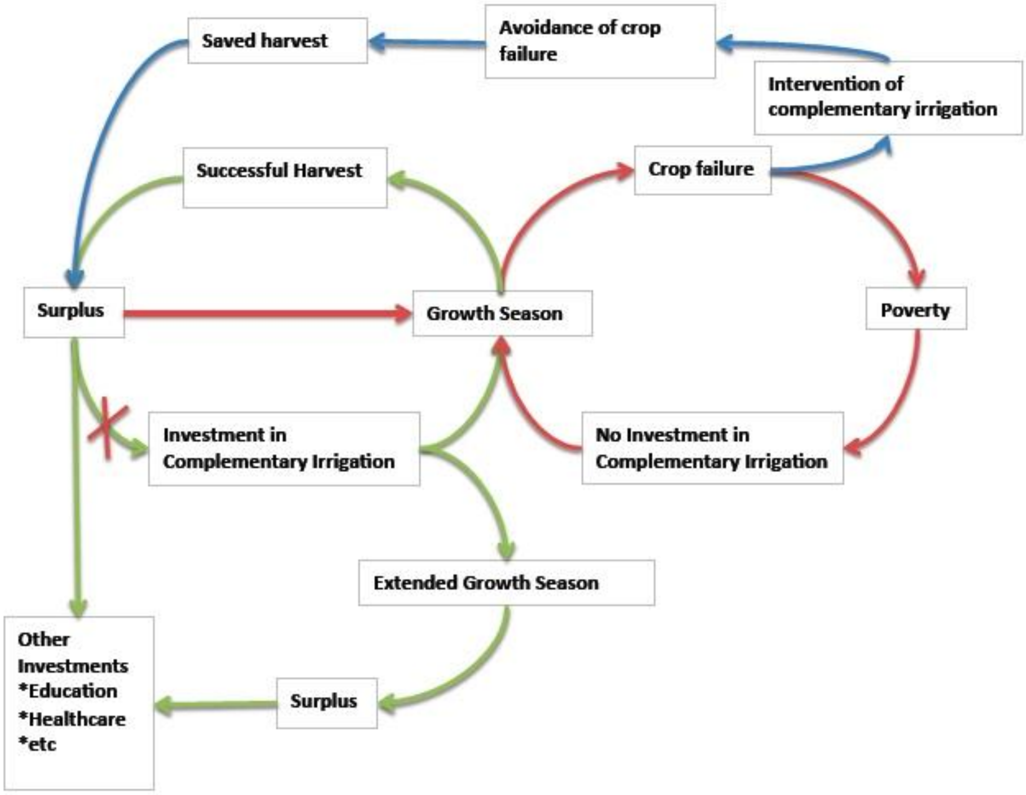


Figure 13 The risks involved in the process

irrigation to further enhance the resilience towards crop failure. The arrow leading towards "extended growth season" shows the possibility to extend the growth season to the dry season if investments in complementary irrigation are made; which could lead to an even greater surplus in the economy.

The problem is if the farmer not will make an own investment in complementary irrigation and rely on that next harvest will be successful. In this case the complementary irrigation will stay as an emergency act started by NGOs or other helping organizations every time needed. This will also cause the farmer to be more exposed to the risk of ending up in the red circle again and will probably not give the poverty reduction effect wanted from the start (Fig. 13).

7.1.2. *Issues encountered*

The scheme above only describes the processes involved not the problems that occur or where the problems could be attacked. In my study I have encountered four main issues that I find is part of the problem to fight poverty in the agricultural sector. These four are:

Private Economical

It is a huge step to get out of the red circle; to avoid crop failure money need to be invested in complementary irrigation techniques but also in tanks or reservoirs that could store the water needed for the complementary irrigation.

Infrastructural Economical

In some regions the farmers might have the money to afford their own pumps but the access to water storage might be limited. Here infrastructural investments need to be made to give access to wells, dams or tanks from where water can be extracted.

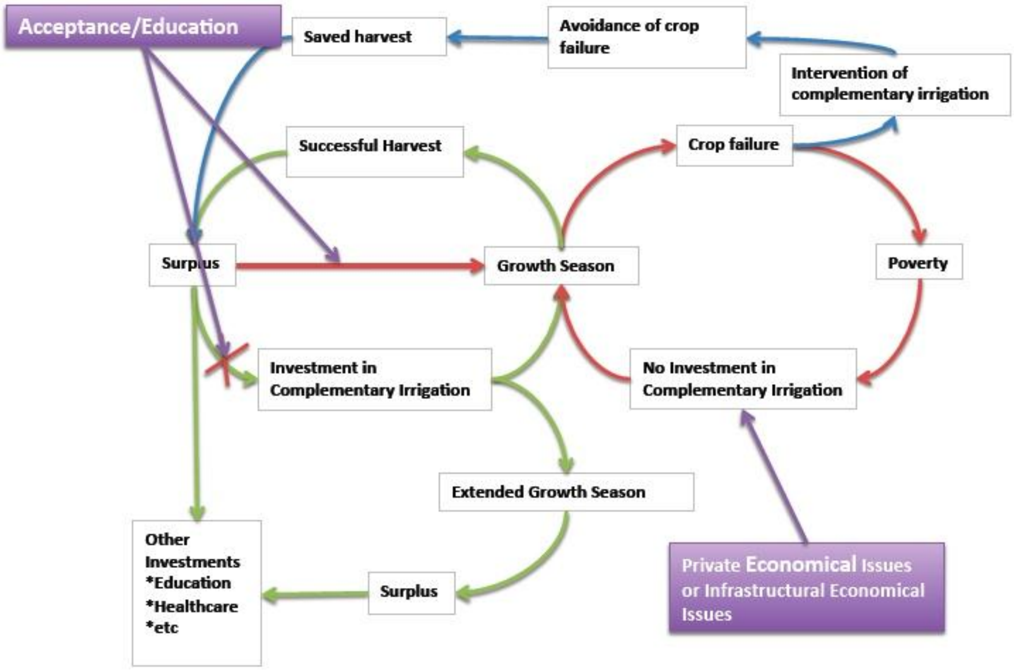


Figure 14 Issues encountered pointed out where in the scheme they occur

Educational

The need for good water governance and the unawareness of the need of saving water is an educational problem that needs to be solved. If people know the impact of not using complementary irrigation more people would be eager to use it.

Acceptance

It is also a question of acceptance, both in educational terms as described above but also in terms of novel techniques that might be provided. The farmer must be a participating stakeholder when techniques for climate change adaptation are chosen.

These issues occur in different stages of the above described cycles (Fig. 14).

7.2. Catchment areas

In this study different catchment areas have been studied, not only the catchment area as a whole but also sub catchment areas for the purpose of for example dam site suitability or runoff calculations.

The whole catchment area was calculated to be in the order of 1800 km^2 +/- 39 km^2 (see appendix 5 for calculations). The two sub catchment areas Badala and Koumi were found to be in the order of 999 km^2 and 346 km^2 (see appendix 1) these are the two in question for the dam sites. The river that drains the urban area of Bobo-Dioulasso is called Wé and its catchment area was calculated to be in the order of 122 km^2 +/- 10 km^2 (Appendix 7).

7.3. Average precipitation and Evapotranspiration

To find out the average precipitation over the Kou catchment area the Thiessen method was used based on the four different stations in the catchment area to get one average value (Appendix 6). The result received was 974 mm per year.

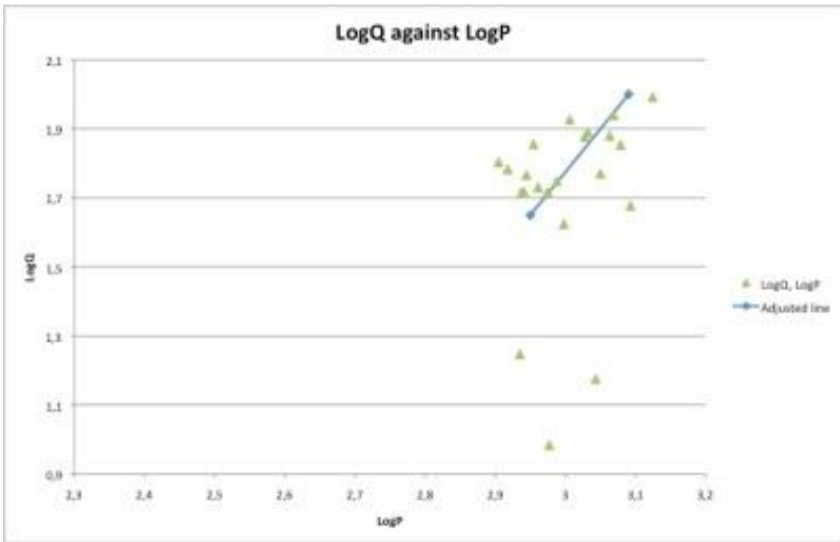


Figure 15 LogQ/logP diagram

To estimate the average runoff (Q_{mean}) the logaritmic values of the last 24 years of precipitation over Bobo-Dioulasso Airport and mean annual runoff from Badala were put in a logaritmic diagram to match the best fitting straight. (Fig. 15) This is based on the following assumption:

$Q_{mean} = a*Q^b$ (20)

With the value of P_{mean} 974 mm/year taken from the Thiessen (see table 5 and appendix 6) above the Q_{mean} for the area was found to be 64 mm/year.

However, due to the big spreading of the values and the resulting difficulty to find a straight fitting line a more accurate value for Q_{mean} is the average of the Q values from 1984 to 2008 (except zero values and the values from 2005 to 2007), the result is:

2,0 m^3/s = 63 072 000 m^3/year = 35 mm/year

This gives the evapotranspiration computed through the formula:

$E = P - Q \rightarrow E = 974 - 35 = 939$ mm/year

7.4. Runoff Bobo-Dioulasso, flood risks

There are two different soil groups in the Wé catchment area and these are distinguished according to the soil group definitions used by the soil conservation service (Chow, V.T., 1988 p. 149). 48 km^2 is soil group C and 74 km^2 is soil group B. For soil map see appendix 15.

The distribution of the different types of land usage at present time (Table 3) were found out through the land use estimations in map 2 in appendix 7 with help of the map in appendix 1.

From table 2 the weighted CN value can be calculated to:

(2146,2+2753)/100 = 49

The approximate growing of Bobo-Dioulasso from pre-colonial time until present (Fig. 16) was used to calculate the changes of the urban situation. The most interesting part is after 1990 when the city has been growing tremendously, more accurately by 120 % area wise according to the area changes. If we assume that the growth shown in the picture has occurred between 1990 and 2010 and that Bobo-Dioulasso will continue to grow with the same area, 6.6 km^2, until 2030. Then the future area of Bobo-Dioulasso would be 18.6 km^2.With the assumption that the percentage in different types of areas within Bobo-Dioulasso remains the same the new distribution in the catchment area, after urbanization, would then be the results in table 4.

The new weighted CN value is:

(2146,2+2906,2)/100 = 50,5

The S value of the present and the future conditions will therefore be:

S_{before}= 1000/49 - 10 = 10,4 inches

S_{After} = 1000/50,5 – 10 = 9,8 inches

The following calculations are made with data from a storm rain that fell over Bobo-Dioulasso on the 12th of October 2010 (Weather Underground, 2010).

During this day 112 mm (4,41 inches) of rain fell, with the present S value the direct runoff will be:

$P_{e,before} = (P-0,2S)^2/(P+0,8S)$ = 0,427 inches = 10,9 mm

$P_{e,after}$ = 0,49 inches = 12,5 mm

7.5. Estimated water extraction from groundwater in Bobo-Dioulasso

Bobo-Dioulasso had a population of 435,543 according to the census of 2006. The population in the city is estimated to have access to water piped into the house but only a single tap.

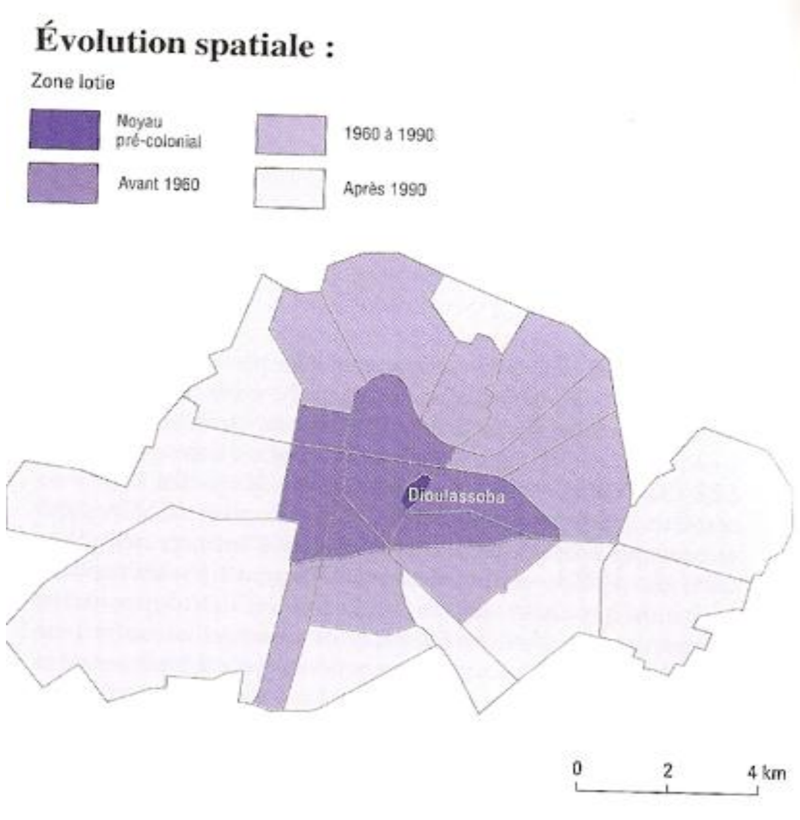


Figure 16 Development of the urban area of Bobo-Dioulasso.(Atlas de l'Afrique)

This result in an average water usage of 30-60 liters/person/day (Johnston, 2010). A value in the higher area of the span is chosen (50 liters/person/day) to try to compensate for the multiple tap households that exist in Bobo-Dioulasso.

