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1 Introduction

1.1 Research context

Uganda is an East African country that derives its boundaries from the British Empire. After independence was achieved in 1962, the vast number of different ethnic groups and cultures prevented the country from establishing a working political community, which led Uganda into the dictatorial regime of Idi Amin. The past 25 years have brought the country relative stability and economic growth. Uganda is a landlocked country situated north of Lake Victoria. It covers an area of 236.000 square kilometres of which 123.000 square kilometres are considered agricultural area. The climate is semi-arid in the northeast and tropical in the rest of the country, which is situated on the African plateau. Uganda's population was 33 million people in 2012 of which only about 13 % live in urban areas. (The World Factbook, 2013)

Agriculture is Uganda's most important economic sector employing 66 % of the workforce (UBOS 2012: 127). The livestock sub-sector contributes 7.5 % of the GDP (WWAP 2006: 120). According to the Uganda Bureau of Statistics (UBOS 2009: 128) 26 % of Uganda's rural households own cattle with a total of 12 million cattle in the country.

1.2 Development problem

Food security and poverty alleviation are major challenges of our time. Over the last decade, water supply and agriculture have been negatively affected by climate change, threatening especially smallholder farmers. The situation in Eastern Africa is particularly challenging as the majority of the population still lives in rural areas and depends on resources that are vulnerable to climate change and its consequences. (Cooper et al. 2008: 24ff)

Food security exists *"when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life"* (FAO 1996). Water is a key ingredient to food security, especially in developing countries. Having insufficient access to water leads to undernourishment and may cause famine. This is particularly important in places where people are depending on the local agriculture. An important factor is the current situation of climate change. Floods and droughts appear more often and while the monsoon period tends to become heavier and more disastrous, droughts and long dry seasons threaten water supply and therefore food security. According to the FAO, droughts are the most common causes for food shortages in developing countries. (FAO 2003: 12)

Estimates indicate that about 60 % of Uganda's pastoral households lack water for domestic and livestock use. As a result, livestock farmers often have to cover long distances in search of water, causing health and productivity risks. In order to address these issues, the government has implemented livestock water supply programs like the Water for Productivity investment plan. This plan seeks to provide each sub-county in cattle rearing areas with a valley tank/dam by 2015. (WWAP 2006: 120-121)

As water is a key factor for food security, water management becomes essential. The efficient use of water resources, water management during dry season and wastewater treatment are main challenges to fighting poverty and eradicating undernourishment. To deal with these challenges, two factors are important: people and technology (FAO 2002: 12). Developing programs need to help people understand the right use of their water resources and to equip them with the technology to maximize their outcome. This research addresses the above stated problem: A development project has supplied a rural Ugandan community with technology to improve the water supply for the locals and their livestock and the outcome needs to be examined.

1.3 Research challenge

Universities have been criticized for not responding to the challenges East African countries face; especially in the areas of water resources and climate change (RUFORUM 2010: 9). In this context, the WATERCAP project seeks

> *"to use a partnership approach to strengthen university capacities in addressing climate change induced water vulnerability and uncertainty"*.

(RUFORUM 2012: 3).

WATERCAP is an APPEAR project ('Austrian Partnership Programme in Higher Education and Research for Development') and was established by a consortium of the Austrian Agency for International Cooperation in Education and Research (OeAD-GmbH) and the Latin-America Institute (LAI). Its coordinating institution, RUFORUM (The Regional Universities Forum for Capacity Building in Agriculture), is based in Kampala, Uganda. RUFORUM is a consortium of 29 universities in East, Central and Southern Africa and states its vision as follows:

> *“RUFORUM envisions a vibrant agricultural sector linked to African universities that can produce high-performing graduates and high-quality research responsive to the demands of Africa’s farmers for innovations, and able to generate sustainable livelihoods and national economic development.”*

(RUFORUM 2011: 1):

Among others projects, WATERCAP (in cooperation with Makerere University, Kampala) got involved in the parish of Wanzogi in the central Ugandan province of Nakasongola. The intention was to improve the water supply for livestock watering and equip the local livestock farmers with proper infrastructure. The project has been ongoing since 2011 and in May 2013 the author of this thesis and three more students were sent to Wanzogi to examine the WATERCAP process and the infrastructure put in place. This particular thesis focuses on technical aspects of the site such as water demand and water availability as well as design, operation and maintenance of the infrastructure.

The conclusions of this thesis ought to help to transform the local community and its infrastructure towards a better and more sustainable use of the available water.

2 Objectives, research questions and hypothesis

2.1 General objectives

The main objective of this thesis is to contribute to the overall objective of the WATERCAP project which is

> *"to use a partnership approach to strengthen university capacities in addressing climate change induced water vulnerability and uncertainty".*

(RUFORUM 2012: 3)

2.2 Specific objectives and research questions

The purpose of this thesis is to examine the Wanzogi valley tank in regards to water availability and water demand as well as operation and management. Consequently it should determine if the amount of water provided by the infrastructure covers the community's needs and how the management of the water resource can be improved.

These objectives were achieved by analysing the Wanzogi valley tank from a technical perspective, evaluating existing management structures and operational rules as well as doing a comparative analysis of different valley tanks in the Nakasongola district.

Consequently the following research questions were drafted:

- Is the Wanzogi valley tank an appropriate infrastructure to cover the community's water demand for livestock?
- What management practices are currently in place at the Wanzogi valley tank and how can they be improved?

These sub questions shall be answered:

- What is the local water demand for livestock?
- Is evaporation a major aspect of the water balance?
- What is the watershed runoff situation in Wanzogi and during what time of the year is the water of the valley tank needed for watering livestock?
- How can siltation be reduced in regards to design and siting of a valley tank?
- Is the tank design adequate for its purpose?

- Are responsibilities clear and is the distribution of responsibilities well designed?
- How should the valley tank be managed in order to provide the maximum amount water for livestock during dry season?

Not parts of this research are the following aspects:

- In-depth analysis of the seepage rate, even though this is an important aspect to draw a conclusion about water supply during dry season. The seepage rate is determined by another ongoing thesis by Percy Kyazze (Makerere University, Kampala)
- The analysis of social conflicts that might lead to the rejection of the infrastructure provided by WATERCAP (addressed by ongoing theses of Lisa Haller, BOKU University, Vienna and Rebecca Mukebezi, Makerere University, Kampala)

Accordingly, the following hypothesis is deduced from the research questions mentioned above:

> *"With proper operational rules in place, the Wanzogi valley tank provides sufficient water to cover the local livestock's water demand during dry season"*

3 Material and methods

3.1 Area of research

Nakasongola district is situated in the centre of Uganda, on the Kampala – Gulu highway about 120 km north of Kampala (see Figure 1). It covers 3.500 square kilometres at the south-western shore of Lake Kyoga and comprises eight sub-counties and one town council. Nakasongola district is in the heart of the so called Ugandan cattle corridor, which stretches from Rwanda in the southwest to Kenya in the northeast. The cattle corridor covers an estimated 84.000 km², making up about 42 % of the country's total land area (REGLAP 2012: 1ff). Nakasongola is considered one of Uganda's driest districts (NDC 2009: ii).

The site of research is a valley tank in the parish of Wanzogi in Kalungi sub-county in the East of the district (see Figure 2). This particular valley tank is the only community owned valley tank in Wanzogi parish and is situated right in between the two villages Kanyonyi and Wanzogi. The valley tank was originally constructed in 1968 and desilted and enlarged as part of the WATERCAP project in early 2013. Furthermore the valley tank was equipped with a concrete trough, pipes and a fuel pump for watering cattle at the end of 2012.

Figure 1: Uganda

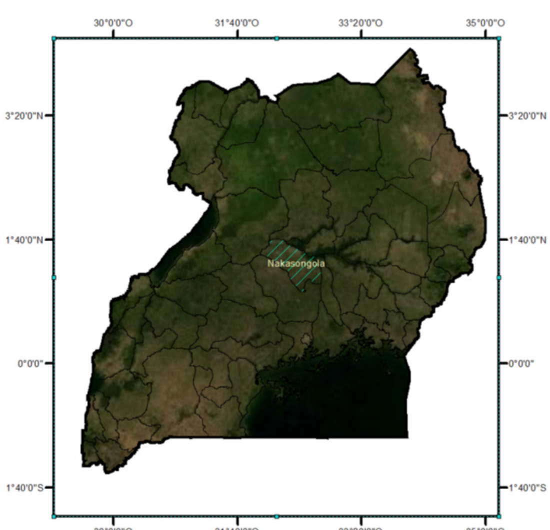
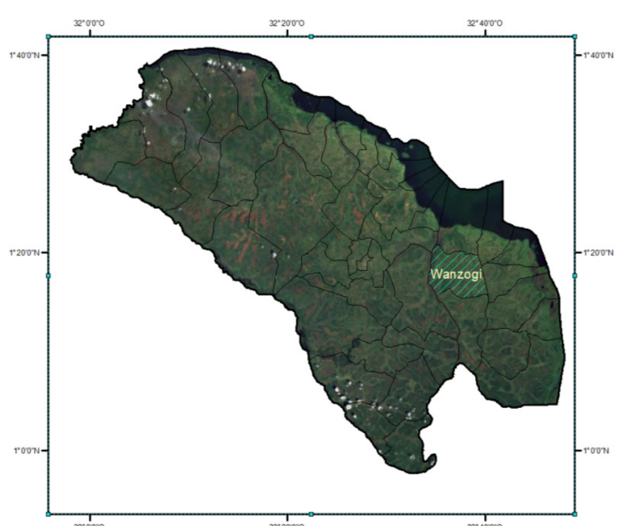


Figure 2: Nakasongola District



Source of the district and parish borders: GADM (2013)

Socio economic attributes

At the last population census (2002), Nakasongola district had a population of 127.000 and a population growth rate of 2 %, which is well below the country's average. The projection for 2012 was a population of 156.500 (UBOS 2012: 103). The population density is one of Uganda's lowest with only 41 persons per square kilometre (NDC 2009: 1). The total population of Kalungi sub-county, the sub-county in which the fieldwork took place, was 20.897 in 2012, according to the District Council. 13.5 % of the individuals in Nakasongola district are estimated to be living in households with real private consumption per adult equivalent to or below the poverty line for the region (UBOS 2010b: 75).

According to the national livestock census 2008 (UBOS 2009) 84 % of the households in the Nakasongola district rear livestock. Forty-seven per cent of the households own cattle of which 99.5 % are indigenous breeds (45 % Ankole and 54 % Zebu / Nganda), making a total of 222,000 head of cattle. The mean cattle herd size is 17 head; the share of dairy cows is 38 %. Furthermore, 48 % of the households own goats, 41 % pigs and 68 % chicken with respective mean herd sizes of 6, 3 and 9. The mean landholding size is 2 square kilometres.

Apart from cattle keeping, subsistence agriculture is essential for most parts of the population, in particular the cultivation of maize, cassava, groundnuts and sweet potatoes (UBOS 2010a: 277, UBOS 2012: 159). Fishing (mainly at Lake Kyoga) is considered the most important economic activity by about one-third of the Nakasongola households (NEMA 2010: 109). According to UBOS (2010a: 272) 14.3 % of the agricultural household members in Nakasongola have completed secondary school and 62.9 % have primary school as their highest level of education. With 13.9 % having received post-secondary education, 8.9 % have never been to school. The Gini coefficient is 0.38 and rising, indicating that inequality is worsening. This is due to the fact that the lower poor saw their living standards raise more slowly than the affluent (UBOS 2010b: 86).

Climate and rainfall characteristics

Nakasongola district is situated in the Ugandan cattle corridor, which is a semi-arid stretch across Uganda. Annual rainfall occurs mainly during two rainy seasons and amounts up to 1200 mm. The first rainy season takes place from April to May and is shorter but more intense. The second rainy season occurs between August and November. The mean temperature during dry season is 30℃ and during rainy season

25°C, with the dry season at the beginning of each year generally being the hottest time of the year. (Taylor and Howard 1999: 48ff)

Vegetation and soil condition

Deforestation together with land degradation occurs in most parts of Uganda. According to NEMA (2010: 26) there is even evidence of increasing bare areas, especially in the district of Nakasongola. The deterioration of vegetation has happened due to the high stocking rates of livestock and the consequent need for more pasture as well as the increasing number of immigrating pastoralists from neighbouring districts. Furthermore in the past 20 years charcoal production and selling to urban areas has emerged as a major commercial enterprise and thus there has been a considerable reduction in the number of trees (NDC 2009: ii). As a consequence of the loss of vegetation, there is severe land degradation due to soil erosion. NEMA (2010: 40) states the large numbers of cattle that trample the soil as the major factor for soil erosion.

3.2 Theoretical context

3.2.1 The community management model

Until 25 years ago it was considered that good management of a system including water supply was attained by one single authority. However, the disappointing results have led researchers to the conclusion that the use of local informal groups, associations, committees or cooperatives improves the efficiency of development projects (Pallas 1986). Over the past two decades, community management has become the leading model for implementing rural water projects in developing countries. General principles of community management include cost sharing, ownership, participation and control, and the model is considered essential to long-term operation and maintenance (Lockwood 2004: 5). While community management is currently the most practiced model, it has to be added that it is not the only model and might not be applicable in all situations, e.g. in systems based on large networks serving many communities (ibid: 7). The basic principles behind this model are that the community benefiting from a certain infrastructure should (Harvey, Reed 2006: 365):

- have a major role in its development
- own the water system or facility
- have overall responsibility for its operation and maintenance

To achieve these goals, generally the formation of a community water committee consisting of local users of the infrastructure, who are then responsible for its operation, maintenance and the collection of money, is essential (ibid: 365f). Furthermore the community is involved by making decisions on the type of technology used, the service level, the form of local organization, local rules and regulations on use, financing mechanisms as well as sanctions (WHO 2000: 170). There are a number of different interpretations of the goals of community management, but they share the following general objectives (Lockwood 2004: 8):

Empowerment

Water supply projects are seen as an entry point for community empowerment and self-improvement, building up capacity in the community.

Efficiency

By including the resources of millions of communities around the world, the use of financial resources becomes more efficient through the utilization of human capacity, voluntary time and material inputs.

Sustainability

One major aim of community management is to increase and guarantee sustainability. The argument is that communities will have an increased interest in seeing the beneficial service continue when being in control of the process of delivery.

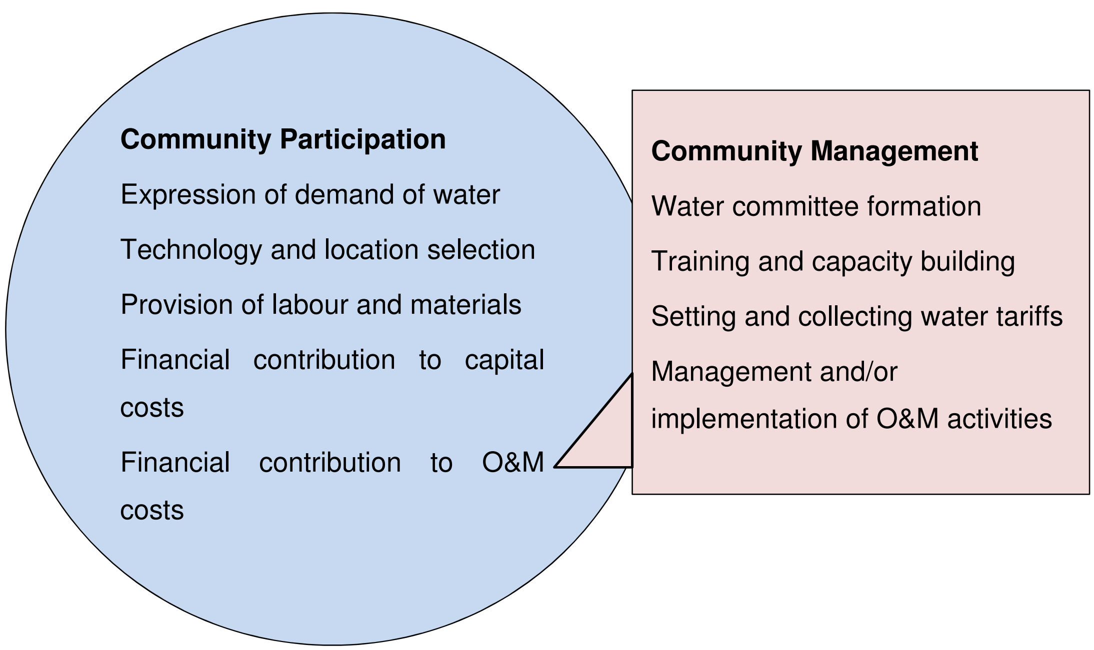
The World Health Organization lists several reasons in favour of a community management in rural water supply systems (WHO 2000: 168):

- Building on existing local knowledge and management capacities
- All social groups feel concerned and can participate
- Addressing the true needs of community members
- Solutions acceptable to community members
- Solutions adapted to community capacities
- Increased community commitment to improve the situation
- Better understanding of the causes and effects of problems
- Empowering the community and reducing dependency
- Increased sense of ownership and responsibility
- Increased self-consciousness and confidence in own capacities

- Direct interest to have a system well maintained
- Possible improvement of willingness to pay
- Reduced overall and government costs
- Improved reliability and sustainability of systems

The difference between mere community participation and community management becomes evident with the element of control. Community participation means that the community partakes in the provision of labour, materials and finances and is included in the process of the selection of a management system as well as technology and location, but the government or other institutions stay in control of the project. Community management gives all the control to the community, including social, technical and financial management and responsibilities. A schematic overview is displayed in Figure 3. (Fielmua 2011: 176f; WHO 2000: 159-165)

Figure 3: Segregated aspects of "Participation" and "Management" (Source: Harvey, Reed 2006: 369)



3.2.2 Limitations of the model

Rural water supply sustainability levels remain low despite the fact that community management approaches are extensively used throughout sub-Saharan Africa

(Harvey, Reed 2006: 370). Limitations can be caused within the community (community dynamics, political or social conflict, lack of maintenance etc.) or be brought into the community from external sources (poor design, poor implementation, lack of spare part supply etc.). Often the impact of those limitations only becomes evident after a number of years (Lockwood 2004: 10).

A study performed by Harvey and Reed (2006: 370) in sub-Saharan Africa sums up the six most commonly cited causes for breakdown of management systems in community managed water supply systems.

- Community management often relies on voluntary inputs from community members, which people may do for a while but are reluctant to do in the long term; there are often no long-term incentives for community members.
- Key individuals on the water committee leave the community or die, and there is no mechanism to replace them with trained individuals.
- The community organization charged with managing the water supply loses the trust and respect of the general community. This may be related to a lack of transparency and accountability, and lack of regulation by a supporting institution (e.g. local government).
- Failure by community members to contribute maintenance fees leads to disillusionment among committee members who abandon their roles. This may be due to a lack of legal status and authority of the water committee or lack of community cohesion.
- Communities have no contact with local government (or the implementing agency) and feel that it has abrogated responsibility for service provision; they therefore feel abandoned and become demotivated.
- Communities are too poor to replace major capital items when they break down.

To deal with these limitations Harvey and Reed (2006: 372f) as well as Lockwood (2004: 12ff) suggest the provision of institutional support for community management. There is evidence that community management is sustainable only where a strong local institution is supporting the communities. This support comprises the following components (Harvey, Reed 2006: 272f):

- encouragement and motivation
- monitoring and evaluation
- participatory planning

- capacity building
- specialist technical assistance (including financial support where required)

3.3 Overview of methods used during fieldwork

The following methods were used in the process of research:

Technical analysis of the Wanzogi valley tank

An analysis of the water balance of the Wanzogi valley tank was performed during fieldwork to estimate if the available amount of water is sufficient to cover the community's demand. Furthermore the soil erosion potential of the watershed was determined to make statements about the impact of changed land use as well as soil and slope variability. Details about the technical analysis are described in chapters 3.5 and 3.6.

Comparative analysis of selected valley tanks in the Nakasongola district

In order to determine best practices for operation and maintenance as well as management and design of the Wanzogi water resource and siting of new resources, a comparative analysis of six valley tanks in the Nakasongola district was performed (see chapters 3.6 to 3.8).

Quantitative interviews

During the fieldwork quantitative interviews in the community were carried out. The sampling included (1) all (localized) household heads of Kanyonyi village and (2) all (localized) main users of the Wanzogi valley tank (those with the largest herds, as stated by the local livestock committee).

Group Workshop

Towards the end of the fieldwork, a group workshop with local leaders and livestock farmers took place in order to clarify together with the community the management structures that had not been clear before. Additionally this workshop served to verify some of the findings and to give feedback and suggestions back to the community.

Observation

Furthermore the results were complemented with observation (Atteslander 2010: 88). The observation was open and unstructured and aimed to verify the data obtained from the basic research and the quantitative interviews. It was used to determine local practices of watering livestock during the dry month of July at the Wanzogi valley tank and five other valley tanks in the Nakasongola district. Since the willingness of the locals to give correct information was unknown, observation was an important tool for the verification of data obtained by interviews and informal conversations.

3.4 Ascertainment of water resources and water users

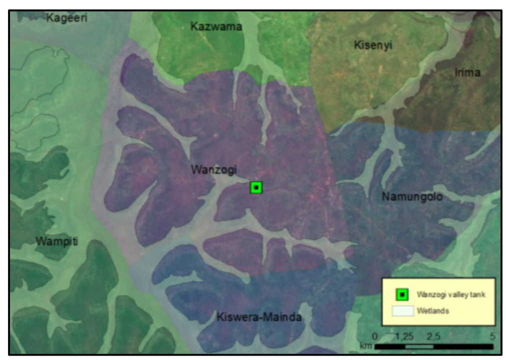
3.4.1 Examination of water resources for livestock

An inventory of the local water resources used for livestock watering was made in order to get an overview of the available water sources and to be able to compare the Wanzogi valley tank to other local water resources. The location of the water resources was recorded with GPS, and the storage capacity of some of the ponds and valley tanks was measured and calculated. The following water resources are used by the local livestock farmers and were identified during the fieldwork through interviews and observation:

Swamps

The so-called swamps are areas that are flooded during rainy season. Large portions of the Nakasongola district turn into swamps twice a year and thus provide water for the local livestock for at least some months. Swamps are used as water sources during the rainy season and at the very beginning of the dry season.

Figure 4: Swamps in the Wanzogi parish



Source: swamps: WRI (2013); parishes: GADM (2013)

Ponds

Ponds are small natural or manually excavated water reservoirs. During rainy seasons they fill up and consequently provide water for part of the dry season. Ponds are used when the swamps dry up, but they don't hold enough water to cover the demand for the whole dry season.