435 543 * 50 = 21 777 000 liters/day

This value is probably shifting during the course of the year, so to compensate for that in the total yearly usage a value of 75% of the above given value is used during the rainy season (5 months of the year). During the dry season a value of 120% of the above given value is used. In this way the yearly usage will be:

21 777 000*0,75*5*30,5+21 777 000*1,2*7*30,5 = 8 070 012 m^3/year

This gives an average demand of pumping from the groundwater source of: 8 070 012 000/(3600*24*365) = 256 lit/sec

Table 3 The distribution of land types after urbanization

Land types	% (B)	CN (B)	Product (B)	% (C)	CN (C)	Product (C)
Cultivated land (WCT)	3,3	64	211,2	8,2	76	623,2
Savannah	52,3	37	1935,1	20,8	51	1060,8
Residential areas				10,9	79	861,1
Industrial districts				1,6	81	129,6
Commercial areas				0,3	87	26,1
Roads				2,6	79	205,4
Sum	55,6		2146,2	44,3		2906,2

Table 4 The driest 24-month period recorded in Badala (Ministère de l'agriculture, de l'hydraulique et des ressources halieutiques, 2011)

year	month	m^3/s	year	month	m^3/s
	august	6,3		august	3,3
	september	4,6		september	6,2
	october	0,7		october	0,7
	november	0,7		november	0,5
	december	0,7		december	0,6
1992	january	0,4	1993	january	0,4
	february	0,4		february	0,4
	march	0,4		march	0,4
	april			april	0,4
	may	0,9		may	0,7
	june	1,2		june	
	july	1,7		july	

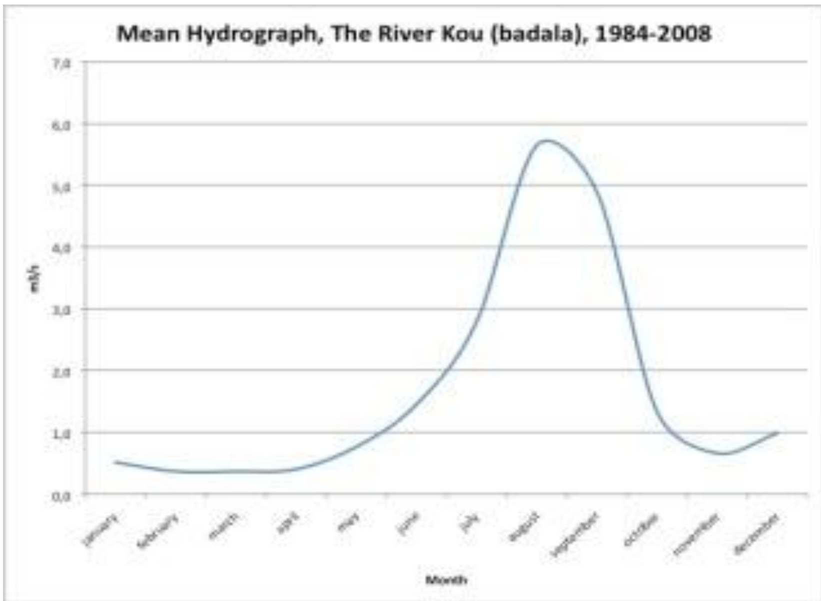


Figure 17 Mean Hydrograph, The River Kou (Badala) 1984-2008

7.6. Calculations for the dam sites

The calculations for the two dam sites are found below, first Badala and then Koumi. After that follows a frequency analysis on both sites.

7.6.1. *Badala*

The driest 24-month period recorded in Badala during the period 1984 to 2008 is found in table 4 and the mean hydrograph is found in figure 21.The hydrograph (Fig. 17) and the flow duration curve that shows how many months per year a certain flow is exceeded (Fig. 18, mean between 1984 and 2008, for calculations see appendix 4) are based on the driest 24-month period recorded in Badala during the period 1984 to 2008 (Table 4). The area below the curve is equal to the total volume of runoff during a mean year during this period. The result is that the mean total runoff is 100,8 Mm^3/year.

The mass curve in Badala(Fig. 19, this figure is not adjusted for evaporation loss) is made with the help of the driest 24-month period recorded (Table 4).

The maximum constant release is:

1,415m^3/s

According to the diagram the required storage volume of the reservoir to maintain this release at Badala is:

18 848 160m^3

7.6.2. *Koumi*

The runoff data observed in Badala can be adjusted with the assumption made in the part ”Calculation of runoff in a sub catchment” area in the chapter ”theoretical background” to fit the whole area or a subcatchment of the river basin. To find out how the flow conditions are at Koumi the runoff measurements from Badala have been used (for area calculations see appendix 8). The assumption has been made that the runoff is changed into the condition at Koumi with the help of the above-described principle. This assumption has been verified with the

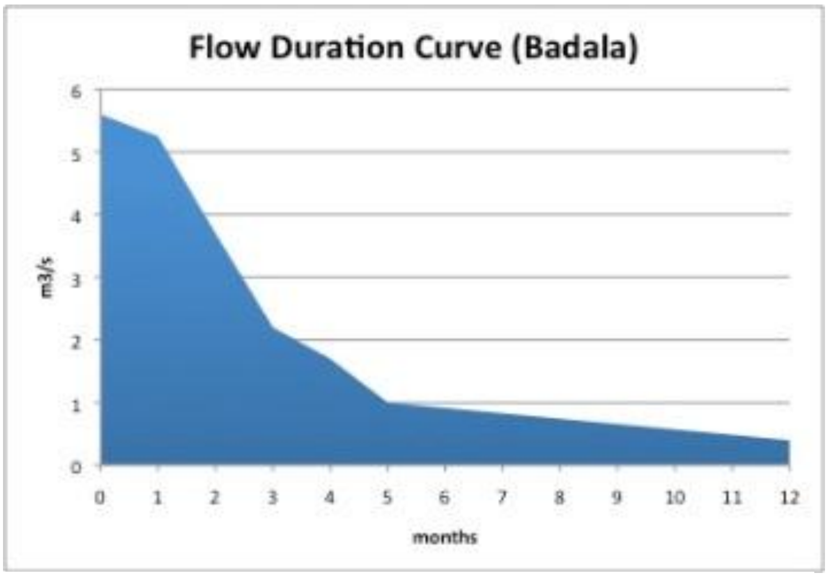


Figure 18 Flow Duration Curve Badala

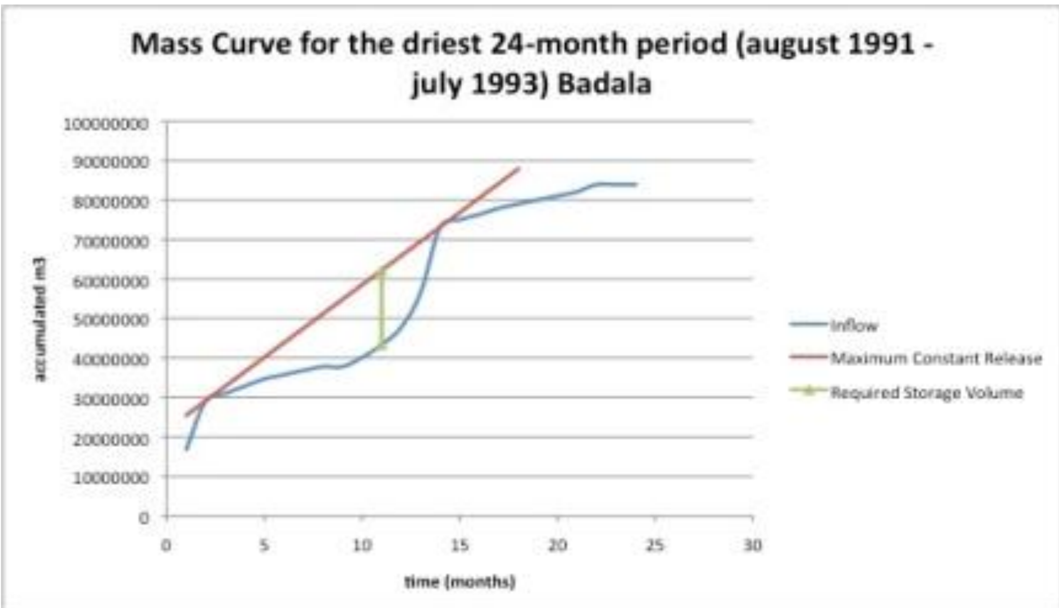


Figure 19 Mass curve for the driest 24-month period in Badala

help of the water balance equation to see that the evaporation is approximately the same (Table 5) over the whole area.

The Q_{mean} value is 35 mm/year and the average precipitation is approximately the same for both the Badala and Koumi catchment so the assumption above is correct.

The size of the Badala and the Koumi catchment areas are 999 km^2 and 346 km^2. The assumption gives:

$$\frac{Q_1}{Q_2} \rightarrow \frac{A_1}{A_2} = \frac{346}{999} = 0,346$$

The hydrograph (Fig. 20), the flow duration curve (Fig. 21) and the mass curve (Fig. 22, this figure is not adjusted for evaporation losses) for Koumi are based on the driest 24-month period for Koumi (Table 6).

The mean total runoff for the Koumi catchment area is 35 000 000 m^3/year.

The maximum constant release is:

0,490 m^3/s = 490 l/s

According to the mass curve the storage volume of the reservoir is:

6 525 840m^3

7.6.3. *Frequency analysis*

The results from the graphical and analytical methods are shown in table 7. For more detailed calculations see appendix 10.

7.7. Comparison of dam sites Koumi and Badala

To give more farmers the opportunity to use complementary irrigation, both during the dry and the rainy season, investments need to be done to provide water for irrigation. One of these solutions is to build reservoirs where water can be stored from the rainy season. This section will cover the question whether a dam could be placed in Koumi or in Badala (see map in appendix 1), the discussion will cover the suitability in terms of where it is in the catchment area, what is found up- and downstream of the site and how much land that could be expected to be irrigated with help from the reservoir.

7.7.1. *Dam construction*

In terms of which kind of dam that will be constructed there are no differences between the two dam sites discussed. The areas and the conditions are the same for both sites. A suitable construction would therefore be a homogenous embankment dam with a chimney drain.

Table 5 Total average rainfalls (mm) over Kou Basin

Total average rainfall over the catchment area

	Av. 1977-2010	Area	Area*Precipitation
Bobo-Dioulasso Int. Airport	954	431	411147
Farakoba	1028	355	364789
Nasso	994	556	552564
Vallée du Kou	929	481	446681
Summa		1823	1775181
	Average rainfall	1766015/1823 =	974

Average rainfall over Koumi area

	Av. 1977-2010	Area	Area*Precipitation
Bobo-Dioulasso Int. Airport	954	16	15263
Farakoba	1028	291	299024
Nasso	994	39	38759
Vallée du Kou	929	0	0
Summa		346	353046
	Average rainfall	362187/355 =	1020

Average rainfall over Badala area

	Av. 1977-2010	Area	Area*Precipitation
Bobo-Dioulasso Int. Airport	954	34	32434
Farakoba	1028	357	366844
Nasso	994	542	538650
Vallée du Kou	929	66	61291
Summa		999	999220
	Average rainfall	991412/991=	1000

Table 6 The driest 24-month period for Koumi

year	month	m³/s	year	month	m³/s
	augusti	2,18		augusti	1,14
	september	1,59		september	2,15
	oktober	0,24		oktober	0,24
	november	0,24		november	0,17
	december	0,24		december	0,21
1992	januari	0,14	**1993**	januari	0,14
	februari	0,14		februari	0,14
	mars	0,14		mars	0,14
	april			april	0,14
	maj	0,31		maj	0,24
	juni	0,42		juni	
	juli	0,59		juli	

This is because the design of these is mainly determined by the earth material available nearby and this is important in this context to get a reasonable cost for the dam construction. As the soil is homogenous in the catchment area the homogenous dam is suggested. To avoid high pore water pressures in the downstream part of the dam, it will be designed with a chimney drain.

7.7.2. *Conditions for a dam construction at Badala*

The hydrological conditions at Badala are well monitored as the flow measurement station for the Kou River is situated here. The storage volume of the reservoir needs to be sufficiently large so that a certain discharge can be released to meet the demand for the water supply and/or irrigation during a dry period. Therefore the storage volume and thus the dam height are determined from a selected dry period and the design water consumption. Useful information (Table 4, Fig 19, 20 and 21) and the estimations on the design water consumption are found in the part "potential irrigable land".

7.7.1. *Conditions for a dam construction at Koumi*

The flow at Koumi is naturally smaller than at Badala but still sufficiently large to be interesting for a dam construction. Useful information (Table 6, Fig. 20, 21 and 22) and the estimations on the design water consumption are found in the part "potential irrigable land".

7.8. Crop water requirement

To be able to estimate the water usage will be in the different techniques observed information about site-specific crop water requirement is needed. The water requirement values have been calculated for four common crops in the Burkinabe agricultural sector and with consideration of the climatic conditions in this region.

To estimate the crop water requirement the following equation is used:

$$ET_{crop} = K_c * ET_0 \qquad (21)$$

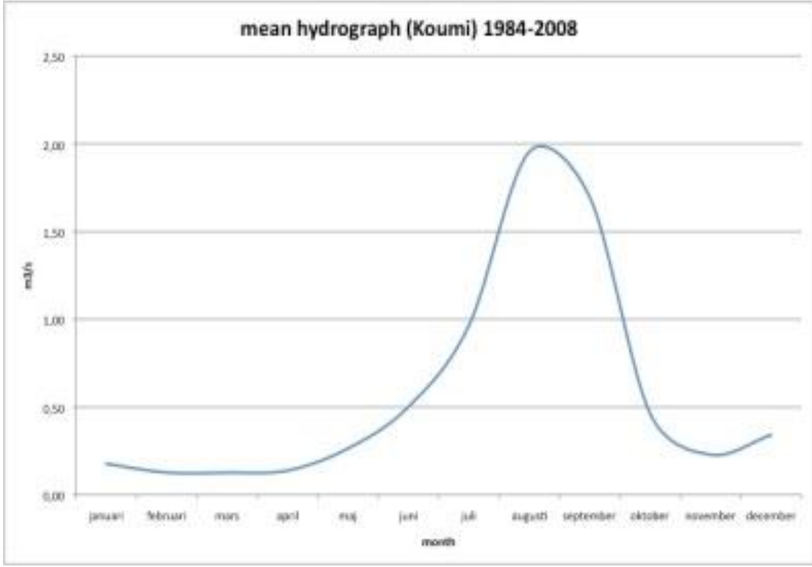


Figure 20 The mean hydrograph (Koumi) 1984-2008

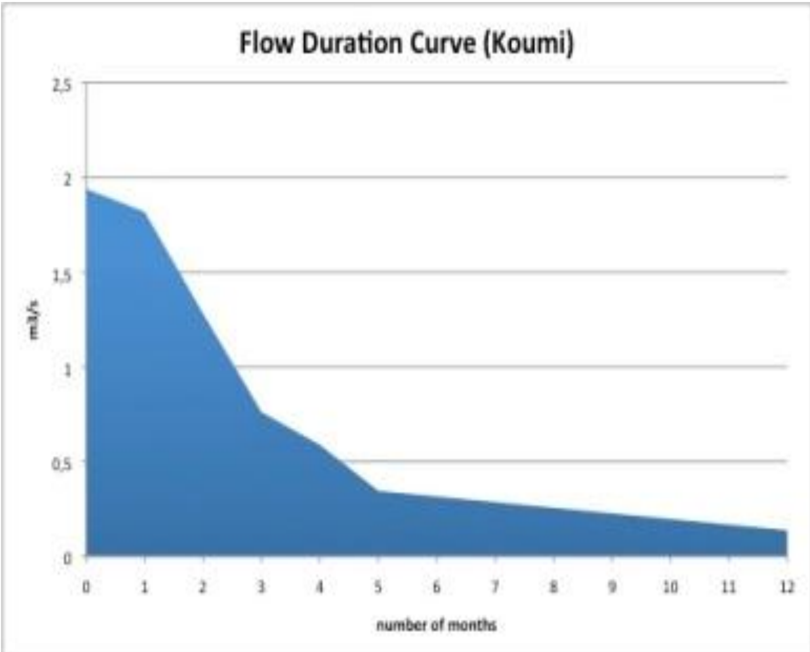


Figure 21 Flow duration curve Koumi

To calculate ET_{crop}(Evapotranspiration crop) the K_c(crop factor) value and ET_o (the reference crop evapotranspiration) value is needed, the first one is found in table 2 and the second one can be calculated through the Blaney-Criddle formula.

$$ET_0 = p(0{,}46T_{mean} + 8) \qquad (22)$$

T_{mean}, and p can be found in table 8, where also the ET_o calculations can be found, the blue marked area is the rainy season and an average ET_o is found in the right bottom corner.

The average ET_o value is then multiplied with the K_c values for the respective crop and the result is found in table 9.

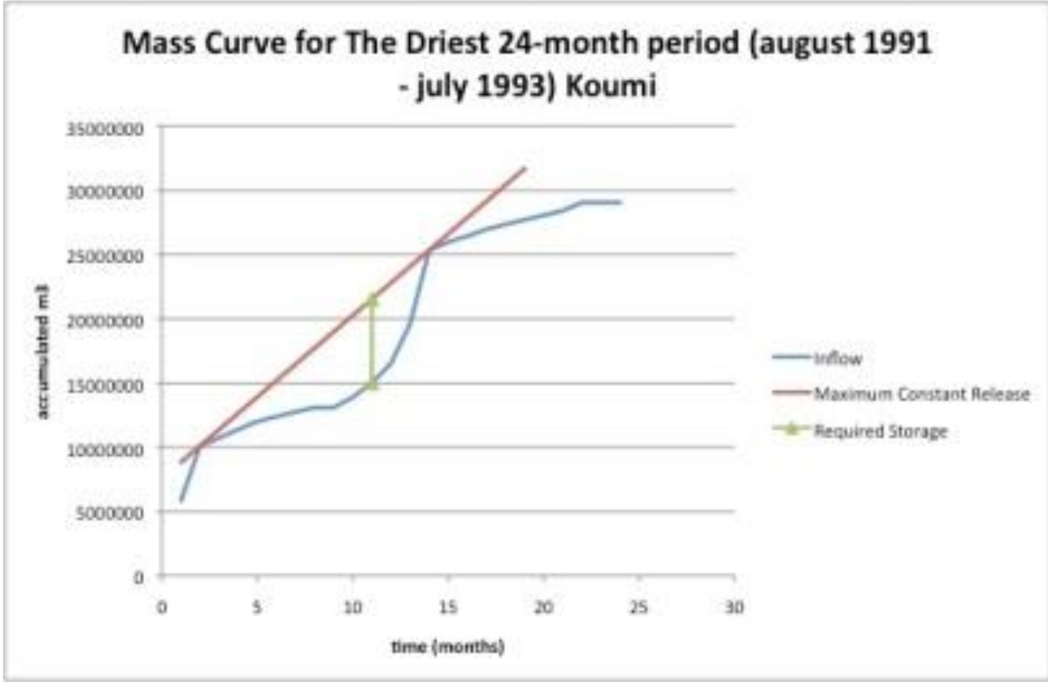


Figure 22 Mass curve for the driest 24-month period Koumi

Table 7 Frequency analysis results

	Badala	Koumi
The graphical method	**m³/s**	**m³/s**
100 years flood	42	32,5
1000 years flood	58	45
The analytical method	**m³/s**	**m³/s**
100 years flood	38	29
1000 years flood	51	40

7.1. Rainwater harvesting results

The potential water storage from one roof of 120 m² in the Kou Basin is approximately 100 m³ during one year. The result (Fig. 23) is based on table 10 where the average monthly precipitation data from 1995-2005 in the Bobo-Dioulasso area can be seen to the left. The values are then multiplied with the size of the roof and the runoff coefficient. The accumulated water storage can be seen to the right. The usage of rainwater harvesting could be very useful in regions where there are no nearby rivers with all year round flow or if the groundwater is not abundant enough to provide water both for domestic use and for complementary irrigation. One problem that arises is that the water is collected during the rainy season when the water for complementary irrigation is supposed to be used i.e. the reservoirs are full when the harvest season is over. This could be solved if water is saved from one rainy season to next so that the reservoir is full when the harvest season starts, what is needed in this case is good governance so that there is a sufficient storage of water available.

Another problem is if the storage could be sufficiently large to provide enough water for the use of complementary irrigation. The precipitation statistics from two years of crop failure from 1977 and 1978 are found in appendix 12. These are compared to the precipitation statistics of 1979 that was a year with a successful harvest and the different crop growing stages starting in the middle of May; the approximate start of harvest season.

Table 8 calculations on the ET_o values

Month	Precipitation (mm)	Average Temperature (°C)	Mean daily percentage of annual daytime hours (for 15th latitude)	Eto (mm/day)
January	0	26	0,26	5,1896
February	1	29	0,26	5,5484
March	0	31	0,27	6,0102
April	28	30	0,28	6,104
May	116	27	0,29	5,9218
June	54	27	0,29	5,9218
July	117	25	0,29	5,655
August	249	24	0,28	5,3312
September	274	24	0,28	5,3312
October	143	26	0,27	5,3892
November	0	27	0,26	5,3092
December	0	26	0,25	4,99
			Average Eto (may-sept)	5,6322

Table 9 Crop factors for major crops in Burkina Faso

Crop	av. ETcrop/day	Etcrop/total growing season
Maize	4,62	577
Sorghum	4,39	527
Millet	4,45	512
Groundnut	4,45	578

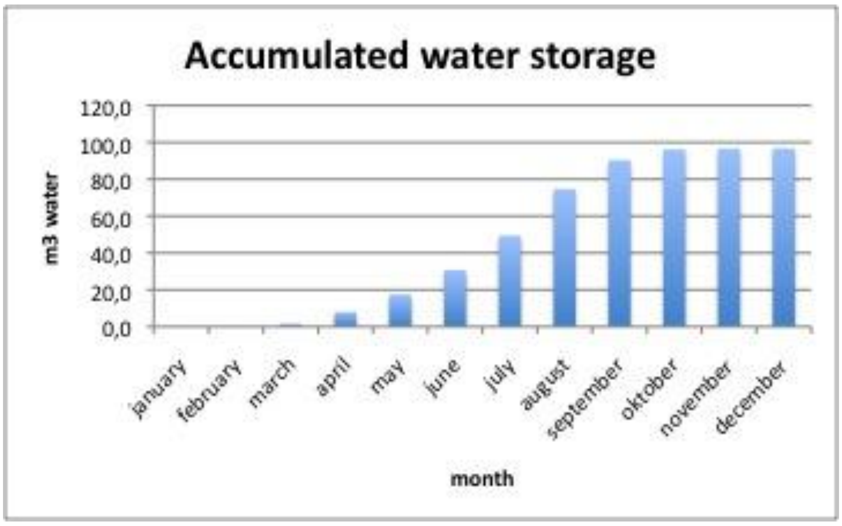


Figure 23 Accumulated water storage for a 120 m² roof in the Kou Basin

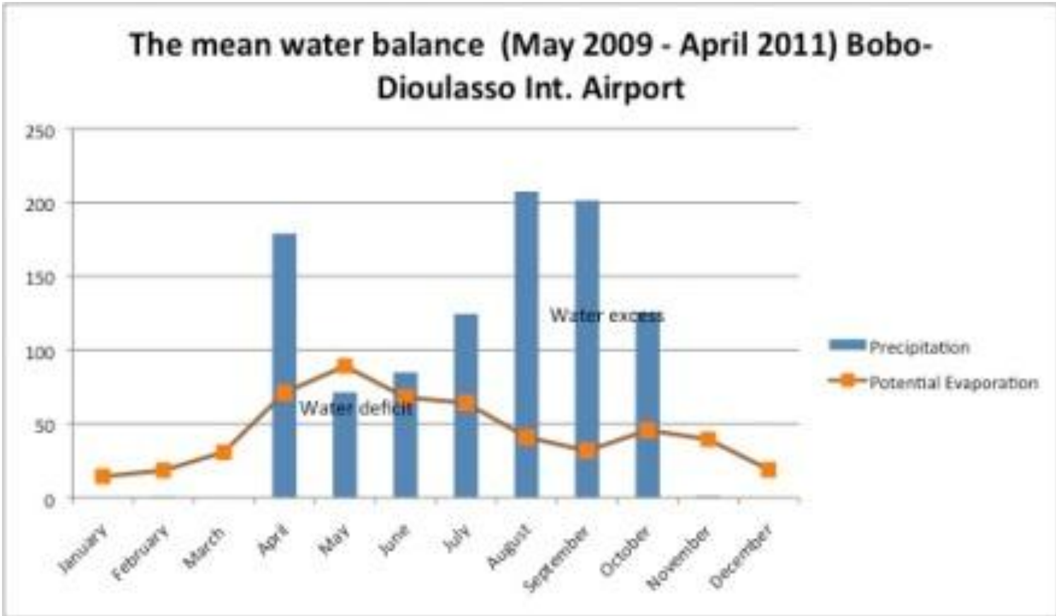


Figure 24 The mean water balance (May 2009 – April 2011) Bobo-Dioulasso Airport

Table 10 Rainwater harvesting calculations

Accumulated water from a 120 m2 roof in the Bobo-Dioulasso area
Average 1995-2005

	(mm)	m^3/month	runoff coeff. 0,8	accumulated
January	0,2	0,0	0,0	0,0
February	0,8	0,1	0,1	0,1
March	16,0	1,9	1,5	1,6
April	65,5	7,9	6,3	7,9
May	99,2	11,9	9,5	17,4
June	138,0	16,6	13,3	30,7
July	194,5	23,3	18,7	49,4
August	263,5	31,6	25,3	74,7
September	163,5	19,6	15,7	90,4
October	60,3	7,2	5,8	96,1
November	5,2	0,6	0,5	96,6
December	1,2	0,1	0,1	96,7
total	1007,8			

When three days of no rain in a row occurs these days are marked with light orange and when there are four days or more of no rain these are marked with dark orange. Suppose that the crops cannot withstand four days of no rain in a row, fields are irrigated every third day in the Kou basin (Compaoré, P, 2011), when this happens the days are marked with blue. Suppose also that for every blue mark another 44,8 m^3/day*hectare must be added to avoid crop failure (suppose that these 4,48 mm/hectare of artificial rain is enough for the crops to avoid crop failure until next rain arrives). During 1976 a total of eight blue marks have been made, if an average Burkinabe farm size is 5 ha (Waters-Bayers, A, Reij, C., 2001), this means that the need for complementary irrigation this year was:

$44{,}8 * 5 * 6 = 1344$ m^3

The volume of this reservoir is clearly too big; few Burkinabe farmer can, on his or her own, have a reservoir of this size. The catchment roof area to fill this reservoir would also be too big, approximately:

$120 \text{ m}^2 * 13{,}9 = 1668 \text{ m}^2$ $(1344/96{,}7 \approx 13{,}9)$

So to be more realistic a look at the problem from another point of view would be appropriate; how many days of drought could a normal-sized storage tank withstand?

Say that a tank has a size suitable for the conditions described above i.e. a storage tank of 100 m^3. This would give the farmer a possibility to irrigate:

$100/44{,}8 \approx 2{,}23$ hectares

$2{,}23*4 \approx 9$ days

As supposed above the farmer needs to start the complementary irrigation on the fourth day of a drought, then he has two choices, either irrigating 2,23 hectares one time or one hectare could withstand nine days of drought.

Example:

However, if cooperation between farmers could be established (even though there have been problems with that in the past) a bigger reservoir could be supplied with water creating bigger water supply possibilities. This could be obtained by leading water from several roofs and/or plastic material could be put on the ground to lead water into the reservoir. If a 20*20*2 meter (800 m^3) reservoir would be excavated the following catchment area would be needed:

$120*8{,}3 \approx 990 \text{ m}^2$ $(800/96{,}7 \approx 8{,}3)$

If the above supposed roof area of 120 m^2 is used this would mean:

$990/120 = 8{,}25$ houses

Say instead that 4 households cooperate to dig the reservoir then each household would have access to 200 m^3 of water for irrigation, which is:

$200/44{,}8 = 4{,}46$ hectares of irrigable land one time or:

$4{,}46*4 = 17{,}84 \approx 18$

Thus, one hectare could withstand 18 days of drought.

The plastic covered ground could collect the rest. The area that needs to be covered by plastic when the rain arrives would be:

$990 - 4*120 = 510 \text{ m}^2$

So for example a tarpaulin of size 23*23 m on a slope side could be suitable.

If this reservoir could be constructed in concrete most of the infiltration problems would be solved, there would however be some problems with evaporation loss.

The mean water balance from the Bobo-Dioulasso area between May 2009 and April 2011 (Fig. 24, the calculations that lead to this diagram is shown in appendix 11).The sum of all monthly evaporation rates from a water surface sums up to be 762 mm/year and therefore the evaporation loss from a 20*20 m big water surface is:

$762*0{,}001*20*20 = 304{,}8 \text{ m}^3$

In a reservoir containing only 800 m^3 this is not sustainable; therefore a sealed reservoir is necessary. The evaporation rate is adjusted to be the rate of evaporation from a land surface.

7.1.1. ***Evaporation loss calculations***

According to the calculations in Appendix 11 the total evaporation loss from a water surface in this region is 762 mm/year.

The respective reservoir sizes are as follows:

Badala: 18 848 160m^3 = 18,85 Hm^3 (Cubic Hectometer)

Suppose a reservoir area of 4 km^2 (see map in appendix 1).

Then the average depth of the reservoir is:

18 848 160/4 000 000 = 4,71 m

The evaporation loss is therefore:

762*0,001*4 000 000 = 3 048 000 m^3/year = 8351 m^3/day

Koumi: 6 525 840m^3 = 6,53 Hm^3

Suppose a reservoir area of 1 km^2 (see map in appendix 1)

Then the average depth of the reservoir is:

6 525 840/1 000 000 = 6,5 m

The evaporation loss is:

762*0,001*1 000 000 = 762 000 m^3/year = 2087 m^3/day

7.2. Potential Irrigable land around Koumi and Badala

To determine how many hectares of land that could be irrigated with the help of the two dam suggestions the result from the crop requirement calculations are used. The average water requirements for the most usual crops in Burkina Faso (Table 2) are used to find an average water usage.

So an average value of these four values would be:

$$\frac{4{,}62+4{,}39+4{,}45+4{,}45}{4} = 4{,}48\text{mm}$$

Thus 4,48 mm rain/day times 10 000 m^2 to get the volume of water needed per hectare of farmland. This gives the following result:

$4{,}48 * 0{,}001 * 10\ 000 = 44{,}8$ m^3/day*hectare

If the constant release is set to be 50% of the maximum constant release the following potential extraction values are obtained (Table 11, for calculations see appendix 13):

This shows that the potential for irrigable land is bigger in Badala than in Koumi, even though not very much bigger.

Or in terms of a 5 ha Burkinabe farm in need of complementary irrigation

1179/5 = 236 days

898/5 = 180 days

Thus, one Burkinabe farm can withstand 236 days of drought from a reservoir in Badala and 180 days of drought from a reservoir in Koumi.

Table 11Potential irrigable land

	Badala	Koumi	
Potential extraction flow	0,708	0,245	m^3/s
total water volume/day	61171	42336	m^3/day
adjusted for evaporation loss	52820	40249	m^3/day
divided with the water need gives	1179	898	hectares

8. DISCUSSION

8.1. Discussion on climate change

As described above the future climate in this region is very hard to predict. Some predictions say that there will be an increase in precipitation and some say that there will be a decrease. The temperature predictions predict an increase but the difference between an increase of 1,5°C and that of 5,2°C is rather big.

While the IPCC report does not give any answers of what the future climate will look like it for sure does give a picture of an unpredictable future climate. With this knowledge the process of adapting the agricultural sector to the present climate change gets even more important, this to enhance their resilience towards the unpredictability of the future climate. With the uncertainty of the predictions of the future in mind, no estimations of what a future climate would look like will be performed in this report.