Figure 5: Pond in Kanyonyi village

Boreholes

Most boreholes never dry up and for that reason some cattle keepers use them as a water source. Especially farmers with only a few head of cattle often go to the boreholes during dry season. However, this is not an option for the bigger herds as pumping groundwater takes a long time and access is limited. Some boreholes have the rule that cattle keepers are only allowed to water their animals during night hours to make sure fetching water for domestic use is not restricted during daytime.

Figure 6: Kanyonyi village borehole

Figure 7: Kainamura private valley tank

Figure 8: Kisweramayinda communal valley tank

Private valley tanks

Some local livestock farmers have managed to excavate valley tanks on their own land. These valley tanks are dug manually or by an excavator and store large amounts of water. The number of farmers being able to afford their own valley tanks has been increasing recently and thus some of them do not rely on communal water sources anymore. Yet because of selling water to other farmers, some of the tanks will also run dry during dry season.

Communal valley tanks

There is only one communal valley tank in Wanzogi parish – the one dealt with in this thesis. Yet a number of other communal valley tanks are situated in the area, and especially due to the effort of World Vision, many new communal valley tanks are being excavated. The distance between those tanks determines how far livestock farmers, who have run out of alternative water resources, walk to water their livestock and thus is essential for a valley tank's cattle catchment area. Some communal valley tanks run dry during dry season, while others never dry up. The reason why some valley tanks don't dry up even while there are cattle having to move to Lake Kyoga at the same time is that every valley tank only provides a certain area for grazing animals. Consequently the number of animals at one valley tank is not only restricted by the amount of water, but also by its surrounding grazing / resting area.

Valley dams

There is one valley dam in the Nakasongola district which is situated right next to the Nakasongola town council. The valley dam is an embankment dam and holds much more water than the average valley tank. However, it is not an option for Wanzogi cattle keepers, due to its distant location.

Lake Kyoga

When all the other water sources have run dry, Lake Kyoga usually is the last option for most herds. Towards the end of the long dry season at the beginning of each year, many cattle keepers are forced to move to the lakeshores and stay there with their animals until the rains start. This means the lack of access to water makes them semi-nomadic. However, moving to the lake has recently become increasingly difficult since much of the land at the lake is not available for cattle keepers anymore and the amount of cattle is ever increasing. Furthermore the gathering of such big numbers of animals supports the spreading of diseases and the water quality of the lake is very poor. The distance between Wanzogi and Lake Kyoga is about 10 km and in exceptionally hot and dry seasons such as 2009/10 a significant number of animals may perish on the way due to the heat and subsequent exhaustion.

3.4.2 Spatial distribution of Wanzogi valley tank users

An analysis of the distribution of the users of the Wanzogi valley tank as well as the distance they cover in order to reach the resource was carried out during the fieldwork. To achieve this, the main valley tank users (as identified by the local livestock committee) were localized and their farms' positions recorded with a GPS. The result of this analysis allows drawing conclusions about the cattle catchment area of the Wanzogi valley tank and serves as input for the demand analysis.

3.5 Water balance

Figure 9: Wanzogi valley tank

To determine the adequacy of the Wanzogi valley tank (displayed in Figure 9) in regards to water quantity, it is essential to take a closer look at the water balance. The terms of the water balance are the water provision represented by the *catchment yield* of the valley tank's drainage area, the local *water demand* for watering livestock and *water losses* of the valley tank. Water losses include evaporation and seepage. While the calculation of evaporation is part of this thesis, seepage will only be estimated from a water balance approach and determined in detail in a different thesis by Percy Kyazze.

3.5.1 Valley tank capacity

The Wanzogi valley tank is an excavated reservoir and as such has a fairly regular rectangular shape. It was desilted and enlarged during the dry season in early 2013. The length and width of the valley tank were determined using a tape measure. Since the valley tank was full of water during the time of research, the slopes and depth of the valley tank had to be measured from the outside. By stretching ropes across the valley tank, a 3 x 3 meter raster was created. Measurements were taken using a tape measure with a pulley (100 m). The tape measure was led from the shore through slings in the rope to the water, sinking to the ground by having a weight tied to it.

3.5.2 Water demand

An animal's body consists of 60 - 70 % of water. To maintain this level, the animal must take water from drinking and from the water content of dry matter intake (Peden et al. 2002: 505). The total water demand of the Wanzogi valley tank depends on the actual number of livestock watering at the site and the specific water need of each animal per day. Locally bred cattle species are Ankole and Zebu with some exotic breeds and cross-breeds.

Amount of cattle using the valley tank

The Wanzogi valley tank is being used by livestock farmers of the surrounding area but mainly by the inhabitants of Wanzogi and Kanyonyi villages. The local livestock committee provided a list of all the main users (those with the largest herds) of the valley tank during the past dry season in early 2013). By localizing these main livestock farmers and taking their farm's location coordinates with a GPS, the cattle catchment area of the valley tank could be roughly estimated. However, apart from the main users on that list, there are many small-scale stock farmers who also use the valley tank as most people in the area breed at least some animals. During the time of the fieldwork, a census of the whole area's livestock was conducted by a local community leader in order to locate those farmers and to estimate their amount of cattle. To complete this fragmentary census, representative quantitative interviews were taken for all the households of Kanyonyi village where the household head could be localized on one of three days in June 2013. The questionnaire was about the amount of livestock and the seasonal watering habits. The results of these interviews were taken as representative for the Wanzogi parish and extrapolated for the determined cattle catchment area of the Wanzogi valley tank to give an estimation of the number of cattle using the water source. There are issues when it comes to asking people about the amount of cattle they possess, as they might state a lower number to pay a smaller share in valley tank maintenance costs. Considering this, the data obtained by interviews and the census was verified by observation when the livestock farmers started to use the water source at the beginning of dry season.

Calculating the number of cattle using the valley tank, one has to consider that the numbers might vary significantly from one season to another. The reasons are the excavation of new private and communal valley tanks, a high rate of people moving to different places and variations in herd sizes. Out of 31 main users during the past dry season, one had excavated his own valley tank, two more were allowed to water their cattle at that valley tank, one had moved away and another had sold almost all his cattle. Additionally there were two communal valley tanks excavated by World Vision that will most likely have a direct impact on the cattle catchment area of the Wanzogi valley tank by attracting some of the livestock farmers who have to cover a far distance to reach Wanzogi. Stating this, it becomes evident that the determination of the amount of cattle using the valley tank will be a rough estimation with a fairly high variability. Yet the aim of this thesis is not to determine the exact number of cattle watering at the valley tank, but rather to make a statement if the available amount of water is adequate to cover the demand of that area. This estimation is accurate enough to make that statement.

The number of livestock using the Wanzogi valley tank has been estimated in different ways. Data available for Kanyonyi village was extrapolated for the whole cattle catchment area and data available for Nakasongola district was interpolated.

Estimation using the number of livestock owning homes

Basis for this calculation is the assumption that all cattle farmers of Kanyonyi and Wanzogi villages, as well as some farmers from other villages in the parish, use the valley tank. This has been confirmed by the locals. The only village that provides proper census data is Kanyonyi village. Furthermore, data about the Wanzogi parish consisting of seven villages (including Wanzogi and Kanyonyi) is available. Using this data, the number of homes in each village was calculated assuming that the six villages apart from Kanyonyi have the same size. From the list of the main users, the general pattern of how many percent of valley tank users come from villages outside Kanyonyi and Wanzogi is known. This data was used to calculate the number of homes potentially using the Wanzogi valley tank.

From census data and quantitative interviews, the percentage of homes owning cattle and the number of animals per home is known and thus leads to the total amount of cattle watering at the valley tank.

$$N = H * \%HC * CpH$$

N	total number of cattle watering at the valley tank
H	number of homes potentially using the valley tank
%HC	percentage of homes owning cattle
CpH	heads of cattle per home

Estimation using the distance to the surrounding communal valley tanks

The distance to the nearest alternative communal water resources was calculated from GPS readings taken during the fieldwork. Assuming that cattle keepers take their cattle to the nearest water resource, the size of the cattle catchment area can be calculated. According to the last livestock census, the Nakasongola district has a cattle population density of 47.5 heads of cattle per km² (UBOS 2009: 128). Using this data, the number of cattle watering at Wanzogi was calculated.

Estimation using the location of the main users' farms

GPS readings taken during the fieldwork period were used to draw the location of the main users on a map. From these locations, the cattle catchment area was calculated and multiplied with the above stated cattle population density.

Estimation using the local livestock census

A livestock census was carried out by the local leader during the time of research. Unfortunately the census seems to be inadequate for the purpose of this study since on one hand it is incomplete and on the other hand it includes farmers not belonging to Wanzogi.

Water consumption per head of cattle

Daily water consumption per head of cattle was determined by literature research and field observation. For the latter, the average water demand per head of cattle was calculated at different occasions when the stock farmers watered their livestock at the valley tank in July 2013. The literature suggests that the average water intake of one Small East African Zebu cow is 20 litres of water per day under normal conditions (Mati et al. 2006: 10). The water intake of Ankole cows is similar because their body size is within the same range (Payne and Wilson 1999: 197).

The National Livestock Census (UBOS 2009: 136) states that 41.7 % of all cattle in Nakasongola are adult cows and 5.5 % adult bulls; the rest is shared between calves and heifers. The proportion of milk cows to all adult cows is 38 %. The share of Ankole and Zebu cattle is almost equal, and exotic breeds are negligible.

There are a few issues that cause a variation in water intake of cattle that might need consideration (Peden et al. 2002: 505): (1) Seasonal variability of ambient temperatures and moisture of the dry matter, (2) lactating cows naturally have a higher water demand and (3) the distance covered to reach the water source impacts the water demand. The latter is not treated in this study due to the lack of existing data.

Seasonal variability of water intake

Few studies have been performed to investigate on the water intake variability due to the seasonal change of conditions. Results of Duguma et al. (2012: 28ff) suggest that the voluntary water intake during dry season in Ethiopia is 5 times higher than during rainy season. This is of course due to the fact that during rainy season the cattle find water sources while grazing and the moisture of the dry matter is higher. The water demand can be calculated depending on the air temperature according to the relationship displayed in Table 1:

Table 1: Water requirement and air temperature (Source: Pallas 1986)

Air temperature [°C]	Water requirement [l/kg of dry matter consumed]
-17 to +10	3.5
10 to 15	3.6
15 – 21	4.2
21 – 27	4.7
more than 27	5.5

Pallas (1986) shows that voluntary water intake of average cattle with a live-weight of 180 kg varies from 27 litres per day during dry season at 27°C to 10 litres per day during wet season, the feed plants having moisture of 10 % and 70 – 75 % respectively.

Herd structures have been described in terms of Tropical Livestock Units (TLU). One TLU equals a mature animal weighing 250 kg. That equals one cow or 0.7 cattle in a herd. The dry matter intake for one TLU is 7.5 kg / day or 2.5 kg of dry matter per 100 kg live weight and day (Kassam et al. 1993). With these numbers, water intake was calculated based on the ambient temperature as stated above. Water demand during wet season is not relevant since the valley tank is not being used during that time. There are obviously some variations in the water demand due to the stage of the dry season and the subsequent moisture of the dry matter, but for the purpose of this thesis the above stated premises are precise enough.