8.2. Discussion on "average precipitation and Evapotranspiration"

Most of the values in the logP/logQ-diagram follows the same value tendency and therefore shows a coherent picture of an average line going through them. There are, however, three values that show a completely different tendency (Figure 18). A tendency of values lying within the same range can be followed from 1984 until 2004, but in 2005 all of a sudden the values changes and gets a completely new tendency for three years 2005 to 2007. In 2008 the value is back in the same trend as between 1984 and 2004. Due to this the three values between 2005 and 2007 have been neglected. The divergence could be due to an over extraction of water upstream of the measurement station, this could be interesting to analyze as Bobo-Dioulasso is taking their water resources from the groundwater around Kou upstream from Badala. However, the most probable explanation for this divergence is that the measuring instruments have been moved and that the instrument has not been reinstalled correctly until 2008.

The estimated value of the Evapotranspiration might seem high but considering that Burkina Faso is a very hot country with a high solar radiation this seems reasonable.

8.3. Discussion Runoff Bobo-Dioulasso

The estimation of future change in land use rendered in a change in direct runoff of 12,5 – 10,9 mm = 1,6 mm/km^2.

The increase in direct runoff over the whole Wé catchment area would, however, result in an increase of water volume that needs to be transported in the streams and sewer systems of the Wé catchment area and Bobo-Dioulasso. The rain in the example fell in October and during this time of year the soil is saturated and the waterways could be filled already. It could be noticed that 1,6 mm is not a very big increase in terms of runoff, but the importance of developing the sewer and waterways systems in the same speed as the urbanization still remains a fact to consider.

8.4. Discussion Dam sites advantages/disadvantages

To determine so far which dam site that is the most suitable the advantages and disadvantages have been listed down below.

Badala disadvantages

- One disadvantage is that the area around the dam site is already used for irrigation, so this area would be lost if a reservoir would be constructed.

- The uncertainty of how much the extraction point affects the flow downstream of this site
- The terrain around Badala is very flat which would cause the reservoir to have a big area which causes big evaporation losses

Badala advantages

- As this site is further down in the catchment area the possible storage capacity is larger than in Koumi
- This site is downstream from the extraction point for the water supply of Bobo-Dioulasso
- The irrigable land potential is bigger in Badala than in Koumi.

Koumi disadvantages

- The storage capacity is smaller than in Badala as the catchment area is smaller
- The uncertainty of how much the extraction point affects the flow downstream of this site
- The fact that the natural reserve of "forêt classée du Kou" and "forêt classée de Dinndéresso" is situated downstream from this site is also a fact that needs to be considered; the question is if the natural reserves will be affected negatively.

Koumi advantages

- The area around Koumi is not used for irrigation so there would not be a loss of irrigable land when the reservoir is created.
- The terrain around Koumi is more hilly which makes it more suitable for a reservoir as a deep reservoir with smaller surface area reduces evaporation losses compared to a shallow reservoir with a big surface area

As the advantage/disadvantage list above describes, there are maybe more benefits from building the dam at Badala instead of Koumi. There is a bigger potential for irrigable land and the potential drawbacks of forêt classée du Kou and the groundwater extraction point for Bobo-Dioulasso has been passed. A possible drawback would be that the irrigable land lost due to the dam equals or exceeds the irrigable land gained from constructing the dam. With these arguments in mind the best option is therefore Badala. Koumi also has an advantage if the map in appendix 1 is studied, the terrain seems to be more suitable for a dam construction and a small valley could be filled up for a reservoir. The terrain around Badala is so flat that the reservoir will have a big area and small depth i.e. big evaporation losses. However, the basic data and information about the situation in the area and on the two sites are not sufficient enough to make a decision. So the question is also if it is reasonable to build a dam at Koumi or Badala at all?

First and foremost maybe the natural conditions at the suggested dam site are not suitable for a dam construction; this cannot be known before a thorough investigation has been made. Secondly maybe the downstream natural reserve of forêt classée du Kou stops any possibilities of building any dams upstream due to legislation. Thirdly, we also have the encountered problem of how the dam construction could affect the groundwater reserve that Bobo-Dioulasso takes its water from and vice versa. Either the reservoir upstream reduces the water infiltrated into the groundwater reservoir or the groundwater extraction disturbs the inflow to the reservoir downstream. This could start a competition and further on conflicts within the catchment area around the water usage. Finally, as the dam of Samandéni is under construction a couple of kilometers northwest of the Kou catchment area and the region will draw benefit from that maybe a dam at Koumi or Badala loses its purpose.

Whether it is reasonable or not the idea is interesting because projects like this might need to be conducted in other catchment areas in Burkina Faso in the future. The question in those areas could be if it is more reasonable to build big dams like the one in Samandéni or if it is better so put effort into constructing more but smaller dams (or other solutions ex groundwater reservoirs, water harvesting etc.) to collect water for the use of irrigation. The answer is that in some catchment areas they do not have the access to such a big river as the Mouhoun or to a river with an all year round flow as the river Kou. With this consideration probably the best way to go is to propose several different solutions considering both the use of groundwater and surface water to in this way further extend the access to complementary irrigation.

8.5. Discussion Irrigation techniques

The irrigation techniques at the agriculture school do have some disadvantages, the water loss through infiltration and due to destroyed channel walls are larger compared to a channel system built in concrete. Optimizing of the system through calculations of how much water should be added to every field and how much time that will take is harder; this is because there are no hatchets and gates that control the flow and where a flow could be determined.

The advantages are, especially in a developing country context, that the technique is fairly simple. When the access of water is established the only thing you need is manual labor, plastic pipes and a couple of shovels. This fact gives also the advantage of being a relatively low cost investment.

The three techniques studied are of different investment costs but also of different degree of efficiency. The first and simplest one is the use of watering cans to get water from the river or from a hole dug down to the groundwater. This technique is the cheapest one as the only investments needed are the watering cans, shovels and the rest is up to manual labor. This technique has its clear disadvantages, as it demands hard manual labor and the efficiency decreased considerably with the distance from the water source. It also needs the natural condition of a groundwater level close to the surface to work. Otherwise there would be a need for a well instead of just a simple hole to access the water.

The second type is the use of portable pumps to transport the water from the water source. This reduces the manual labor considerably as the transport part from the water source disappears. This technique has a higher investment cost, as the pumps are needed. What it does is that it gives higher efficiency as the transport part is gone and the range is increased, as the pump is easily portable with the help of a car.

The third type is the installation of permanent pumps that are pumping water into a reservoir (like the one at the agriculture school in Banankélédaga), this means of course even higher investment costs to build the system but when it is built the result is a more reliant water source and the irrigation procedure is simplified as there are water extraction points all over the farming area so that water could be taken from wherever needed.

8.5.1. ***Concluding discussion Irrigation techniques***

The most important whether which irrigation technique that is used is to get a system where the different techniques are combined to get best possibilities in the environment they are intended to be used. If dams are used then the pumps or the stationary system is the only way to efficiently transport the water from the reservoir to the field. However, in terms of rainwater harvesting maybe the watering cans can be used to distribute the water from the tank to the fields, this could be to try to keep the investment costs down.

8.6. Cost analysis

This cost analysis is uncertain as it is based on assumptions and price indexes from outside Burkina Faso. The cost analysis is based on similar project made by the international development group at the Swedish Salvation Army (Lerne, 2011).

8.6.1. ***Water harvesting, one household***

Information was received from two of the Salvation Army's projects that are dealing with rainwater harvesting, one in Kenya and one in Ghana, the following information was obtained:

Water project in Kenya:

Water tank (size 24 000 liters) 3000 United States Dollar (USD)

Roof construction and rain gutter 600 USD

Water project in Ghana

Water tank (size 16 000 liters) 1242 USD

To be able to store the supposed 100 m^3 of water described in the section water harvesting a four times bigger tank than the one in Kenya and a six times bigger tank than the one in Ghana would be needed. I use the Ghana price as it is closer to Burkina Faso and suppose that the price increases proportionally with the size, in that case the price is:

1242*6 = 7452 USD

And with the adding of the cost for the roof construction and the rain gutters:

7452 + 600 = 8052 USD

One USD is equal to 460 CFA francs (The money converter, 2011), therefore:

8052*460 = 3 700 000 CFA franc

To facilitate the work of transporting the water from the reservoir to the fields the farmers a diesel pump is also needed. The cost of these are for a small one 200,000 CFA franc and for a big one 900,000 CFA franc (Compaoré, P, 2011). This would add up a total investment cost of at least:

3 700 000 + 200 000 = 3 900 000 CFA franc = 8045 USD

8.6.2. ***Water harvesting, cooperation reservoir***

As there are not enough background for estimating the costs of excavating and building a reservoir in concrete an estimation of the costs are difficult. However, the costs would most certainly be lower with a co-financed reservoir than a tank for every household. The system on the agriculture school in Banankélédaga could be a good complement to a water harvesting system. The size of the reservoir could be smaller if it is supplied with some water from the groundwater during the year.

8.6.3. *Dam*

To estimate a cost for a dam is even harder than the above-described reservoir. What could be said is that investments to build a dam must be made by external investors like the government or foreign development agencies or similar. The investment of a dam is far too huge for the Burkinabe farmers to finance it themselves.

9. CONCLUSION

The hydrological investigation covers several areas and the conclusion from the investigation of the increased flood risks due to urbanization around Bobo-Dioulasso has shown that the risk for increased floods is low; the increase in runoff is approximately 14 %.

In terms of complementary irrigation it is a fact that the unpredictable climate has a big impact on the Burkinabe farm sector even if it is called climate change or just drought. Whatever the reason is for the more harsh conditions the necessity of adaption in the agricultural sector is important. The use of complementary irrigation is one way of adaptation and the lack of infrastructure that could provide the water supply for this is a limiting factor. Dams are a working solution but require governmental investments. Of the two studied dam sites the one in Koumi was found to be the most suitable as the plain areas around Badala would render in a shallow reservoir with a big area with big evaporation losses. Whether these dams could be constructed or not there is a need for construction of more but smaller dams to supply the farmers with the water supply needed for complementary irrigation.

Rainwater harvesting is not efficient enough on a small-scale level (one household) due to the limited storage capacity in comparison to the actual crop water requirement and due to the high investment costs. However on a large-scale (cooperative) there is potential to create an efficient and cost-effective system to provide water for complementary irrigation.

The conclusion is therefore that rainwater harvesting can be the only working solution in parts of Burkina Faso where there is no access to streams or easy extractable groundwater. The crucial thing about rainwater harvesting is that the knowledge about it is enhanced among farmers but also in the education system so that there will be a future domestic expertise. The domestic expertise could elucidate the need and the importance of cooperatives in a more effective way that would lead to greater acceptance among the Burkinabe farmers.

10. FUTURE STUDIES

Some can be done within the scope of a Minor Field Study but most of the work that has to be done within this area cannot be included. The limited size of a degree project is the limiting factor in this case. Things that need to be studied further that have connections with this project are:

- The studies of the precipitation data and where the crops fail is a field that needs to be further investigated:
    - The conditions for 1976 could have been extra or less severe than for another year of crop failure and could therefore imply a bigger or smaller need for complementary irrigation.
    - The soil retention time has not been considered i.e. how many days after a rain is the soil still humid enough to supply the plants with water.

    - The exact water requirement differs from the different crop stages i.e. for a more effective irrigation system different amount of water could be distributed depending on in which crop stage the crops are.
    - The crops might withstand more or less than four days of drought, in that case complementary irrigation actions must be started earlier or later than calculated.
- The cost analysis is uncertain and is not based on actual costs of products and cost of labor in Burkina Faso. So a more thorough investigation needs to be done in this area to estimate the investment costs for different techniques.
- The dam site investigations are not complete and to offer a background material for the suitability of building a dam in both Badala and Koumi further studies need to be done.
- The analysis of changes in runoff due to urbanization is also incomplete and needs further studies to be able to act as background material in any kind of decisions.

REFERENCES

Atlas de l'Afrique. 2004. Atlas du Burkina Faso. *Les éditions J.A.* 115p.

CEEPA (Center for Environmental Economics and Policy in Africa). 2006. Climate change and African agriculture. *University of Pretoria.* 114p.

Chow, V.T., Maidment D.R., Mays L.W. 1988. Applied Hydrology, *McGraw-Hill International Editions.* 572p.

Critchley, W., Siegert, K. 1991.Water harvesting – A manual for the Design and Construction of Water Harvesting Schemes for Plant Production. *Food and Agriculture Organization of the United Nations.*

Fries, J. 1991.Kampen mot ökenspridningen i Sahel. *Sveriges lantbruksuniversitet U-landsavdelningen.* 32p.

Johansson, I. 2003. Banankélédaga – platsen som förändrar Västafrika. *Johansson, Karlsgatan 34 C, 703 41 Örebro.*

McSweeney, C., New, M., Lizcano, G. UNDP Climate Change Country Profiles – Ghana.*School of Geography and Environment, University of Oxford and Tyndall Centre for Climate Change Research.* 27p.

McSweeney, C., New, M., Lizcano, G. UNDP Climate Change Country Profiles – Documentation. School of Geography and Environment, *University of Oxford and Tyndall Centre for Climate Change Research.* 18p.

PDIS. 2007. Programme de développement integré de la vallée de Samendeni. Ministère de l'agriculture, de l'hydraulique et des ressources halieutiques. *Secrétariat général, direction générale du génie rural.*

Sida. 2004. Landsstrategi: Burkina Faso 2004 – 2006, *Utrikesdepartementet.*

The World Bank and others. 2003.Poverty and climate change – reducing the vulnerability of the poor through adaptation. *MediaCompan.* 56p.

Sida. 2010.Country Fact Sheet Burkina Faso sector: Environment. *Sida.*

Unicef. 1999. A Water Handbook. *UNICEF/programme Division, Water, Environment and Sanitation Section.*116p.

Wanielista, M. Kersten, R. Eaglin, R. 1997. Hydrology: Water quantity and quality control. *John Wiley & Sons, Inc.*567p.

Waters-Bayers, A.,Reij, C. 2001.Farmer Innovation – a source of inspiration for agricultural development. *Earthscan Publications Ltd.*362p.

Other sources

CIA's homepage: https://www.cia.gov/library/publications/the-world-factbook/geos/uv.html

Homepage of Dagens nyheter: http: //www.dn.se/nyheter/varlden-/150-000-flyr-vatten-i-burkina-faso

Ritter, Michael E 2006. The Physical Environment: an Introduction to Physical Geography: http://www.uwsp.edu/geo/faculty/ritter/-geog101/textbook/title_page.html

The delft university of technology's homepage: http://citg.tudelft.nl-/en/about-the-faculty/departments/watermanagement-/sections/water-resources/leerstoelen/wrm/research/all-projects/phd-research/current-phd-research/owusu-ansah-emmanuel/owusu-ansha-emmanuel/

The money converter's homepage: http://themoneyconverter.com-/USD/XAF.aspx

University of Gothenburg's homepage: http://www.landguiden.se.-ezproxy.ub.gu.se/

Wikipedia's homepage: http://commons.wikimedia.org/wiki/File:-Burkina_Faso_carte.png

WordIQ's homepage: http://www.wordiq.com/definition/Irrigation

Compaoré, Albert, national program officer for natural resources and climate change, The Swedish embassy, Ouagadougou, Burkina Faso. ,March 2011.

Compaoré, Pingwindi, agronomist in Bama, Burkina Faso, February – March 2011.

Ilboudo, Job, Headmaster at the agricultural school in Banankélédaga, Burkina Faso, February – March 2011.