Lactation

Lactating cows require additional drinking water; according to Peden et al. (2002: 506), lactation increases the water consumption by up to 100 %. The National Livestock Census of 2008 concluded that 38 % of Nakasongola's adult cows are milked, dairy cows giving an average of 3.8 litres of milk per week (UBOS 2009: 144). King (1983: 17) states that water consumption in the tropics increases by 3 litres of water per litre of milk produced.

3.5.3 Catchment yield

The catchment yield determines the amount of water available. It depends on the *precipitation*, the *runoff/precipitation ratio* and the *watershed surface area*. While the catchment runoff is often used to estimate river peak flows and thus represents a very sensitive variable, in this study it is used to determine the point of time when the valley tank starts to empty due to a lack of watershed discharge.

Precipitation

To determine the potential rainwater supply, reliable rainfall data are required. According to Gould and Nissen-Petersen (1999: 46) data for a period of at least 10 years should be taken into consideration. Ideally 20-30 years of rainfall data are preferable, but longer rainfall series may give a false picture if changes of the regional climate have occurred. Due to climate change and the high variability of climate data over the past decades, this study uses data of the past 10 years in order to describe the current climatic condition correctly.

Precipitation data was obtained from FAO and NASA. The FAO database uses nearby rain gauges for interpolation of the rainfall data for Wanzogi. These rain gauges include locations at Nakasongola town and Kidera, at a distance of less than 30 km west and east of Wanzogi. FAO does not provide actual daily precipitation data, but rather mean rainfall amounts for each day. However, mean values are only of limited use when calculating runoff, because they do not represent the actual magnitudes of particular rainfall events. Thus another data source is needed.

This second source is satellite based NASA data. NASA provides daily data for the years from 1997 until present, derived from remote sensing using satellites. The reliability of the NASA data was verified by comparing it to the mean FAO measures.

Determination of the watershed

High resolution digital elevation models (DEM) were derived from the HydroSHEDS project. HydroSHEDS (**Hydro**logical data and maps based on **SH**uttle **E**levation **D**erivatives at multiple **S**cales) provides geo-referenced raster data sets including stream networks, watershed boundaries and drainage directions among others. HydroSHEDS is derived from SRTM (Shuttle Radar Topography Mission) elevation data and has a resolution of three arc-seconds (about 90 m in Uganda). These DEMs have been hydrologically conditioned using a sequence of automated procedures as well as manual corrections where necessary. The techniques used include void-filling, up scaling, filtering and stream burning. Quality assessments indicate that the accuracy of HydroSHEDS is significantly better than that of existing global watershed and river maps. (Lehner et al. 2006: 2ff)

To verify the HydroSHEDS DEM, GPS measurements were taken in the whole watershed. The size of the watershed was determined from the DEM using the ArcGIS 10 spatial analyst tools.

Watershed runoff

There are different ways to determine the watershed runoff from precipitation data. According to Steenhuis et al. (2008: 200ff), for monsoonal climates a water balance approach allows better runoff prediction than alternative methods calibrated for temperate climates. However, due to the lack of discharge data, the water balance approach is not applicable in the Wanzogi valley tank's watershed. Hence this study calculates the catchment yield using the SCS curve numbers method, which is widely accepted, and has been adjusted by regional research centres all over the world (Ritzema 1994: 121).

SCS curve numbers

SCS numbers were developed by the United States Department of Agriculture (USDA). The SCS runoff curve number method takes into account water retained by surface depression, vegetation, evaporation and infiltration before actual runoff begins. This initial abstraction was experimentally determined and considers the hydrologic soil group, cover type, treatment, hydrologic condition and antecedent runoff condition (USDA 1986: 13). For East African conditions, according to Ritzema (1994: 126), additionally slope steepness has to be considered. The SCS curve number equation is expressed as (USDA 1986: 13ff)

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Q runoff

P rainfall

S potential maximum retention after runoff begins

I initial abstraction

I_a represents all losses before runoff begins. It can be described by the following empirical equation:

$$I_a = 0{,}2S$$

The potential maximum retention S mainly represents infiltration after the start of the runoff event. The potential maximum retention has been converted into the curve number CN. This relationship is described as follows:

$$CN = \frac{25400}{254 + S}$$

CN = curve number, and depends on hydrologic soil group, cover type, treatment, hydrologic condition, antecedent runoff conditions and slope steepness.

A disadvantage of using this method is that the standard SCS method uses coefficients based on mostly North American basins. Such conditions might not apply to the tropical climate of rural Uganda; particularly the monsoonal rainfalls during rainy season and long dry periods during dry season need to be considered. For instance Muzik (1993: 100) found out that the standard SCS parameters lead to an average standard error of about 25 % for the tropical conditions of Thailand. Due to the lack of runoff events during the time of research, the curve number method could not be calibrated for the catchment area of the Wanzogi valley tank. For this study the curve numbers were determined from tables; in the case of East African semi-arid conditions, suitable numbers were published by Ritzema (1994: 124ff). Since the valley tank floods during rainy season and practically no runoff occurs during dry season, the intention of calculating the runoff is not to determine the total runoff volume. Instead it serves mainly to estimate at what time of the year the valley tank is full and when it starts to empty due to a lack of discharge of the watershed. To achieve this objective the error of being able to calibrate the method is accepted and the curve number method will still yield appropriate results.

3.5.4 Evaporation

Evaporation is one of the main components of the water cycle. For calculating the water balance, the determination of evaporation is essential (Khoob et al. 2007: 936). Evaporation is the water loss due to emission of water vapour. Unlike evapotranspiration, which also takes into account the transpiration of vegetation, this study assesses water losses from open water surfaces. Evaporation is an unproductive water loss, since the water will not be available downstream in contrast to seepage or percolation losses. (Liebe 2002: 21)

There are two types of evaporation: actual (E_a) and potential evaporation (E_p). Potential evaporation refers to the amount of water evaporating if there are no restrictions on the supply side; in other words, if there is an open surface of pure water that cannot be exhausted by evaporation. Actual evaporation takes into account that there is less evaporation from dryer surfaces at the same absorbing capacity of the atmosphere. (ibid: 21f)

Rough estimates of evaporation rates in the Ugandan cattle corridor can be obtained from Dagg et al. (1970: 65). The authors used weather station data to calculate the potential evaporation rates with the Penman equation and concluded the annual E_p to be 1800 – 2000 mm. Taylor and Howard (1999: 58) on the contrary estimate E_p at around 1500 mm/year.

Penman equation

Evaporation from open water surfaces is rarely measured directly, except over very small spatial scales. Most of the time it is computed indirectly through pan evaporation, water balance, energy balance and mass transfer techniques (Jensen 2010:1ff). A common approach to determine evaporation is the combination of aerodynamic and energy balance procedures of which the most popular equation was derived by Penman (Penman 1948). The Penman equation will be used for this study and is written as follows:

$$\lambda E_p = \frac{\Delta}{\Delta + \gamma} Q_n + \lambda \frac{\gamma}{\Delta + \gamma} E_a$$

- λ latent heat of vaporization
- Δ slope of saturated vapour pressure
- γ psychrometric constant
- Q_n net radiation
- E_a combination of wind function and vapour pressure deficit

The Penman equation allows using meteorological data for calculating evaporation. The necessary parameters are average air temperature, average wind speed, humidity and net radiation. According to a study by Irmak and Haman (2003: 500ff), which compared several methods for calculating evaporation, the use of the Penman equation leads to satisfying estimates. Better results would need more data input such as total solar radiation (ibid. 507) or more elaborated wind functions (Tanny et al. 2007: 228). Since no reliable meteorological data from local weather stations is available, this study uses data provided by NASA and the FAO. The data sets are interpolated meteorological data for the exact position of the Wanzogi valley tank (FAO) and remote sensing satellite data (NASA). According to Jensen (2010: 18) it is important to consider that the use of interpolated weather data does not give as reliable values as calculations using data collected directly on the site. In particular, wind and humidity might vary depending on the local environment. In the context of this thesis it is not possible to retrieve on-site meteorological data, especially not for a whole year's cycle, and for this reason the existing data will be complemented by evaporation pan readings.

Evaporation pan

Evaporation pans are used extensively throughout the world to estimate evaporation rate experimentally (Irmak and Haman 2003: 500). Evaporation rates from standard evaporation pans can be measured and then multiplied by a coefficient to determine the actual evaporation rate either from open water surfaces or evapotranspiration from vegetated areas (Jensen 2010: 7). However, there is no evaporation pan in the district of Nakasongola, so the installation of a standard evaporation pan in Wanzogi for the time of this research was necessary (initiated by and eventually serving the thesis of Percy Kyazze with whole-year data). Data from this pan was compared to the evaporation rate calculated by meteorological parameters and thus verifies those results.

The pan installed at the Wanzogi valley tank is a so-called Class A evaporation pan. Class A pans have been standardized by the U.S. National Weather Bureau and are widely used due to their simplicity. They have come to be known the most accurate measure of evaporation in humid areas (Khoob et al. 2007: 936). Usually built of galvanized iron, the diameter of a Class A pan is 120.7 cm and its height is 25 cm. The pan was installed next to the valley tank in June 2013 and thus provides a few months of on-site data for this thesis. Readings are taken daily by a local who refills the pan every morning and records the amount of water poured into the pan. From those readings, the evaporation rate in mm can be calculated using the surface area of the pan and a pan coefficient taken from literature. (Jensen 2010: 7ff)

Additionally a rain gauge has been installed on-site to record the precipitation entering into the pan. For days with rainfall events, the evaporation rate has to be corrected for the precipitation.

3.5.5 Seepage

Seepage is dealt with in detail in another thesis by Percy Kyazze. For the calculation of the water balance in this study, seepage will not be experimentally determined but only roughly estimated by using FAO suggestions based on the soil type published by Coche and van der Wal (1981) as displayed in Table 2. Additionally a level was installed at the valley tank to record the change of the depth of water over time. With knowledge of the evaporation and consumption rates during the corresponding timeframe, seepage was determined from a water balance approach.

Table 2: Seepage rates of different soil types (Source: Coche and van der Wal 1981)

Natural soil type	Seepage losses [mm/day]
Sand	25 – 250
Sandy loam	13 – 76
Loam	8 – 20
Clayey loam	2.5 – 15
Loamy clay	0.25 – 5
Clay	1.25 – 10

3.6 Design

The evaluation of the valley tank design is based on suggestions from the literature and a comparative analysis of six valley tanks in the Nakasongola district. For the Wanzogi valley tank the following characteristics have been considered:

3.6.1 Dimensions

The valley tank dimensions were recorded in Wanzogi as described in chapter 3.5.1. The same procedure was applied to the other valley tanks in the area. Valley tank dimensions are – assuming that the catchment yield is sufficient to fill the valley tank during rainy season – the most important factor when it comes to the quantity of water provided during dry season. Although valley tanks can be excavated in any shape desired, Pallas (1986) suggests a rectangular shape for its simplicity in being built and adapted.

3.6.2 Resource protection

Protecting the water resource is essential to reduce contamination and to prevent humans and animals from falling into the valley tank. Especially children playing close to open water or fetching water directly from a pond are in danger of falling in and drowning (WAC 2005: 88). Dung and other organic material in the water provide ideal food for bacteria and algae. Degradation of this organic material leads to low oxygen content and eutrophication. The water might become unpalatable to the cattle and diseases spread at an increased rate (Liddicoat et al. 2011: 55). In this thesis, resource protection refers to protection of the actual water body as well as protection of the inflow area.