Johnston, Rick, researcher at Swiss Federal Institute for Aquatic Science and Technology (Eawag), Lecture at École Polytechnique Fédérale Lausanne (EPFL), 19 October 2010, Lausanne.

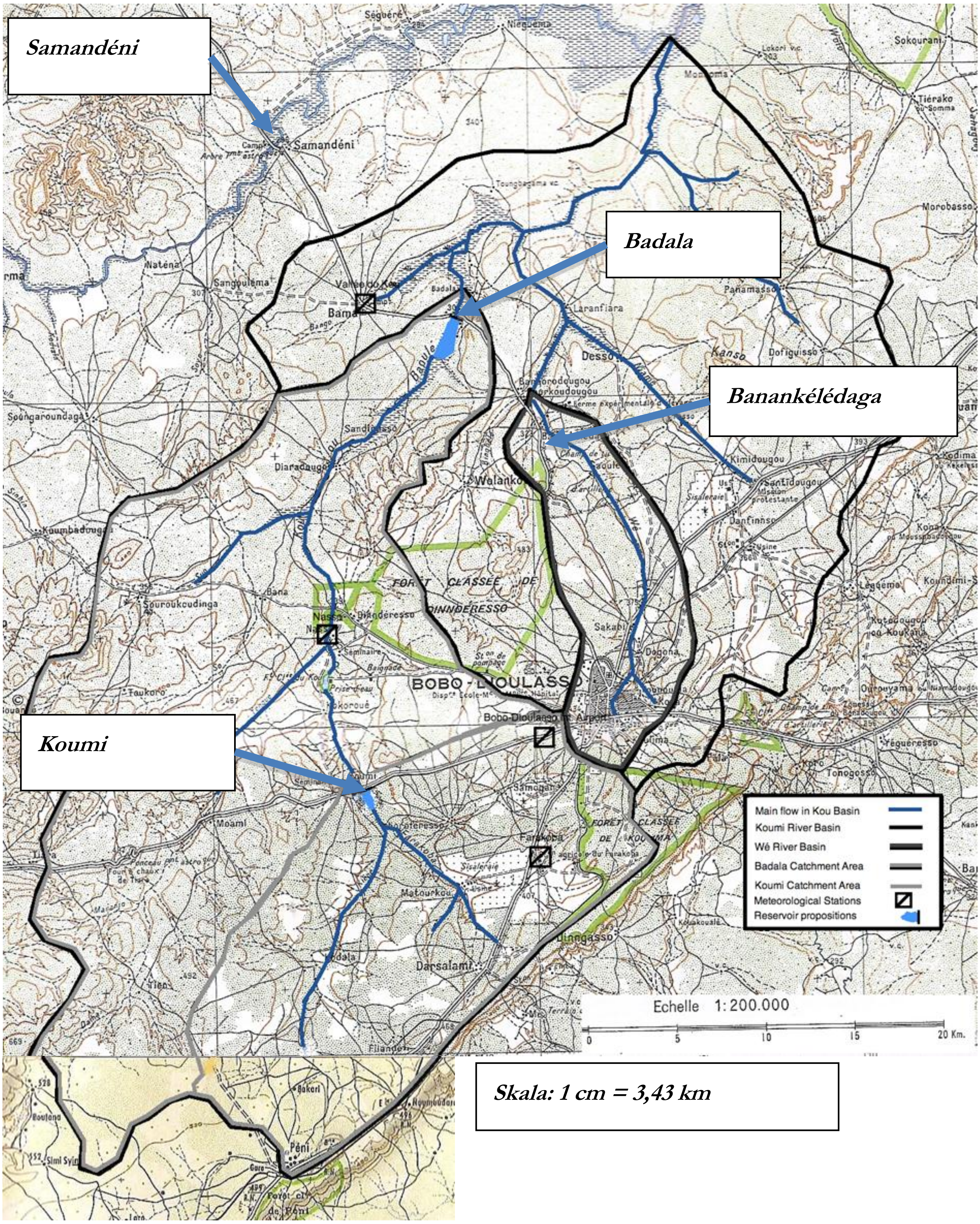
Lerne, Christian, missionssekreterare, The Salvation Army Sweden, Stockholm, May 2011.

Sama, Julien, Observateur agrométéo,station vallée du Kou, Burkina Faso, February -March 2011.

APPENDIXES

Appendix 1

Map of Kou Basin



Appendix 2

Precipitation data from the Kou Basin

Year	Bobo-Dioulasso Int. Airport	Farakoba	Nasso	Vallée du Kou	Year	Bobo-Dioulasso Int. Airport	Farakoba	Nasso	Vallée du Kou
1959	802,9				**1985**	1331,5	1305,6	949,6	1053,8
1960	1248,8	1445,1	974,5		**1986**	879,8	928,1	856,5	881,4
1961	1110,6	1233	1085,3		**1987**	866,3		871,7	815,7
1962	928,4	897,4	1071,1		**1988**	1014,5		952,2	1074,6
1963	1236,7	1096,7	938,1		**1989**	827,5	921,2	857	826,9
1964	1359	1181,6	1306,2		**1990**	994,7	1030,8	848,1	916,9
1965	1028,6	1133,3	1230,3		**1991**	1198,1	952	1246,1	1144,5
1966	1136,4	1096,8	870,6		**1992**	1238,2	1059,8	966,1	928,7
1967	1176,2	1115,7	1049,5		**1993**	943	834	910,2	979,5
1968	1412,9	1262,1	1316,1		**1994**	895,7	1075,8	1293,6	1106,6
1969	1078	998,6	1214,3		**1995**	1277,7	1160,4		944,9
1970	1404,3	1173,4	1248,9		**1996**	900,5	1023,6	950,6	758,5
1971	963,6	1004,5	1047,2		**1997**	872,9	1193,9		814,3
1972	894,2	942,8	967,8		**1998**	1121,4	1232,3		929,3
1973	888,5	802,5	812,8		**1999**	1065,2	1094		1024,6
1974	1084	998,2	1082,6		**2000**	1171,43	1079,6		1065,2
1975	888,1	955,9	1055		**2001**	914,5	778,1		819,6
1976	996,1	1083,6	1112,5		**2002**	802,8	676,7		654,3
1977	835,4	996	901,8	1077,3	**2003**	1156,2	1148,1		1098,5
1978	1036,7	1128,4	1128,3	968,5	**2004**	942	833,3		758,5
1979	1065,7	1018,9	1332,3		**2005**	861,1	858,2		745,8
1980	841,4	904,3	1081,7	890,4	**2006**	1104,9	1272		984,1
1981	1042,3	1145,1	786,9	900	**2007**	948,3	1113,6		1046,5
1982	945,6	1212,3	963,4	988,4	**2008**	1076,5	1139,6		1032,5
1983	778,1	752,8	883	663,3	**2009**		908,8	1047,5	888,5
1984	971,6	815,6		672,9	**2010**	982	1289,5	1049,8	1191
					Medel	1044,4	1055,8	1060,8	880,1

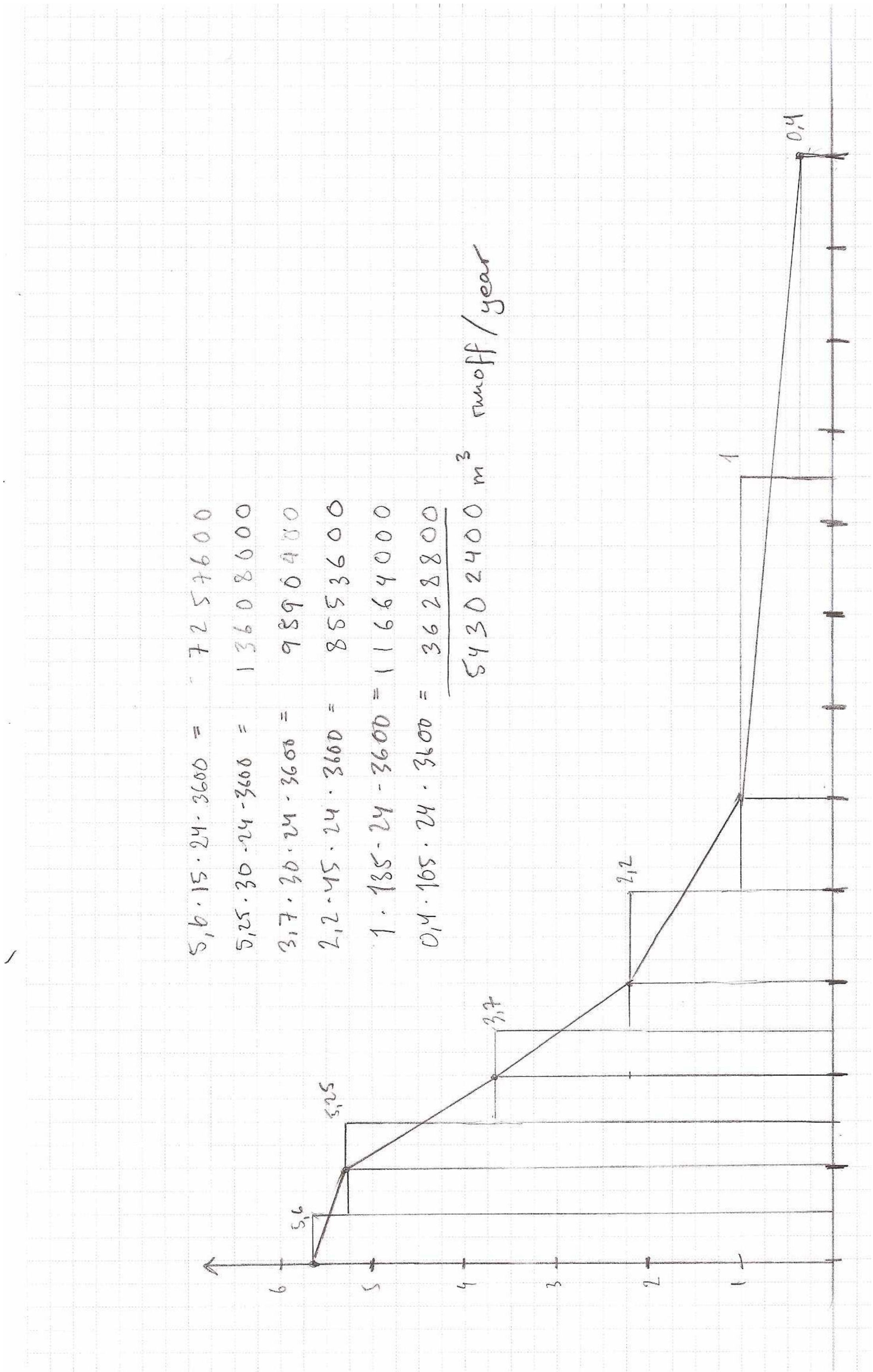
Appendix 3

Flow data from Badala

	jan.	feb.	march	april	may	june	july	aug.	sept.	oct.	nov.	dec.	Yearly av. 84-08
1984						2	1,5	1,4	4,1	0,7	0,7	1,8	1,74
1985	0,2	0	0	0	0,7	3,9	10	12,1	5,8	1,3	0,7	2	3,06
1986	1,2	0,4	0,4	0,4	0,7	1,3	3,2	4,4	6,5	1,2	0,5	1,6	1,82
1987	0,4				0,7	2,1	1,2	4,7	2,8	0,7	0,9	1,1	1,62
1988	0,5				0,8	1,4	3,3	5,4	7,6	2,5	1,2	1	2,63
1989	0,4	0,4			1	0,8	2,4	8,1	3,7	0,5	0,7	0,9	1,89
1990	0,4				0,8	1,3	3,1	3,4	1	0,4	0,7	0,7	1,31
1991	0,4				2,2	1,6	2,8	6,3	4,6	0,7	0,7	0,7	2,22
1992	0,4	0,4	0,4		0,9	1,2	1,7	3,3	6,2	0,7	0,5	0,6	1,48
1993	0,4	0,4	0,4	0,4	0,7			6,4	5	1	0,7	0,8	1,62
1994													
1995													
1996				0,5	0,9	1	1,5	3,7	5,8				2,23
1997	0,5	0,5	0,5	0,5	0,8	3,3	2,3	4	4,9	0,8	0,6	0,8	1,63
1998	0,5	0,5	0,4	0,5	0,7	0,8	2,5	5,9	7,1	1,9	0,6	0,6	1,83
1999	0,5	0,5	0,5	0,5	0,6	0,6	1,4	6,9	8,3	5,9	0,8	1,6	2,34
2000	0,7	0,8	1	1,1	1,3	2,3	4,2	9	7,4	3	0,6	1,2	2,72
2001	0,6	0,4	0,3	0,4	0,6	1,1	2	4,2	7,2	1,3	0,9	1,1	1,68
2002	0,5	0,3	0,3			2,7	2,6	7,9	4,2	0,4	0,4	0,5	1,98
2003	0,3	0,2	0,2	0,3	0,4	0,8	6	10,7					2,36
2004													
2005									0,8	0,4	0,3	0,7	0,55
2006	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,4	0,4	0,4	0,4	0,47
2007	0,2	0,1	0,1	0,1	0,2	0,2	0,3	0,4	0,4	0,5	0,5	0,6	0,30
2008	1,1	0,1	0,1	0	0	0,1	3,3	9,9	8,9	2,3	0,8		2,42
Monthly av. 84-08	0,51	0,37	0,36	0,40	0,76	1,45	2,79	5,65	4,89	1,33	0,66	0,98	