Fencing

Complete fencing of the reservoir is recommended to avoid damage to the banks by trampling animals and thus to reduce soil erosion (Zziwa 2009: 25). Furthermore it protects the water from contamination by animals dropping their dung into the water source or its direct surroundings. A complete fence requires a watering system outside the fence consisting of some sort of trough, a water supply pipe and a pump (Pallas 1986).

Fencing is suggested in almost every handbook, yet Pallas (ibid.) mentions that in developing countries fencing often increases the costs, maintenance requirements and makes watering the herds more difficult to an unreasonable extent. Additionally fences are removed by herdsman being considered an unjustified obstacle or simply trampled by thirsty herds during dry season. To provide a fence that lasts and resists animals at reduced costs, the planting of a live fence as displayed in Figure 10 may be

Figure 10: Lukoni live fence (Kisweramayinda)

preferable to a barbed wire fence (WAC 2005: 92). In the Nakasongola district, a drought-resistant plant called Lukoni has proven to be adequate as a live fence in combination with barbed wire.

Inflow area protection

Another issue is the protection of the direct inflow area. Excavated valley tanks like the ones constructed in the Nakasongola district receive their inflow from direct runoff from the catchment area. This area is naturally part of the livestock pasture and contaminates the inflow water with washed away dung. To reduce the inflowing contaminants, at least the direct inflow area should be restricted from animal access. Consequently the vegetation in this area serves as sponges, absorbing and filtering sediments and contaminants instead of adding to the contamination. The reduced nutrient inputs also reduce the suitability for cyanobacterial growth of a water body. (Zziwa 2009: 25f)

3.6.3 Minimizing Siltation

Siltation is a major problem of excavated reservoirs. Overgrazing, opening of waterways and grazing in riparian areas reduce vegetation and increase soil erosion. Loose soil and manure are carried into the reservoir by the runoff water. While manure affects the water quality, silt carried into the reservoir reduces its capacity (Zziwa 2009: 8). One major factor of siltation is the vegetation of the watershed. The findings of Peden et al. (2008: 13) in the Nakasongola district showed that an unvegetated watershed caused a 20 times higher sedimentation of a reservoir than a vegetated watershed.

Calculating soil erosion

The siltation rate of the valley tank is highly dependent on the soil erosion within the watershed area. The Revised Universal Soil Loss Equation (RUSLE; Renard et al. 1997) has been most widely used to predict soil erosion. Although it has been developed to model soil erosion in temperate climates, it has proven easier to adapt to tropical climates than other existing models (Angima et al. 2002: 296). The RUSLE is based on the Universal Soil Loss Equation (USLE; Wischmeier, Smith 1978), but builds on more databases. Originally these models were used to simulate small scale erosion on an individual property level, modelling only surface runoff erosion and not gully, wind or landslide erosion. The RUSLE uses empirical relationships and therefore is only valid within the range of the experimental conditions from which it has been derived. At a larger scale, it has its limitations due to the constraint of the number of samples in a complex environment. Data restrictions often make a quantitative assessment unreliable and thus results rather reflect a broad pattern of relative erosion. (Claessens et al. 2008: 399)

Remote sensing and geographical information system (GIS) techniques allow the spatial variation of soil erosion models and result in a better accuracy in larger areas. The combination of GIS and RUSLE allows simulating soil erosion loss on a cell by cell basis. (Lu et al. 2004: 500)

The RUSLE equation states the calculation of soil loss as follows (Renard et al. 1997):

$$A = R * K * LS * C * P$$

A average soil loss [$Mg*ha^{-1}$]

R rainfall erosivity factor [$MJ*mm*ha^{-1}*year^{-1}$]

K soil erodibility factor [$Mg*h*MJ^{-1}*mm^{-1}$]

LS topographical slope and length factor [m]

C crop management factor []

P erosion control factor []

Due to the limited fieldwork timeframe, it was not possible to take measures on the amount of siltation in the valley tank or to take samples of the sediment load of runoff water. Hence calibrating the RULSE was not possible. However, various authors (e.g. Mati, Veihe 2001: 151; Claessens et al. 2008: 405), who have used the RUSLE in East Africa, state the importance of calibration and verification of the model. To deal with this constraint, no absolute statements about soil erosion are made in the context of this research. Instead, the objective is to make relative comparisons about the risk of soil erosion in reference to soil type, topography and land use. This study aims at identifying the factor, whose variation over time or space has the most impact on soil erosion and consequently drawing conclusions about how to effectively reduce sedimentation and siltation.

Determining the soil erosion risk

The method to determine the soil erosion risk is to compare different land use (temporal and spatial variation) as well as different topography and soil types (spatial variation). This is particularly interesting, considering that the land use has changed significantly over the past decades due to intense stockbreeding and the production and export of charcoal. The National Forestry Authority (NFA 2005) states that the loss of forest area in the Nakasongola District from 1990 until 2005 equals 49 %.

Furthermore statements about the siting of new valley tanks when it comes to spatial variations in soil conditions and topography were drawn. To solve the impossibility of calibrating the RUSLE erosion model and thus the lack of absolute erosion results for the study area, the R and P factors were removed from the equation. Assuming that climatic conditions are the same throughout the whole study area and support practices don't exist, this reduces the RUSLE equation and allows determining the Soil Erodibility Risk (SER; Lu et al. 2004: 504). The SER does not represent absolute values, but rather permits a relative comparison of different sites / different periods of time.

$$SER = K * LS * C$$

*K – soil erodibility factor [Mg*h*MJ-1*mm-1]*

The K factor describes the soil loss during storm events due to soil properties. It can be estimated through corresponding nomographs or the following equation by Wischmeier and Smith (1978, adapted to obtain SI units Mg*h*MJ^{-1}*mm^{-1}):

$$K = 2{,}77 * 10^{-6} * M^{1{,}14} * (12 - OS) + 0{,}042 * (A - 2) + 0{,}033 * (4 - D)$$

M soil fraction (% silt + % very fine sand) * (100 - % clay)

OM percentage of organic matter

P permeability class

S structure class

For this study, simplified tables published by Mitchel and Bubenzer (1980) as cited by Drake et al. (1999: 14) and displayed in Table 3 were used, that calculate the K factor based on soil structure (M) and organic matter (OM).

Table 3: The relationship between soil texture, organic matter and soil erodibility (Source: Mitchel and Bubenzer 1980)

Texture Class	0.875 < %OM	0.875 – 1.625	1.625 – 2.5	2.5 – 3.5	%OM > 3.5
Sand	0.05	0.04	0.03	0.025	0.02
Loamy Sand	0.12	0.11	0.1	0.09	0.08
Sandy Loam	0.27	0.255	0.24	0.215	0.19
Loam	0.38	0.36	0.34	0.31	0.29
Silt Loam	0.48	0.45	0.42	0.375	0.33
Silt	0.6	0.56	0.52	0.47	0.42
Sandy Clay Loam	0.27	0.26	0.25	0.23	0.21
Clay Loam	0.28	0.265	0.25	0.23	0.21
Sandy Clay	0.14	0.135	0.13	0.125	0.12
Silty Clay	0.25	0.24	0.23	0.21	0.19
Clay	0.13	0.17	0.21	0.25	0.29

A set of samples of the surface soil (top 5 cm) were taken in the watershed of the Wanzogi valley tank and another two samples in the watershed of every one of five other valley tanks in the region. These samples were analysed at the Makerere University and BOKU laboratories by standard methods.

Organic matter was determined at the Makerere laboratories in Kampala according to Okalebo et al. (2002). The method used was oxidation with potassium dichromate ($K_2Cr_2O_7$) and sulphuric acid and then titration against ferrous ammonium sulphate using ferroin ($[C_{12}H_8N_2]_3FeSO_4$) as indicator solution. Soil structure was determined at the BOKU laboratories in Vienna according to ÖNORM L1061. The soil was disaggregated using $Na_4P_2O_7$ and then analysed with the pipette method according to the settling velocity of the different grain sizes.

The K value for each sample plot was calculated and then interpolated and extrapolated with ArcGIS for the whole watershed. The interpolation method used was the standard Kriging in ArcGIS 10.2.

LS – topographical slope and length factor [m]

L represents the length of the slope and S the slope steepness. The LS factor was calculated from the digital elevation model (DEM) based on the formula stated by Moore and Burch (1986) as quoted by Parveen and Kumar (2012: 590).

$$LS = (\frac{A}{22.13})^{0.6} * (\frac{\sin(s)}{0.0896})^{1.3}$$

A upslope contributing factor [m]

S slope [deg]

The upslope contributing factor and slope were determined by using the ArcGIS Spatial Analyst tools "*Flow Accumulation*" and "*Slope*". The result is a raster map of LS values for the whole area.

C – crop management factor []

The C factor varies over time with the change of land use. It represents the soil erosion due to land use (pasture, agriculture etc.) and the effects of a vegetation canopy. Usually it is calculated though empirical equations considering many variables related to ground cover. According to Lu et al. (2004: 507) this is very time-consuming and computer intensive. Instead, the authors suggest the technique of remotely sensed data using Landsat images, assuming that the same land cover classes have the same C value. Using satellite images of the same watershed but during different decades, this method is appropriate for the purpose of this study as it perfectly displays the change of land use over time. The most widely used method of deriving the C value from remote sensing images is the Normalized Difference Vegetation Index (NVDI). The NVDI allows delineating the distribution of vegetation and bare soil according to their reflectance patterns (Karaburun 2010: 78) and thus measuring the amount of green vegetation. The formula to calculate the NVDI can be expressed as (ibid: 79):

$$NVDI = \frac{NIR - RED}{NIR + RED}$$

NIR Reflection of the near infrared portion of the magnetic spectrum

R Reflection of the visible red spectrum

NVDI values range from -1 to +1 with high values indicating abundant vegetation and 0 representing bare soils. Water bodies are represented by negative values. The NVDI has been widely used in remote sensing studies, providing useful information on basis of relatively easy accessible data. (ibid: 78)

Landsat data with a resolution of 30 m was used to generate the NDVI images. Landsat images are available from the U.S. Geological Survey (USGS) for the timeframe from 1984 until the present, with a selection of freely downloadable and processed images for many of those years. While Landsat 7 only provides suitable data from 1999 – 2003 due to technical problems afterwards, Landsat 5 offers reliable images from 1984 until it was abandoned early 2013, and since May 2013 Landsat 8 has replaced its predecessors. All images provide the necessary bands RED and NIR. Most cloudless images are available for the long dry season, especially January – March of each year. Unfortunately these images cannot be used as the condition of the vegetation varies highly depending on the date of the last rainfall at the end of each year. This can be mid-October for some years or mid-December for others and this variation makes images of different years incomparable. The rainy seasons are generally inadequate due to high cloud covers and this leaves only the short dry season for the analysis of the C factor. Hence, July was determined to be the best time for this research. As May always receives rains and the short dry season is not as hot and dry, images for different years are comparable for their vegetation index.

The freely accessible database of USGS is limited, especially when it comes to cloud-free images, and thus the years 1985 and 2013 were selected, providing the best scenes. To assure that some minor clouds in the images don’t affect the results, these clouds were eliminated using the ArcGIS Spatial Analyst and interpolating the RED and NIR values from the corresponding neighbours. These corrections amount to about 15 % of the Wanzogi catchment for 1985 and about 5 % for 2013. However, due to the nature of neighbour interpolation, the impact on the resulting NVDI maps is negligible.