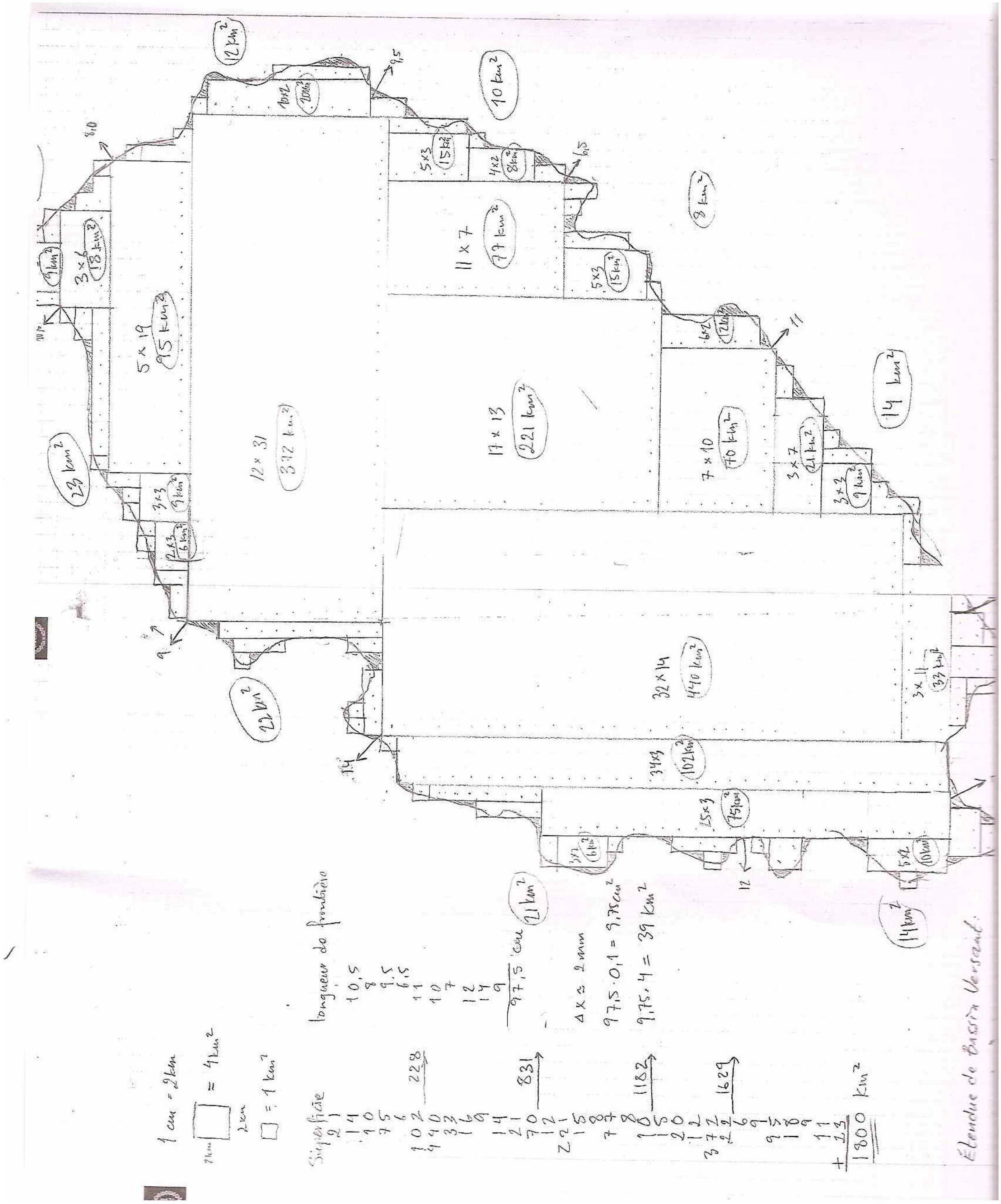
Appendix 4

Flow duration calculations



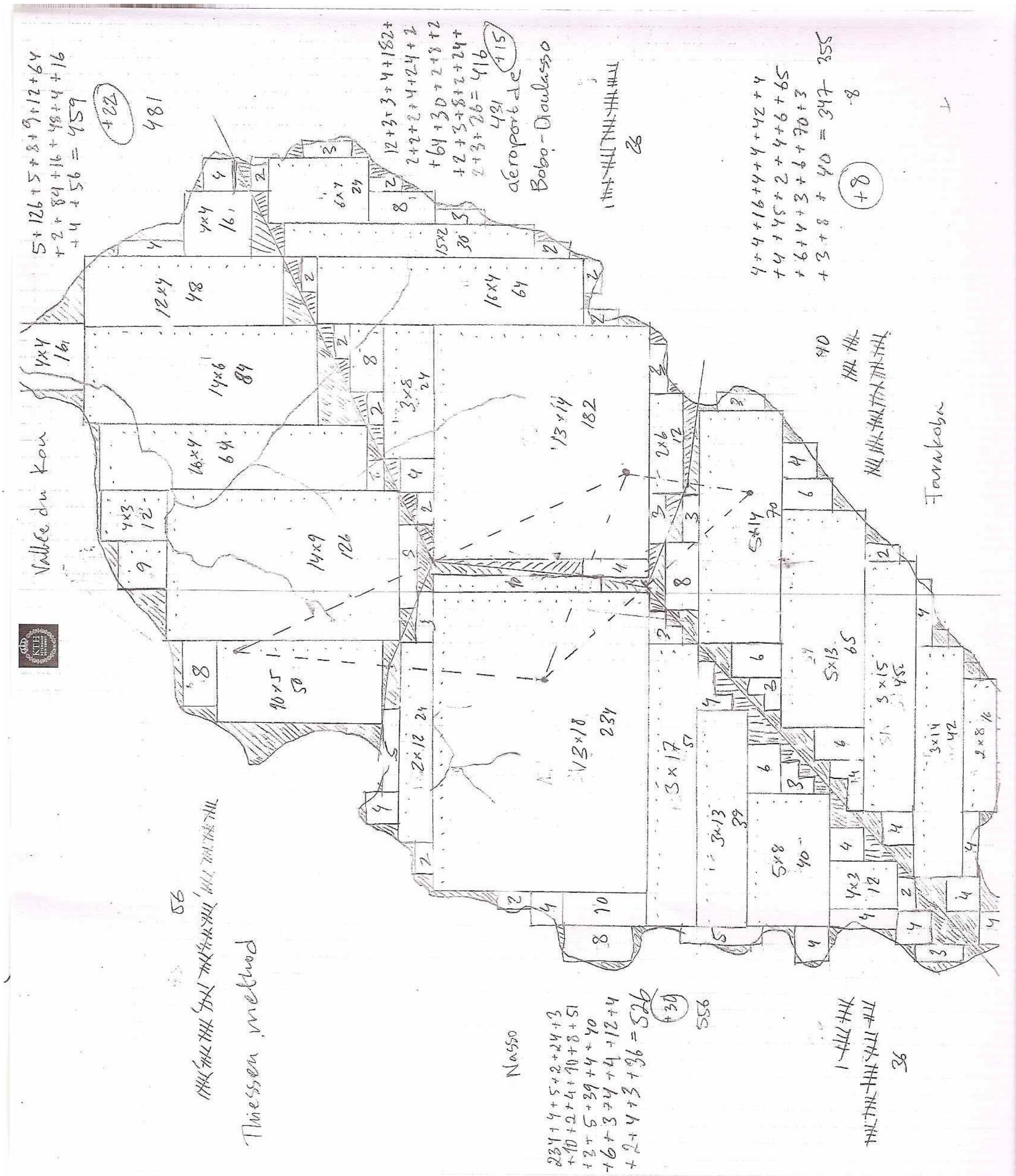
Appendix 5

Area calculations Kou Basin



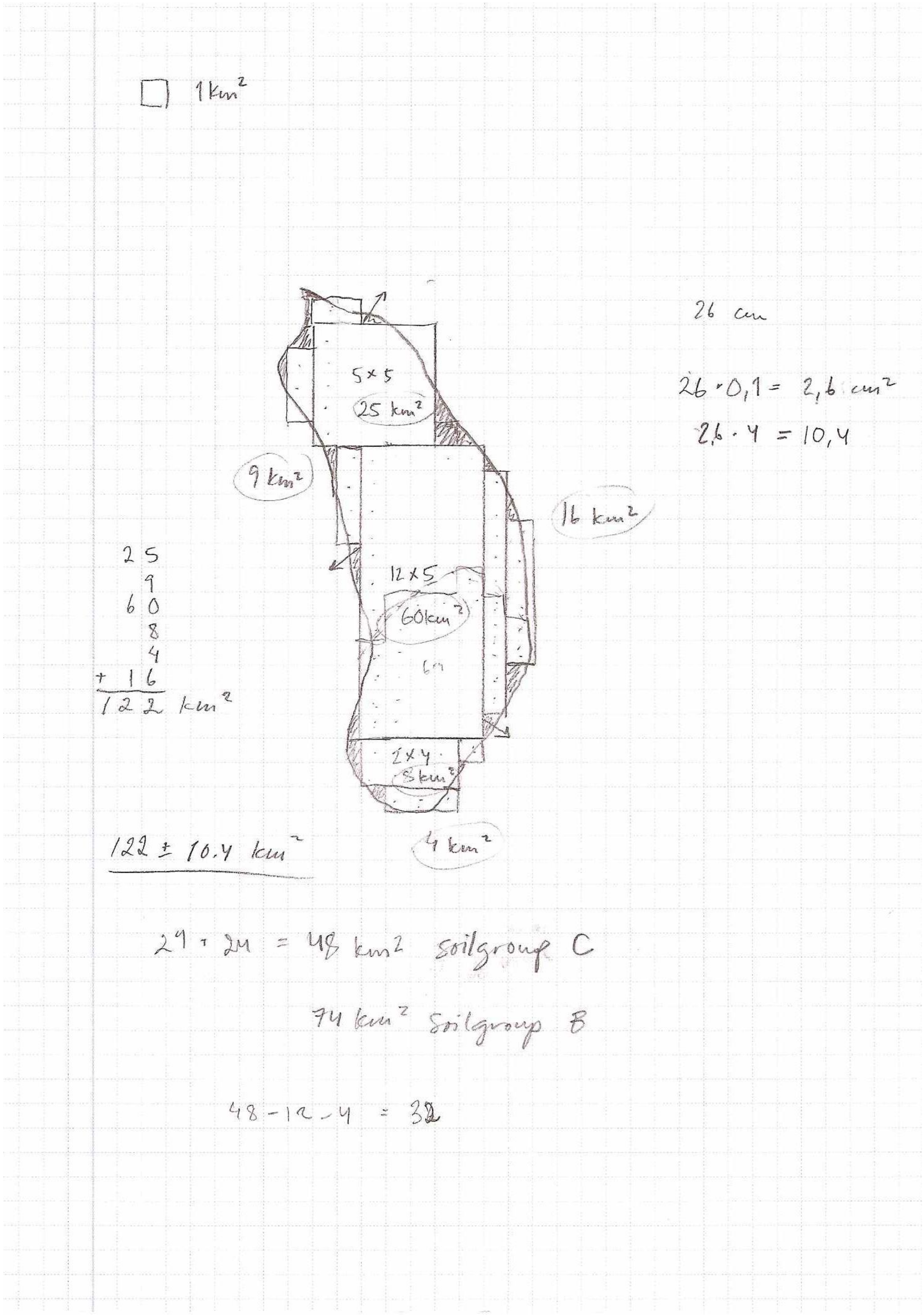
Appendix 6

Calculations with the Thiessen method

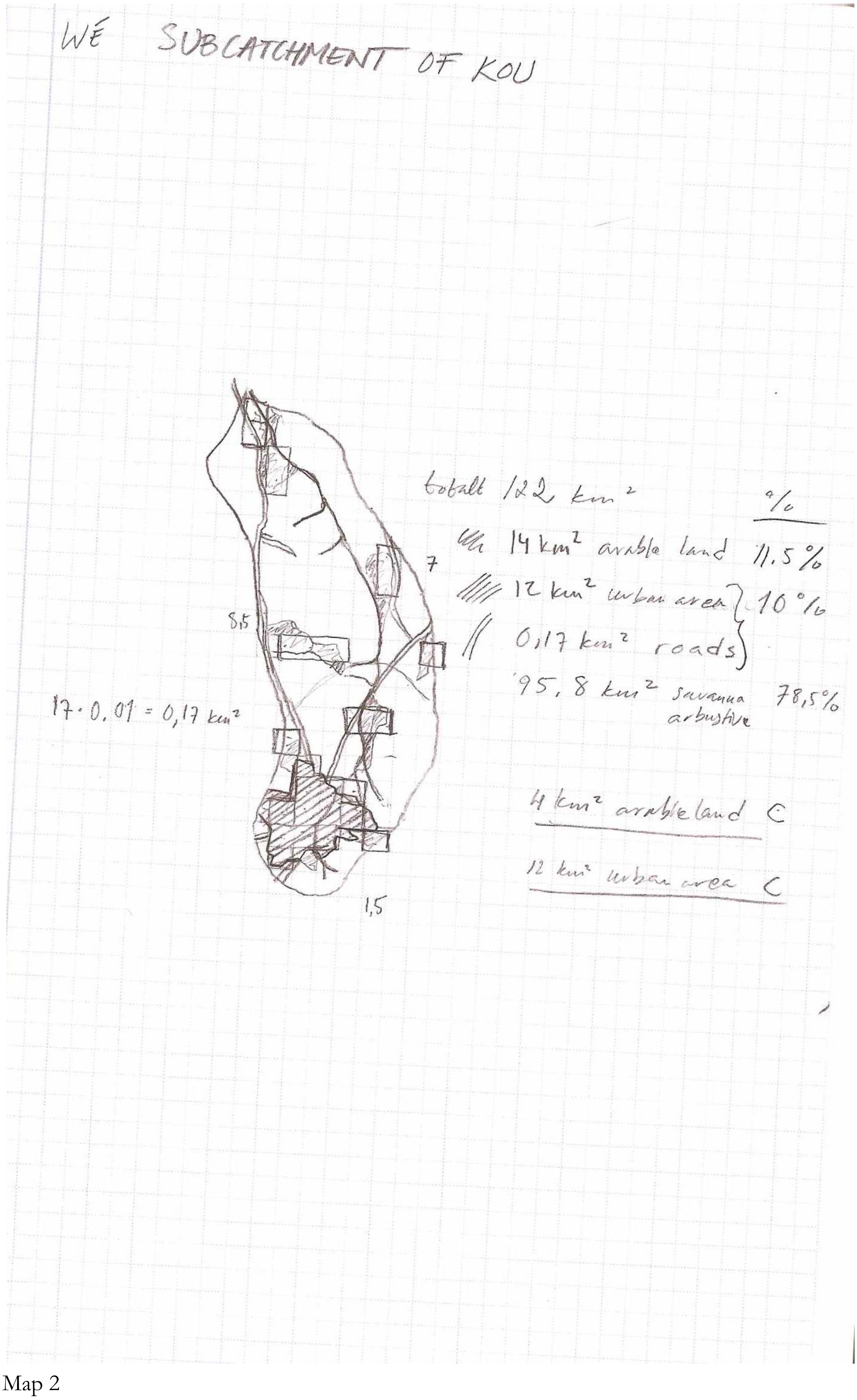


Appendix 7

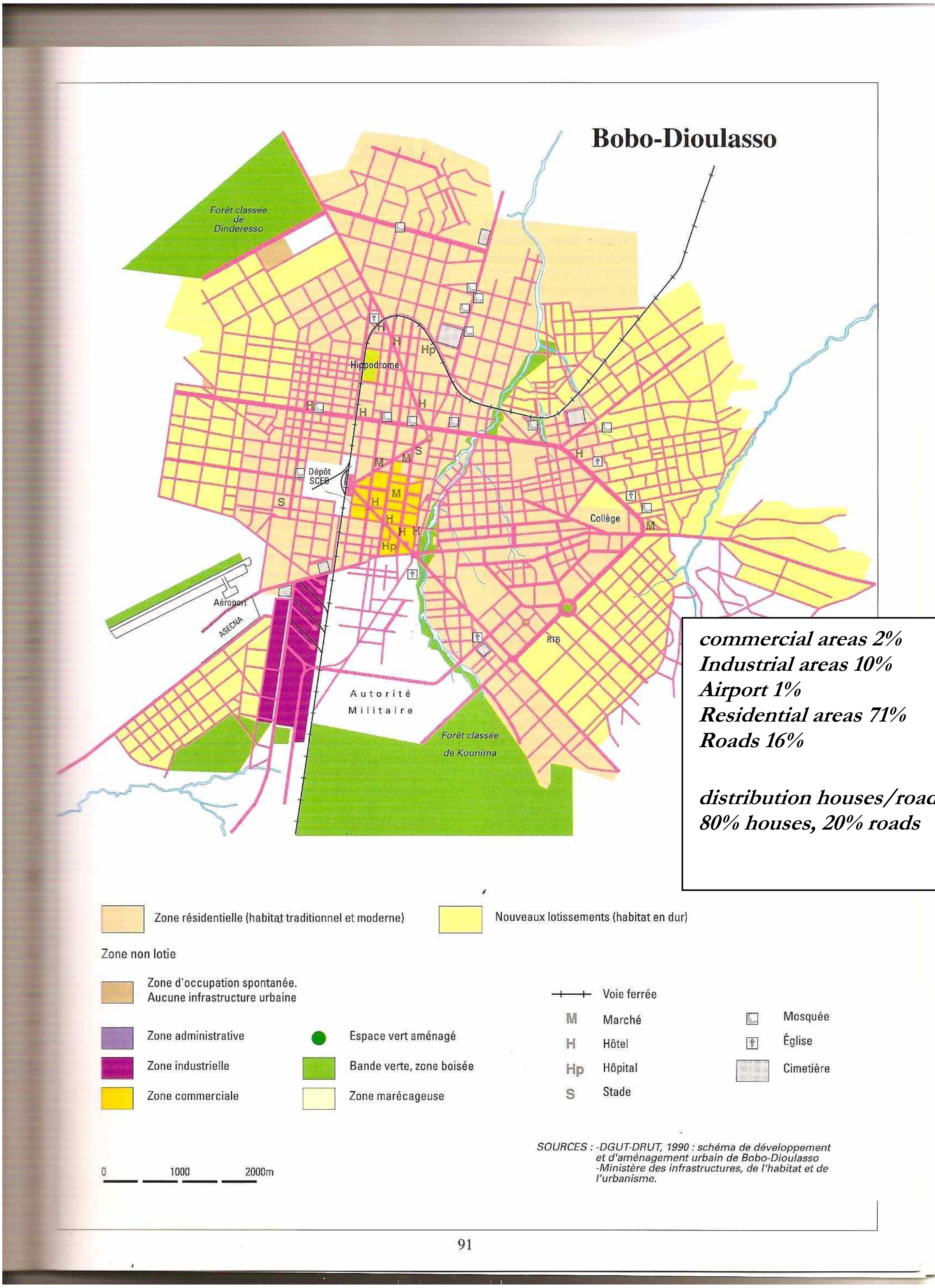
Area, land use and zone distribution calculations for the Wé catchment area