After producing the NVDI images, the results need to be recalculated to provide C factors for the study area. This was done by the following formula cited by Parveen and Kumar (2012: 591):

$$C = e^{-2*\frac{NVDI}{1-NVDI}}$$

The authors suggest that this relationship delivers better results than a linear scaling approach. To make sure the C factor stays within its boundaries of 0 and 1, 0 was assigned to lower values and 1 to higher values.

Figure 11: NVDI image processing flow chart (adapted from Agone and Bhamare 2012: 4)

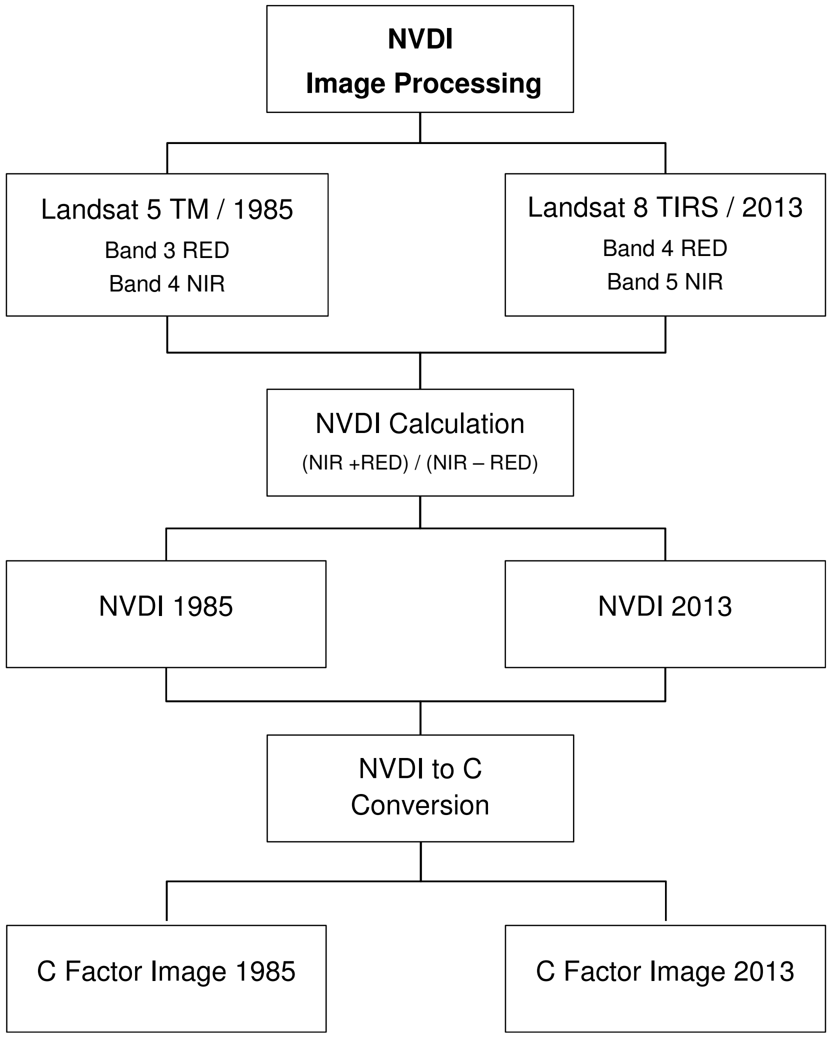


Figure 11 displays the work flow of NVDI image processing. Additionally a supervised classification was performed for 2013 to confirm the reliability of the NVDI calculation. Classification was done with the World Imagery provided by ArcGIS 10; the corresponding classes are listed in Table 4. Once the training samples taken from the images were transformed into polygons representing the classes, a maximum likelihood classifier was used to transform the Landsat image into land use classes. During fieldwork additional training samples of these classes were recorded with GPS and used as training samples for the classification. For each class at least 10 GPS records were taken in the field, with the exception of forest. Due to the severe forest degradation it was basically impossible to locate enough sites that can still be considered as forest. The relation of NDI values and the corresponding classes is published by Agone and Bhamare (2012: 6).

Table 4: Land use classification (adapted from Agone and Bhamare 2012: 6)

Class	GPS training samples	NVDI range
Bare Land	–	0.00 – 0.20
Agricultural land	10	0.10 – 0.30
Pasture	10+	0.20 – 0.46
Scrub / Bushes	10	0.20 – 0.46
Forest	3	0.46 – 1.00
Water body	–	-1.00 – 0.00

The supervised classification was not used to determine the C factor directly (but only to confirm the NVDI results), as the quality of determination of this factor is highly sensitive to the classification accuracy and the estimation of a suitable C factor for each class. Furthermore classification was only possible for 2013 as neither GPS training samples nor remote sensing images in adequate resolutions are available for 1985.

Once the GIS layers for K, LS and C factor were developed, they were used to generate SER maps. Comparing the SER maps on a spatial scale (for different catchments in the area) allowed drawing conclusions about the impact of soil condition and topography on the risk of soil erosion, the same way comparing SER maps on a temporal scale (for different decades at the Wanzogi watershed) allowed drawing conclusions about the impact of the change of land use. Combining these results indicates which factor has the highest influence on the soil erosion risk and how erosion and consequently reservoir sedimentation can be reduced.

3.6.4 Banks

Bank slope

The literature suggests that the steepness of the bank slopes should be from 2/1 to 3/1 when the valley tank is equipped with external water troughs. Steeper slopes are prone to erosion. If the animals access the water directly, the slopes must be flatter to provide easy access. (Pallas 1986; Liddicoat et al. 2011: 33)

Riparian vegetation

To protect the valley tank banks from erosion, they should be established with drought-proof grasses (Liddicoat et al. 2011: 33). Resistance to drought is of particular importance since the first runoff events after dry season hit completely dry vegetation and wash away weak plants.

3.6.5 Watering facilities

The main feature of watering facilities is to make the water available for the animals without permitting direct access to the water source. It is essential that the infrastructure suits the habits and preferences of the human users as well as their capacity to maintain the mechanical devices (Pallas 1986). There are still many water sources in the Nakasongola district that aren't equipped with any water delivery infrastructure, allowing the cattle to drink directly from the water body.

Trough

The use of properly built troughs is advisable according to Pallas (1986) in order for the livestock to drink easily and avoid crowding the place. He further suggests that concrete troughs – if properly constructed – are the most satisfactory for permanent use. Recommended sizes are: 0.7 to 1 m of drinking space for each head of cattle, 0.5 m of height for calves to reach the water, and a top width of at least 0.7 m to ensure use from both sides.

Different types of troughs found in the Nakasongola district are:

Traditional troughs

Traditional troughs are made of soil and have a diameter of about 1 meter. They are constructed at the beginning of the dry season directly at the water body and sealed by smearing so-called "royal soil" from anthills on the surface of the trough every day before watering the animals. The water is scooped into the trough by jerry cans.

Portable troughs

These troughs include any sort of simple troughs that can be moved from one place to another. This allows changing the access point for the herds when the water level of the valley tank becomes lower. Portable troughs are usually placed directly at the water body and filled with jerry cans if they don't have any pump and piping system. Portable troughs are e.g. carved out trunks, barrels or bath tubs.

Concrete troughs

Some valley tanks have concrete troughs to water the animals. Concrete troughs are usually much bigger than the above mentioned and thus serve more animals at a time. Due to their capacity they almost always require a pump to fill them with water. Concrete troughs are placed at a certain distance to the water body.

Pump

The pump is particularly sensitive when it comes to operation and maintenance. Fuel – if needed – must be accessible and affordable. In case of breakdown a mechanic needs to be available and access to spare parts has to be possible. Pumps can be classified as mobile or stationary. Mobile pumps are stored away every day after watering the animals. Stationary pumps are installed on-site and need to be protected from stealing and vandalism. Different types of pumps used in the Nakasongola district include:

- Hand pumps
- Treadle pumps
- Fuel pumps

3.7 Operation and Maintenance

Operation and maintenance (O&M) of the Wanzogi valley tank were examined on-site and compared to the suggestions from the literature as well as to five other valley tanks in the Nakasongola district. The following aspects were considered:

3.7.1 Management structures and responsibilities

Until the 1980s it was considered that a single authority is the best solution for managing a system including rangeland and water supply. Unfortunately the results have shown to be disappointing and have led livestock development planners to use informal and formal groups of livestock owners, cooperatives, associations and political authorities as a channel for developing activities. This includes financing, maintenance and management and involves the communities more directly into the development process. (Pallas 1986)

According to WAC (2005: 13f) it is important to understand the existing management structures in order to implement a successful water project. Having analysed the existing structures and determined the local responsibilities, it is possible to agree with the community on the most appropriate structure of the project. The responsibilities of the management structures include (ibid. 13f):

- O&M of the valley tank
- charging for services to finance O&M
- supervising staff that works on the valley tank
- organizing meetings and elections of the responsible committees,
- implementing decisions discussed in the meetings
- equitable distribution of the water
- engaging community members

It becomes evident that clearly defined management structures and responsibilities are essential for a working project. The responsible committees need to be accepted by the local community, and structures ensuring that every party involved meets its duties have to be put in place. From the institutional side, there are guidelines concerning the committees managing public resources. According to the District Engineer, until this year, these committees were elected for an unlimited period of time but the past has shown that the structures tend to slacken if people are not subject to frequent elections. Thus, there is currently a process going on at the district council that will limit the term of such committees to 2.5 years and that demands frequent re-elections.

Most (communal) valley tanks in the Nakasongola district have their management structures in place. However, the efficiency of these structures varies greatly. During the time of the fieldwork, the existing structures of six valley tanks were examined in order to make statements about what works and what doesn't and how to improve management at the Wanzogi valley tank. The structures at the Wanzogi valley tank were analysed with particular rigor by interviewing leaders of all the parties involved in O&M as well as making representatives of the community draw their view of the management structures during a workshop meeting. This allowed a deep insight into existing structures as well as into perceptions that parts of the community have.

3.7.2 Maintenance

Maintenance of the valley tank and the corresponding infrastructure is organized by the parties identified as described above. There are different parts of the infrastructure at the Wanzogi valley tank that need to be maintained in order to ensure the operability of the system.

Fence maintenance

When fenced, a pond needs permanent maintenance to ensure the integrity of the fence during the watering period. The fence is one of the most sensitive issues at the valley tank as it protects the water source from contamination, but often the community lacks awareness of its importance. The main issue is that a ruinous fence does not affect the usability of the valley tank visually; the impacts of contamination will be creeping and unseen at the beginning. (Pallas 1986)

The fence must be stable enough to keep livestock from accessing the valley tank directly and the livestock must be kept from slowly wearing out the fence. Especially a young live fence needs to be protected from livestock eating the young plants and thus hindering its growth.

Pump maintenance

The pump is an essential part of the water delivery infrastructure as there will be no means to get the water into the trough when the pump is not working. Pump maintenance includes making sure that all the supplies needed for operation are at hand and, in case of defect, that a capable mechanic is available.

Trough maintenance

Zziwa (2009: 27) states that frequent trough cleaning offers cleaner water for livestock. Recently cleaned troughs are likely to contain fewer bacteria until they are contaminated from an external source again.