Map 1


WÉ SUBCATCHMENT OF KOU
totall 122 km²
%
14 km² arable land 11,5%
12 km² urban area
0,17 km² roads
10%
95,8 km² savanna arbustive 78,5%
7
8,5
17 · 0,01 = 0,17 km²
4 km² arable land C
12 km² urban area C
1,5

Map 2



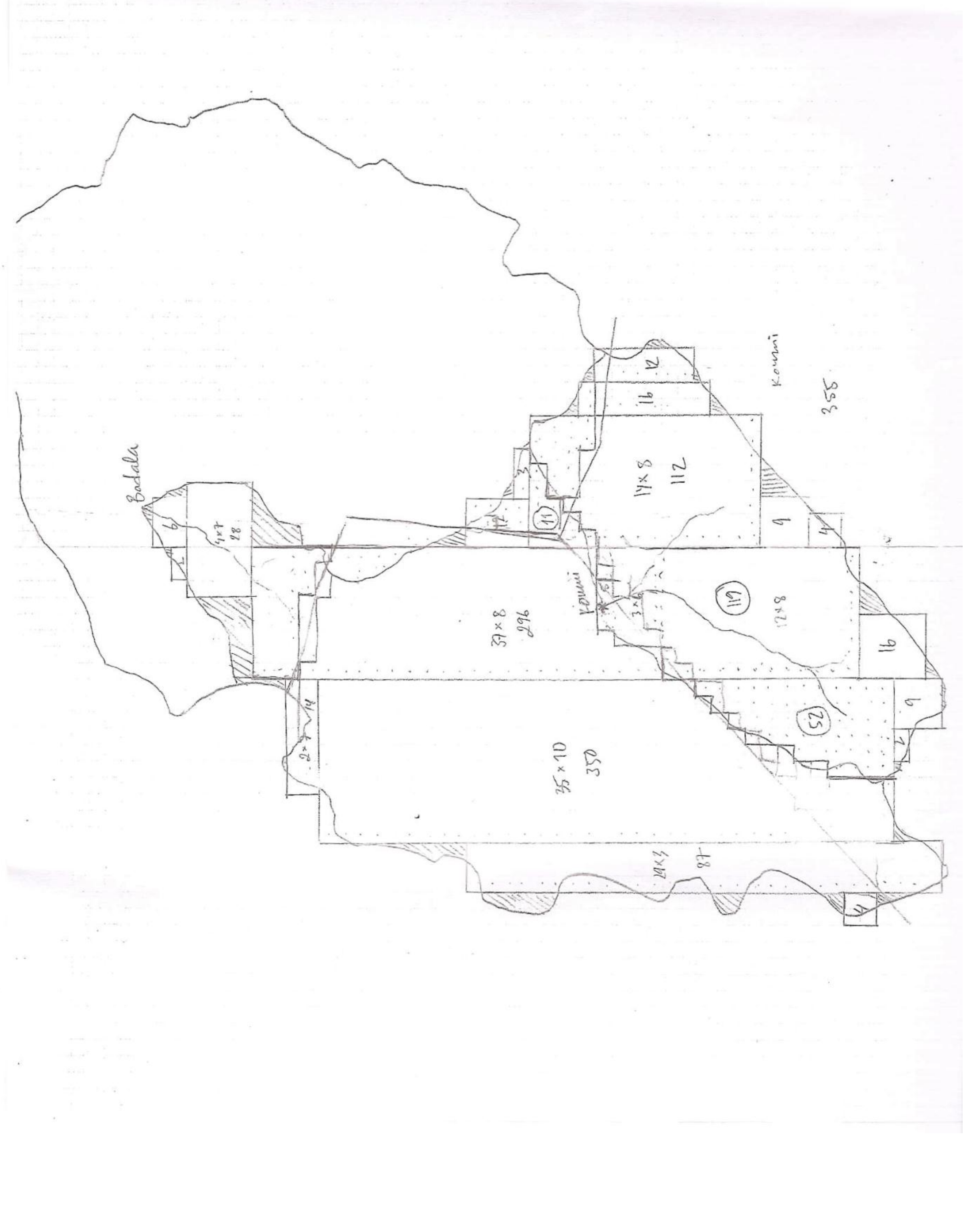
commercial areas 2%
Industrial areas 10%
Airport 1%
Residential areas 71%
Roads 16%

distribution houses/roads
80% houses, 20% roads

Map 3

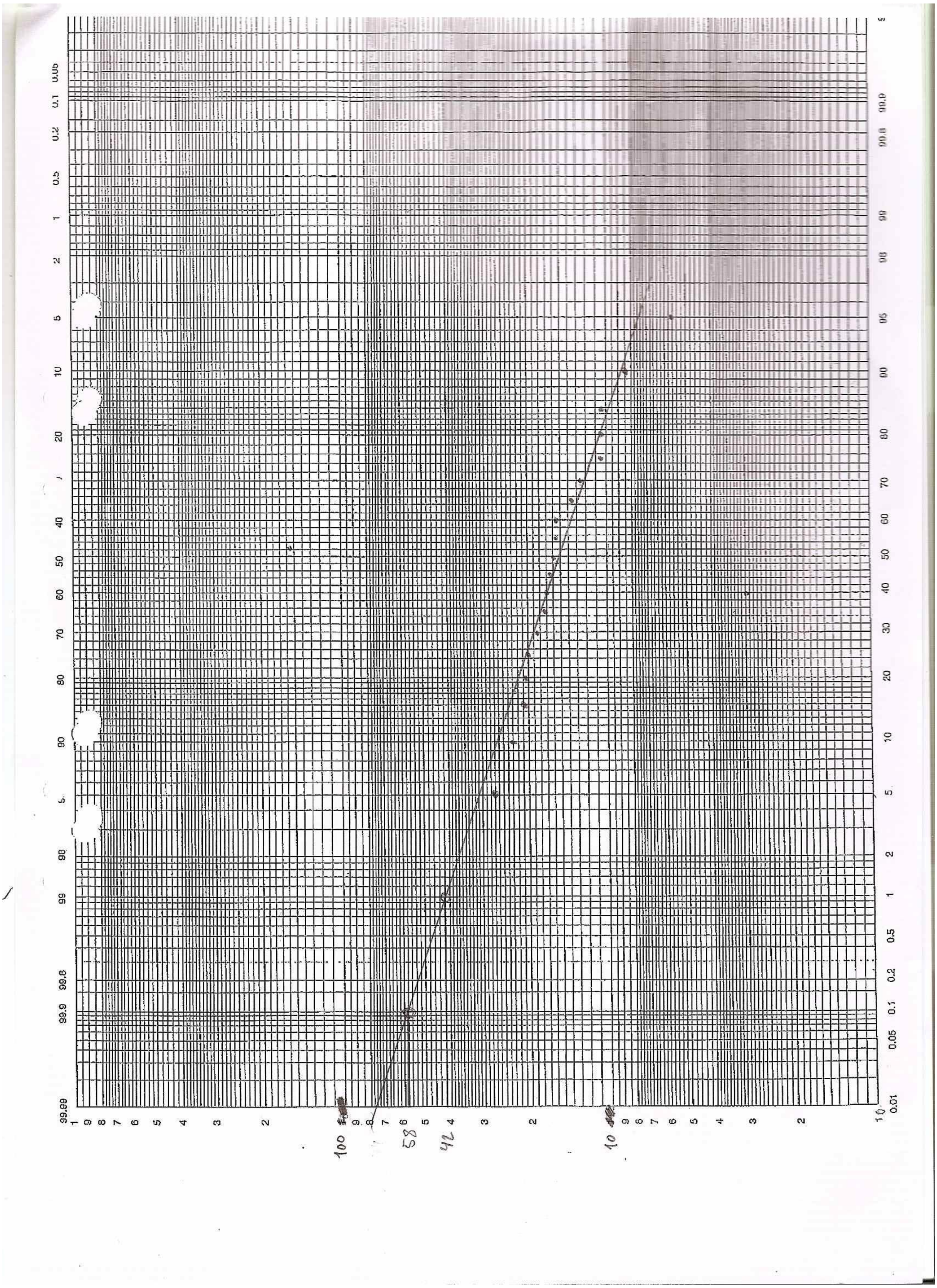
Appendix 8

Area and precipitation (Thiessen method) calculations for the sub catchments of Koumi and Badala



Appendix 9

Calculation of the 100 and 1000 years flood



The maximum annual floods from 1984 to 2008.

year	Q	logQ	Maximum annual flood	order number	Weibull number
1984	12,4	1,093421685	27,8	1	0,05
1985	20,8	1,318063335	24,6	2	0,1
1986	20,4	1,309630167	20,8	3	0,15
1987	8,5	0,929418926	20,4	4	0,2
1988	10,6	1,025305865	19,9	5	0,25
1989	19,3	1,285557309	19,3	6	0,3
1990	5,7	0,755874856	18,2	7	0,35
1991	17,5	1,243038049	17,8	8	0,4
1992	16,6	1,220108088	17,5	9	0,45
1993	19,9	1,298853076	16,9	10	0,5
1994			16,7	11	0,55
1995			16,6	12	0,6
1996	16,9	1,227886705	13,7	13	0,65
1997	16,7	1,222716471	12,4	14	0,7
1998	13,7	1,136720567	10,6	15	0,75
1999	18,2	1,260071388	10,6	16	0,8
2000	17,8	1,250420002	10,6	17	0,85
2001	10,6	1,025305865	8,5	18	0,9
2002	10,6	1,025305865	5,7	19	0,95
2003	27,8	1,444044796	0,9	20	
2004			0,6	21	
2005	0,9		0,5	22	
2006	0,5				
2007	0,6				
2008	24,6	1,390935107			

av. logQ	1,182246217	z_{100}	2,326785333
s	0,169992601	z_{1000}	3,090522226
K_T =	z	Q_{100}	37,82531097
w_{100}	3,034854259	Q_{1000}	51,00492671
w_{1000}	3,716922189		

Appendix 10

The graphical method: To determine the 100 and 1000 years flood the maximum annual floods were analysed with a log normal diagram (see appendix 9). The result for Badala is:

100 year flood = 42 m^3/s

1000 year flood = 58 m^3/s

The analytical method: Another method to determine the 100 and 1000 years flood is the analytical method described in the theoretical background (for calculations see appendix 9).

100 year flood = 38 m^3/s

1000 year flood = 51 m^3/s

With the assumption described in the theoretical background the results for Koumi is:

Average water flow Badala = 2,0 m^3/s

Average precipitation is 1000 mm over the Badala catchment.

Area of the Badala catchment: 999 km^2

Average precipitation is 1020 mm over the Koumi catchment.

Area of the Koumi catchment: 346 km^2

$\alpha = 0,5$

q_s (for Badala)= (2*1000)/999 = 2,0 $l/s*km^2$

1020-1000 = 20mm/year = 0,02 m/year

$(0,02*10^6*1000)/31,5*10^6 = 0,63\ l/s*km^2$

q_s (forKoumi): 2,0 + 0,63 = 2,63 $l/s*km^2$

Badala: $Q = 42 = k * 2,0 * (999)^{0,5}$

Koumi: $Q = k * 2,63 * (346)^{0,5}$

Thus, Q_{100} for Koumi with the graphical method is:

32,5 m^3/s

And Q_{1000} is:

44,9 m^3/s

The results for Koumi with the analytical method is in the same way:

$Q_{100} = 29\ m^3/s$

$Q_{1000} = 40\ m^3/s$

Appendix 11

Evaporation calculations

	January	February	March	April	May	June	July
Precipitation	0	0,5	0	179	71,5	85	124,5
Average temperature (°C)	25,5	27,5	30,5	29,5	28	26,5	25
es sat. vap. pressure (e as)	3268	3687	4372	4129	3789	3467	3171
e actual vap. pressure (e a)	637	847	1301	2069	2576	2568	2646
Mean relative humidity	0,20	0,23	0,30	0,50	0,69	0,74	0,83
Mean net radiation	250	260	270	280	270	260	250
mean wind speed (m/s)	3,2	3,3	3,1	3,8	3,9	3,3	3,9
mean air pressure (kPa)	100,9	100,9	100,9	100,9	100,9	100,9	100,9
roughness height z0	0,03	0,03	0,03	0,03	0,03	0,03	0,03
density of air	1,15	1,15	1,15	1,15	1,15	1,15	1,15
density of water	996	996	996	996	996	996	996
The psychrometric constant (Pa/°C)	67,2	67,2	67,2	67,2	67,2	67,2	67,2
latent heat of evaporation (kJ/kg)	2437	2437	2437	2437	2437	2437	2437
Cp (J/kgK) for air	1005	1005	1005	1005	1005	1005	1005
Kh/Kw	1	1	1	1	1	1	1
atmospheric pressure (kPa)	101,3	101,3	101,3	101,3	101,3	101,3	101,3
Δ (Pa/°C)	193,90	215,50	249,85	237,69	220,63	204,15	188,86
Er	1,0298E-07	1,07099E-07	1,1122E-07	1,1534E-07	1,1122E-07	1,071E-07	1,03E-07
z_2	2	2	2	2	2	2	2
z_0	0,0003	0,0003	0,0003	0,0003	0,0003	0,0003	0,0003
B	1,1225E-08	1,60809E-08	2,5188E-08	8,6248E-08	1,6779E-07	1,6775E-07	2,485E-07
Ea	2,9531E-05	4,56769E-05	7,7364E-05	0,00017762	0,00020357	0,00015082	0,0001303
E (mm/s)	7,6731E-06	1,09336E-05	1,6476E-05	3,9218E-05	4,7586E-05	3,7411E-05	3,427E-05
E (mm/month)	21	26	44	102	127	97	92
E total (mm/year)	762						