Furthermore, regular maintenance will ensure that the trough is not leaking. While wooden troughs deteriorate quicker, concrete troughs tend to crack due to temperature changes. Traditional troughs can only be used when maintained at a daily basis.

General maintenance

This includes removing the wind or water transported material which reduces the valley tank’s capacity. Desiltation should be done every 4 to 5 years (Pallas 1986), depending on the sediment inflow.

Financial contribution

Financial contribution by the water users is important to finance maintenance. Particularly when a fuel pump is involved, operative costs need to be considered and shared among the beneficiaries of the water resource. Structures for cost recovery and managing of funds must be carefully designed and put in place. (WAC 2005: 13)

3.7.3 Water access

There must be structures in place that regulate the access of cattle to the trough. This comprises the amount of cattle accessing the trough at once, the order of herds accessing the trough and the organization of those having to wait for access. For the latter, resting and grazing areas close to the water source are essential.

3.7.4 Domestic water use

Domestic water use is always an issue when it comes to managing water resources in the Nakasongola district. Although domestic water is mainly fetched from boreholes since they provide better water quality, many locals still fetch water directly from a pond or valley tank. The main reason for this is that for some people it takes significantly longer to reach a borehole. The domestic water fetched from ponds and valley tanks is primarily used for sanitary matters, but some do also use it for drinking and cooking – despite the poor quality and the associated dangers.

This causes several issues. (1) Water for domestic use is most of the times fetched directly from the valley tank by using jerry cans. This causes contamination and can also lead to dangerous situations. Various men have stated their concern of their women or children falling into the valley tank when trying to fetch water. (2) The water demand at the valley tank increases by domestic consumption, which might lead to exhaustion of the reservoir earlier than anticipated. The alternative resources – boreholes – usually never run dry. (3) During fieldwork it was observed that the locals sometimes do their laundry and other cleaning work directly at a valley tank. That causes additional contamination.

It becomes evident that domestic water use needs to be considered in the planning and managed properly during the use of the valley tank. There are different methods to deal with this issue, as the results of this analysis have shown. In Wanzogi, the livestock valley tank is not being used for domestic purposes since a smaller domestic valley tank is situated right next to it.

3.8 Comparative evaluation

To identify design and management practices that lead to satisfactory results, a comparative analysis of different valley tanks in the Nakasongola district was carried out. For this purpose the valley tanks in Table 5 were selected. The selection of these valley tanks was purposeful, making sure that some seemingly well managed sites (Kisweramayinda, Kainamura) as well as some questionable water sources (Kalungi, Nakasenyi, Nakasongola) were part of the sampling. Consequently the results of this investigation were used to compare and evaluate the valley tanks. The most meaningful indicator of the comparative analysis is the water quality. Further evaluation has been done in regards to water quantity, siting and O&M.

Table 5: Valley tanks selected for the comparative analysis

Name	Sub-county	Ownership	Construction type	Abbreviation
Wanzogi	Kalungi	Communal	Excavated reservoir	WAN
Kalungi	Kalungi	Private	Excavated reservoir	KAL
Kisweramayinda	Kalongo	Communal	Excavated reservoir	KIS
Nakasenyi	Kalongo	Communal	Excavated reservoir	NSY
Kainamura	Kalungi	Private	Excavated reservoir	KAI
Nakasongola	Nakasongola	Communal	Earth dam	NAK

3.8.1 Water quality

Water quality guidelines for livestock

Table 6: Guideline for water quality (adapted from Bagley et al. 1997, Higgins et al. 2008, Peterson 1999)

<table>
<tr><th>Comment</th><th>pH</th><th>TDS [mg/l]</th><th>Nitrate [mg/l]</th><th>Sulphate [mg/l]</th><th>Faecal Coliforms [CFU/ml]</th></tr>
<tr><td>Safe for consumption</td><td rowspan="2">5 – 9</td><td>< 1.000</td><td>0 – 44</td><td rowspan="2">< 1000</td><td rowspan="2">< 10</td></tr>
<tr><td>Typically safe</td><td>1.000 – 2.999</td><td>45 – 132</td></tr>
<tr><td>Potentially harmful</td><td rowspan="3">–</td><td>3.000 – 6.999</td><td>133 – 220</td><td rowspan="3">> 1000</td><td rowspan="3">> 10</td></tr>
<tr><td>Will result in health problems</td><td>7.000 – 10.000</td><td>221 – 660</td></tr>
<tr><td>Unsafe to drink</td><td>> 10.000</td><td>> 660</td></tr>
</table>

Animal growth and production can diminish when animals consume water containing high levels of contaminants. Cattle may fall sick or drink less which leads to increased heat stress. Quality parameters of water that affect livestock include physiochemical parameters (pH, TDS), nutrients (nitrate, sulphate) and microbiological agents (faecal coliforms) (Higgins et al. 2008: 1). Suggestions from the literature are summarized in Table 6.

Water samples were collected several times during the fieldwork. Some of the parameters could be tested on-site using field equipment, but for some of the tests transporting water samples to the Makerere University laboratories was necessary. For the latter, sample bottles were provided by the laboratory and cooled with ice-packs during transport. The laboratory tests were performed within 24 hours according to methods published by the American Public Health Association (APHA 1992).

Tested parameters

pH

Determination of pH should be made in situ. There are three different methods of measuring pH: indicator paper, liquid colorimetric indicators and electronic meters (WHO 1996: 95). The latter one has proven to be the most accurate. For this study a Cyberscan PC 300 multimeter by EUTECH Instruments was used.

Total dissolved solids (TDS)

The substances remaining after evaporation of a water samples are called residues. Out of these residues the filterable ones are called total dissolved solids (WHO 1996: 191). TDS was measured using the same multimeter as for pH.

Turbidity

Turbidity affects the acceptability of water to consumers and is measured in NTU (Nephelometric Turbidity Units). On-site measurements can be taken using electronic meters (WHO 1997: 68). However, no such device was available for this study and thus the samples were brought to the University laboratories and determined spectrophotometrically with a Helios Aquamate spectrophotometer using suitably diluted samples against a distilled water blank.

Faecal coliforms

The principal health risk associated with drinking water is faecal matter, in particular *Escherichia coli* which usually accounts for more than 95 % of the faecal contamination (WHO 1996: 230). Analysing the hygienic quality of a water source requires the insulation and enumeration of organisms that indicate faecal contamination (WHO 1997: 56). For this study the determination of faecal coliforms is essential, as it indicates direct access of cattle to the valley tank or to the inflow area. Faecal coliform contamination was determined using a membrane filtration method. Serially diluted samples were filtered through 47 mm mixed cellulose ester membrane disc filters of 0.45 µm pore size and then incubated at 37°C for 48 hours on Chromocult TBX agar as growth medium. The colonies with dark blue to pink colours were then counted as faecal coliforms.

Total bacteria and total alive bacteria

Another method to make statements about the microbiological condition of water is the total bacteria count. Having access to a flow cytometer, this represented a quick and easy method to analyse water samples for this study. A flow cytometer is laser based and counts living and dead cells in water samples (Kötzsch et al. 2012: 5ff).

Nitrate

Nitrates are commonly present in surface and ground waters being the decomposition of organic matter. The determination of nitrates helps to assess the degree of oxidation in surface waters. High concentrations of nitrates might support algae growth and thus have secondary effects on the water quality (WHO 1996: 166). Nitrate concentration was determined using Nitraver 5 powder pillows. To 10 ml of sample, the content of one sachet of Nitraver powder pillows was added and then mixed for one minute. After allowing the solution to stand for 5 minutes, the concentration of Nitrates was read using a Helios Aquamate spectrophotometer against a sample blank.

Sulphate

Sulphate results from the breakdown of organic compounds. It is determined by the titrimetric method a maximum of seven days after taking the sample (WHO 1996: 187). To the sample a buffer, Sodium acetate, glacial acetic acid and KNO_3 were added and mixed with a magnetic stirrer. Sulphates were measured in a spectrophotometer at 420 nm using a 5 cm path length cuvette.

3.8.2 Management and design

Siting

Siting was evaluated on the basis of the soil erosion potential of the catchment area (see chapter 3.6.3) including the spatial distribution of soil erodibility, slopes and vegetation cover of the watersheds.

O&M

O&M practices as described in chapters 3.6 and 3.7 were compared between the sampled reservoirs and their adequacy evaluated.

Water quantity

The dimensions of the valley tanks and the watersheds were determined. This allows drawing conclusions about the adequacy of the size of each of these water sources. An in-depth analysis of the water balances of the additional valley tanks could give further insight, but due to the limited fieldwork time, this was not possible.

4 Results and analysis

4.1 Water balance

4.1.1 Valley tank capacity

The measurements of the valley tank are 62 m length, 23 m width and an average depth of 2.5 m (ranging from 1.77 m at the most shallow point in the centre to 2.88 m). The slopes are 2:3 and the total capacity of the valley tank when full with water is about 3175 m^3.

4.1.2 Water demand

Number of livestock

Quantitative interviews in Kanyonyi village have shown that 97 % of the cattle farmers use the Wanzogi valley tank. The remaining 3 % are omitted for this calculation since it is assumed that all homes owning livestock do use the Wanzogi valley tank at some point during dry season.

<u>Estimation using the number of livestock owning homes</u>

The list of main users of the valley tank during the past dry season (29 farmers owning a total of around 830 head of cattle) shows that 24 % of these farmers were from outside Kanyonyi and Wanzogi villages. Taking that number, this study assumes that apart from Kanyonyi and Wanzogi, the inhabitants of one more village water their cattle at the Wanzogi valley tank. That probably slightly overestimates the total number, ensuring that the calculated water demand is rather too high than too low.