	August	September	October	November	December
Precipitation	207,5	201,5	126	1	0
Average temperature (°C)	24,5	24,5	26	26,5	26
es sat. vap. pressure (e as)	3079	3079	3365	3467	3365
e actual vap. pressure (e a)	2646	2646	2646	1549	814
Mean relative humidity	0,86	0,86	0,79	0,45	0,24
Mean net radiation	253	256	260	256	253
mean wind speed (m/s)	2,8	2,2	2,4	2,5	2,9
mean air pressure (kPa)	100,9	100,9	100,9	100,9	100,9
roughness height z0	0,03	0,03	0,03	0,03	0,03
density of air	1,15	1,15	1,15	1,15	1,15
density of water	996	996	996	996	996
The psychrometric constant (Pa/°C)	67,2	67,2	67,2	67,2	67,2
latent heat of evaporation (kJ/kg)	2437,4	2437,4	2437,4	2437,4	2437,4
Cp (J/kgK) for air	1005	1005	1005	1005	1005
Kh/Kw	1	1	1	1	1
atmospheric pressure (kPa)	101,3	101,3	101,3	101,3	101,3
Δ (Pa/°C)	184,1	184,1	198,9	204,2	198,9
Er	1,0422E-07	1,05451E-07	1,071E-07	1,0545E-07	1,0422E-07
z_2	2	2	2	2	2
z_0	0,0003	0,0003	0,0003	0,0003	0,0003
B	1,8861E-07	1,50892E-07	1,3399E-07	4,5796E-08	1,5646E-08
Ea	8,1569E-05	6,52553E-05	9,6262E-05	8,7816E-05	3,9915E-05
E (mm/s)	2,1879E-05	1,75193E-05	2,4377E-05	2,1815E-05	1,0153E-05
E (mm/month)	59	45	65	57	27
E total (mm/year)					

Appendix 12

Analysis of precipitation data from Bobo-Dioulasso

Daily prec.				Monthly prec.				Extra water need	Extra water need	Crop factors			
1976	1977	1978	1979	1976	1977	1978	1979	m^3		Initial stage	Crop dev. Stage	Midseason stage	Late season
0,0	0,0	22,8	1,0					1976(crop failure year)	1979 (successful harvest)				
0,4	0,0	8,5	0,0										
0,0	26,9	37,7	0,0										
16,7	3,3	11,2	0,0					200					
0,0	0,0	0,0	0,0	2008,9	2015,0	2081,3	1980,0						
0,0	0,0	0,2	2,0										
0,0	12,6	0,0	0,0										
0,0	7,2	0,0	13,2										
0,0	0,0	6,2	6,0										
0,0	0,0	0,0	0,0										
0,0	2,6	0,0	0,1										
0,0	0,0	0,0	4,6										
0,0	2,0	0,0	0,0										
0,0	0,0	12,8	7,5										
8,8	1,9	0,0	0,0										
5,4	0,8	0,0	0,0										
1,7	0,0	0,0	0,0										
0,0	0,0	0,9	0,0										
9,4	0,0	0,0	0,0										
0,0	0,0	0,0	0,0							Start of stage			
0,0	0,0	0,0	0,1										
0,0	0,0	0,0	0,0										
0,0	30,5	0,0	0,0										
14,5	2,3	0,0	0,0										
0,0	0,0	0,0	0,0										
11,8	0,0	0,0	0,0										
1,8	0,0	0,0	0,0										
0,0	0,0	0,0	21,5										
0,0	0,0	14,4	0,0										
0,3	0,0	0,0	11,8										
2,3	0,0	23,3	2,3										
0,0	0,0	0,0	17,6										
11,2	0,0	0,0	0,0										
0,0	0,0	0,0	0,0								Millet		
15,0	0,0	0,0	0,0										
15,2	5,7	0,0	11,0	97,4	65,6	57,8	97,7						
8,1	0,0	0,0	0,0										
0,0	7,6	0,0	4,9										
0,2	20,0	10,9	3,1								Sorghum/maize		
0,0	0,0	18,6	0,0										
10,7	0,0	0,0	20,4								Start of stage		
0,0	0,0	0,3	0,0										
0,0	2,2	1,4	0,0										
0,0	0,0	0,0	0,0								Groundnuts		
0,0	21,4	0,0	0,0										
0,0	0,0	1,2	23,4										
0,0	0,0	0,0	0,0										
10,1	37,2	0,0	11,0										
0,0	0,0	0,0	1,7										
16,2	3,3	1,4	0,0										
0,0	0,0	0,0	0,0										
25,6	0,0	0,0	56,5										
0,0	0,0	0,0	4,2										
0,0	2,1	0,0	8,5										
0,0	0,0	25,0	0,0										
18,3	0,0	0,2	0,0										
0,0	0,0	0,0	0,0										
0,6	6,2	0,0	5,3										
0,0	0,0	0,0	0,0								Millet	Millet	
0,0	33,7	1,3	0,0										
0,0	14,0	0,0	7,2								End of stage		
0,0	0,0	0,0	0,0										
2,1	0,0	0,0	18,8										
0,0	0,0	25,4	30,1									Start of stage	
0,0	7,4	0,0	0,0										
0,0	0,0	0,0	1,4	91,9	155,1	85,7	196,5						

0,4	6,4	0,4	0,0							
14,2	0,0	0,0	0,0							
4,5	0,0	37,5	0,0					Sorghum	Sorghum	
7,6	5,4	0,3	23,5							
0,0	1,3	0,0	0,0							
0,0	0,0	17,2	2,8							
0,0	21,5	2,6	0,0							
0,0	2,8	0,0	0,0					Maize	Maize	
0,0	0,0	0,0	0,0							
6,6	0,0	7,5	5,8							
0,0	0,0	5,9	0,0							
0,0	0,0	2,6	4,7							
0,0	0,0	0,0	12,3					groundnuts	Groundnuts	
0,0	0,0	31,4	3,5							
26,0	0,0	0,0	0,0							
0,0	0,0	0,0	0,0							
0,0	0,0	0,0	6,2							
0,0	0,0	5,9	0,3							
0,0	0,0	0,0	11,2							
26,5	0,0	0,0	0,0							
0,3	0,0	0,0	13,8							
0,0	6,0	27,6	5,1							
0,0	0,0	3,1	31,2							
0,0	0,0	2,2	0,0							
6,3	0,0	0,0	35,2							
0,0	15,8	0,0	22,5							
13,6	0,0	2,7	0,0							
0,0	0,0	0,0	34,1							
0,0	0,3	7,7	0,0							
0,0	0,4	2,3	0,0							
29,3	0,0	0,0	55,1	135,3	59,9	156,9	267,3			
0,0	0,0	0,0	0,0							
19,3	0,0	65,7	0,0						Millet	
0,0	0,0	8,1	2,4							
10,6	19,4	0,0	69,9							
0,0	0,0	50,0	0,7							
0,6	0,0	0,0	0,0							
17,6	0,0	0,0	32,5						**End of stage**	
0,0	20,1	0,0	0,0							
0,0	6,3	0,0	2,3							
4,5	0,0	0,0	0,0							
3,9	7,3	34,1	0,0							
1,1	13,9	0,0	5,6						Sorghum	Millet/sorghum
0,2	4,6	6,2	0,0							
44,9	0,0	20,6	0,0							
15,7	0,0	34,1	0,0							
48,0	20,1	0,0	0,0							
0,0	0,0	0,0	0,0						Maize	Maize
34,5	23,9	17,0	0,0							
0,0	3,2	0,0	7,6							
15,2	0,0	1,4	0,0							
0,2	4,6	0,0	50,3							
6,4	45,7	14,9	11,0							**Start of stage**
3,6	2,1	0,2	2,4							
0,0	0,0	0,0	0,0							
0,4	0,0	2,2	31,4							
0,0	46,5	0,0	7,6							
12,7	1,8	3,5	0,0						Groundnut	Groundnuts
29,7	6,9	3,7	7,5							
20,4	2,8	10,0	0,5							
2,9	0,0	31,0	0,0							
0,0	0,0	9,6	0,0	292,4	229,2	312,3	231,7			

0,0	14,0	12,3	19,3					
1,3	1,1	0,0	0,0					
0,0	0,0	0,0	14,4					
0,0	32,7	0,0	48,1					
33,5	33,0	10,7	21,2					
0,0	0,0	0,0	0,7					Millet
0,0	0,5	0,0	0,9					
0,0	1,8	25,2	0,0					
2,7	61,8	15,2	13,3					
0,0	0,2	0,0	17,5					
0,0	20,3	0,9	16,5					Sorghum
0,0	0,9	4,0	0,0					
0,4	0,0	6,8	1,0					
7,0	23,6	0,0	18,8					**End of stage**
0,0	10,7	49,6	0,0					
0,0	0,3	24,4	0,0					Maize
3,0	0,0	4,6	0,0					
0,0	0,0	0,0	2,0					
42,5	9,4	0,0	0,0					
8,5	0,0	11,5	0,3					
38,7	11,5	2,1	0,0					Groundnuts
0,9	0,0	1,5	18,7					
0,2	1,8	2,9	0,0					
0,0	0,0	12,6	0,6					
0,0	3,0	0,1	7,1					
6,2	0,0	0,0	0,0					
0,0	0,6	0,0	0,0					
0,0	0,0	5,4	0,0					
16,6	0,2	0,0	0,0					
0,0	0,0	0,0	10,8	161,5	227,4	189,8	211,2	
0,0	28,8	3,3	0,9					
0,0	0,0	0,0	13,0					
0,0	0,0	0,0	0,0					
7,9	0,0	0,0	0,0					
0,0	14,6	0,0	0,0					
1,6	0,0	0,0	0,0					
0,0	9,1	0,0	0,0					
0,0	0,0	13,7	0,0					
0,0	0,0	11,6	0,0					
0,0	0,0	0,0	0,4					
0,0	0,0	3,7	0,3					
0,0	0,0	0,0	0,0					
25,7	0,0	0,0	4,8					
32,6	0,0	0,0	0,0					
0,0	0,0	0,0	0,0					
0,0	0,0	0,0	0,0					
0,0	0,0	12,0	0,1					
0,0	0,0	0,0	16,4					
0,0	0,0	0,0	0,0					
0,0	0,0	31,5	0,0					
0,0	0,0	2,6	0,0					
0,0	6,4	0,5	0,0					
13,6	0,0	0,0	0,0					
47,2	0,0	0,0	0,0					
2,0	0,0	0,0	0,0					
0,2	0,0	0,0	0,0					
3,0	0,0	0,0	0,0					
4,1	0,0	0,0	0,0					
0,2	0,0	0,7	0,0					
0,2	0,0	3,3	0,3					
1,1	0,0	4,7	0,0	139,4	58,9	87,6	36,2	
0,0	0,0	6,0						
0,0	0,0	0,9						
0,0	0,0	0,0						
0,0	0,0	0,0						

Appendix 13

Potential irrigable land calculations

If the constant release is set to be 50% of the maximum constant release the following potential extraction values are obtained:

Badala: 1,415 m^3/s * 0,50 = 0,708 m^3/s

Koumi: 0,49 m^3/s*0,50 =0,245 m^3/s

This gives a total water volume/day of:

Badala: 0,708*60*60*24 = 61171 m^3/day

Koumi: 0,49*60*60*24 = 42336 m^3/day

The results are adjusted for evaporation losses:

Badala: 61171 – 8351 = 52 820m^3/day

Koumi: 42336 – 2087 = 40 249 m^3/day

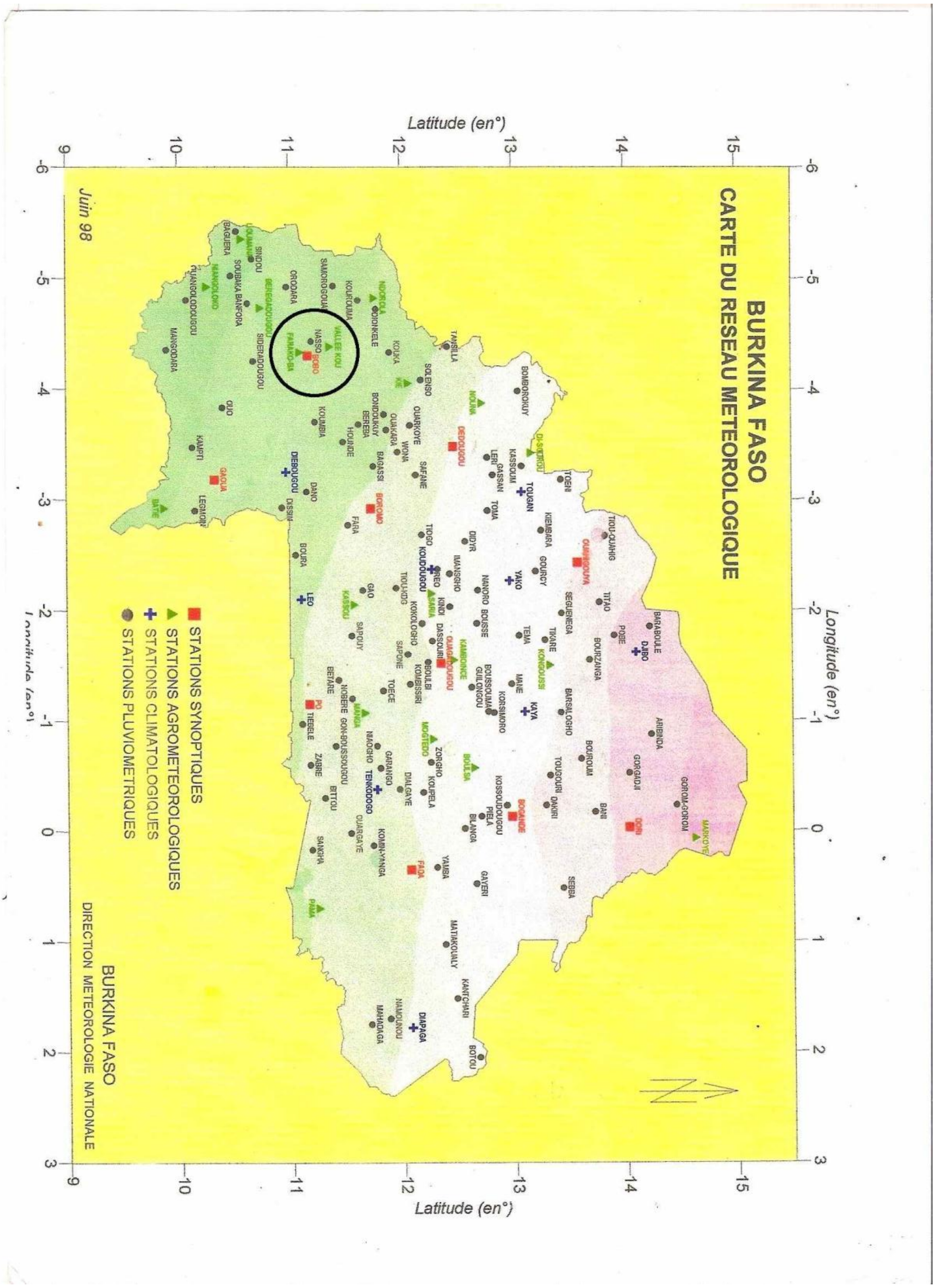
These results divided with the water need/hectare*day above give:

Badala: $\frac{52820}{44,8} = 1179$ hectares

Koumi: $\frac{40249}{44,8} = 898$ hectares

Appendix 14

Map over all the meteorological stations in Burkina Faso (Sama, 2011)



Appendix 15

Soil map of Burkina Faso (Atlas de l'Afrique)