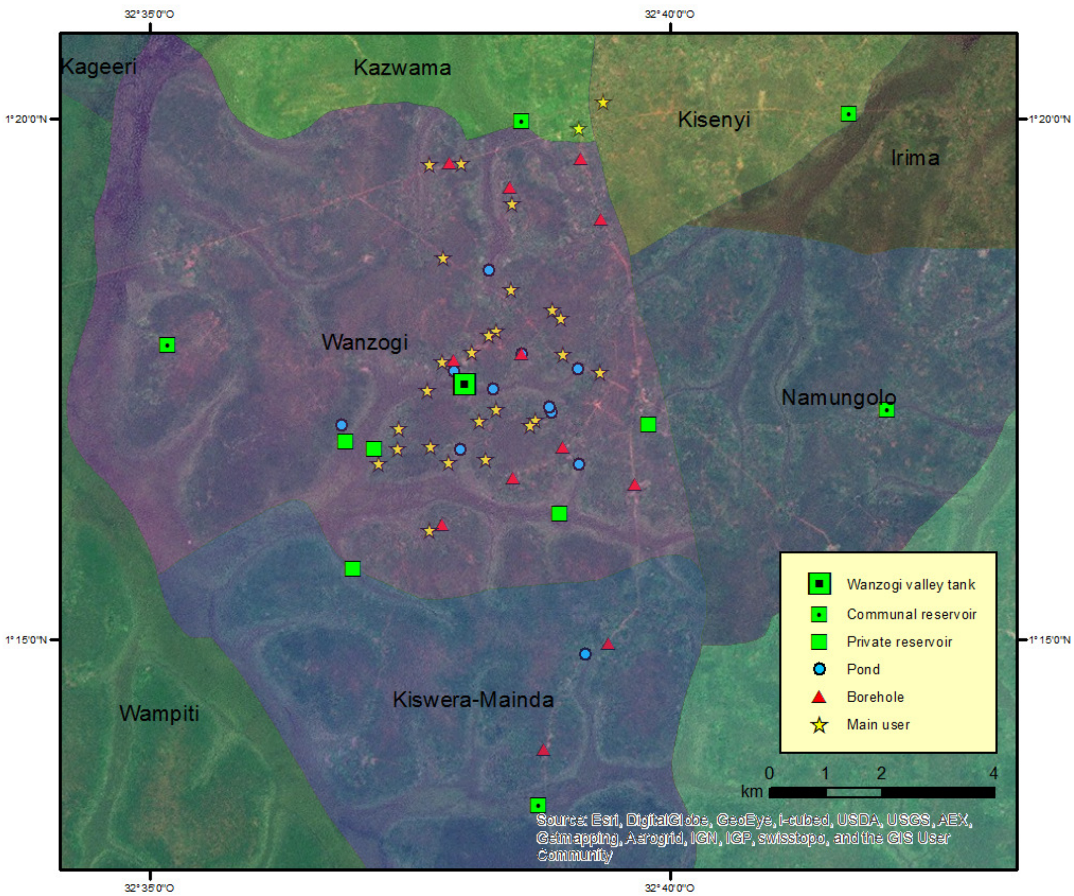
According to a population census performed by the local chairman, in 2012 Kanyonyi village had a total of 906 inhabitants. This makes Kanyonyi the village with the biggest population density in the parish, understandably, since most parts of the village are situated in an elevated position that provides protection from rainy season flooding of the lower areas. The average household size of 6.7 persons in the district (UBOS 2009: 113) was used to calculate the number of homes in the parish (which had a population of 3872 in 2012 according to the District Council) totalling 578. Consequently the number of homes in the three villages of the cattle catchment area is an estimated 283, considering that Kanyonyi village has the largest share of homes.

Using data from the National Livestock Census (UBOS 2009), which states that in Nakasongola district, 46.7 % of the homes own cattle and the average herd size is 7.8 head of cattle, this yields a result of **1030 head of cattle** for the catchment area of the Wanzogi valley tank.

Quantitative interviews performed in Kanyonyi indicate that 64 % of the households own cattle at an average herd size of 7.02. Using these numbers in the calculation results in **1275 head of cattle**. This second number is likely to be more accurate, as district data on homes owning livestock also includes the town population, while the quantitative interviews focus directly on the target group.

<u>Estimation using the distance to the surrounding communal valley tanks</u>

Figure 12: Political map displaying the Wanzogi valley tank and surrounding infrastructure



Source of the parish borders: GADM (2013)

The map (Figure 12) shows that the nearest community valley tanks are at a distance of 5 km to the west and north and 7.5 km to the south and east. Assuming that livestock farmers go to the nearest source of water, this defines the cattle catchment area as covering about 31.9 km². Using the cattle population density of 47.5 head of cattle per km² in the Nakasongola district (UBOS 2009: 128) leads to a total of **1515 head of cattle** watering at the Wanzogi valley tank.

Estimation using the location of the main users' farms

The map (Figure 12) shows the location of the main users. These are roughly located in an area the size of about 8 x 4 km. Applying the livestock density for Nakasongola district to this area gives a total of **1520 head of cattle**.

Estimation using the local livestock census

In addition to the shortcomings of the local livestock census described in chapter 3.5.2, it was noted that some of the herd numbers stated do not correspond to what was verified by observation. The number concluded by the census is **1965 head of cattle**.

Further considerations

The calculated numbers of cattle are mere estimations. If any of the other valley tanks in the area runs out of water before the Wanzogi valley tank, this will yield to an increased demand at Wanzogi. Locals have stated that in very dry years towards the end of dry season as many as 10,000 heads of cattle are watering at the valley tank per day. Yet this high number seems exaggerated considering the logistic problems that come with it and the limited amount of water stored in the valley tank. However, any high number of cattle coming from far distances will cause the valley tank to run dry before the beginning of rainy season. For the calculation of the water balance, this research considers the regular users of the valley tank living in the cattle catchment area and evaluates if the amount of water provided is enough to cover their demand. Restricting others from accessing the water to ensure the regular users will make it through dry season is a matter of reservoir management.

Table 7: Number of livestock estimation results

Method of estimation	Estimated number	Remarks
Number of homes / district data	1030	District data inadequate?
Number of homes / locally inquired data	1275	–
Distance of neighbouring communal valley tanks	1515	–
Location of the main users	1520	–
Local livestock census	1965	Corrupted

Table 7 indicates that the district data for the percentage of households owning cattle probably does not apply well to the situation at the Wanzogi valley tank (as inhabitants of the towns are included in those numbers and might distort the results). For this reason the first number is discarded. From the above mentioned it seems to be adequate to use **1500 head of cattle** for the calculation of the water balance.

Water consumption per head of cattle

Observation in the beginning of July has shown that the average voluntary water intake per head of cattle is about 15 l per day. This number corresponds to the early part of dry season when the animals hardly find any other water sources during grazing, but the dry matter intake still contains a considerable amount of water. For this reason the voluntary water intake is lower than the actual water intake.

The water demand in relation to the dry matter intake and air temperature was calculated as stated in chapter 3.5.2 according to Pallas (1986), Mulindwa et al. (2009) and Kassam et al. (1993). It is summarised in Table 8.

Table 8: Daily water intake of livestock

	Carcass weight	**Dry matter intake**	**Water intake >27℃**	**Water intake <27℃**
	[kg]	[kg/day]	[l/day]	[l/day]
Cattle in herd	180	4.50	24.75	20.25
Bull	375	9.38	51.56	42.19
Milking cow	250	6.25	37.68	31.43
Dry cow	250	6.25	34.38	28.13
Heifers	125	3.2	17.19	14.06
Calves	62.5	1.56	8.59	7.03

The calculated numbers correspond with the information obtained from the locals, stating that during the peak of dry season a cow needs per day up to 40 litres and particularly big bulls up to 60 litres.

Estimation of water demand

As dry season progresses, more and more animals will come to the valley tank to take water from there. To determine the shape of the curve of the number of cattle going to the water source, animals were counted at different stages of the dry season of mid-year 2013. It was concluded that no cattle are watering at the source during the first month of dry season, since there is still abundant water available in the swamps surrounding the valley tank. From the second month onwards cattle keepers still use their private water sources such as ponds, but eventually start coming to the communal valley tank. The number of cattle increases as dry season progresses. From the dry months of June – August 2013 the following equation for the number of cattle watering at the source at different points of time was derived:

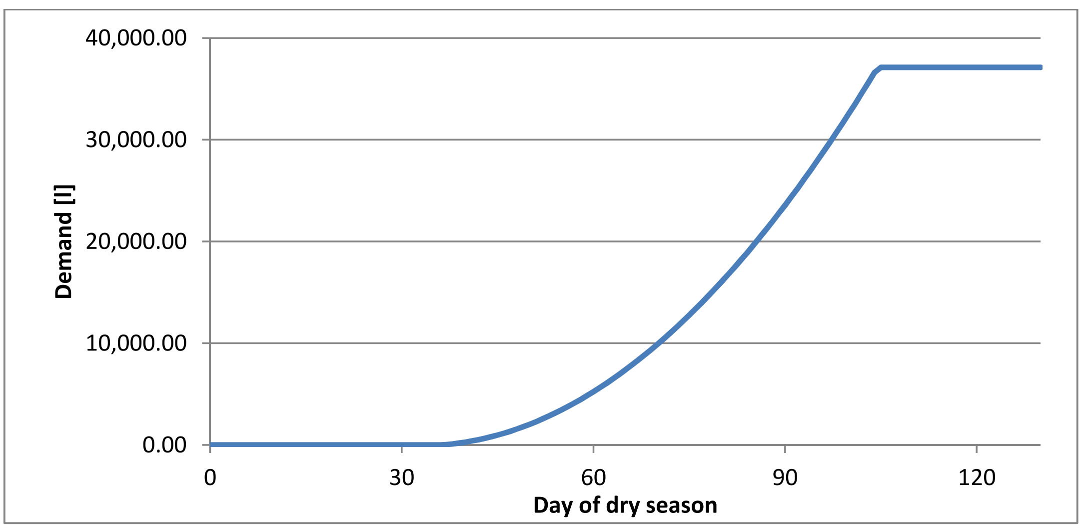
$$N = 0.294T^2 - 1.765T$$

N number of animals watering at the trough

T day, starting at day 31 after the last runoff event

Figure 13 displays the amount of water consumed per day based on the above calculated water intake per day and animal and the calculated number of cattle watering at the valley tank. The upper limit is the maximum number of 1500 head of cattle.

Figure 13: Simplified water demand per day

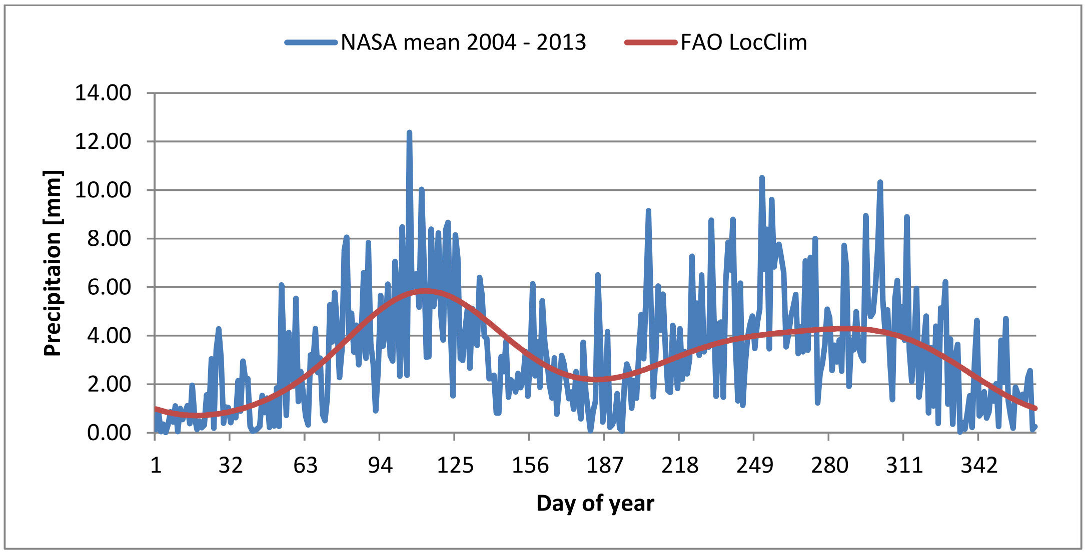


4.1.3 Catchment yield

Precipitation

Comparing the mean FAO precipitation dataset and the NASA (average 2004 – 2013) data leads to the result displayed in Figure 14. The correlation of these two datasets is 0.91 and the absolute deviation as low as 15.71 mm/year. This proves that NASA daily data derived from remote sensing is reliable and may be used to calculate surface runoff. The mean precipitation for 2004 – 2012 was 1177 mm / year. Figure 14 also displays the rainy seasons lasting from March to May and August to November each year. The long dry season is at the beginning of each year and the short dry season around mid-year. Rain reaches the highest peaks during the first rainy season (57 mm), while the second rainy season brings more water altogether.

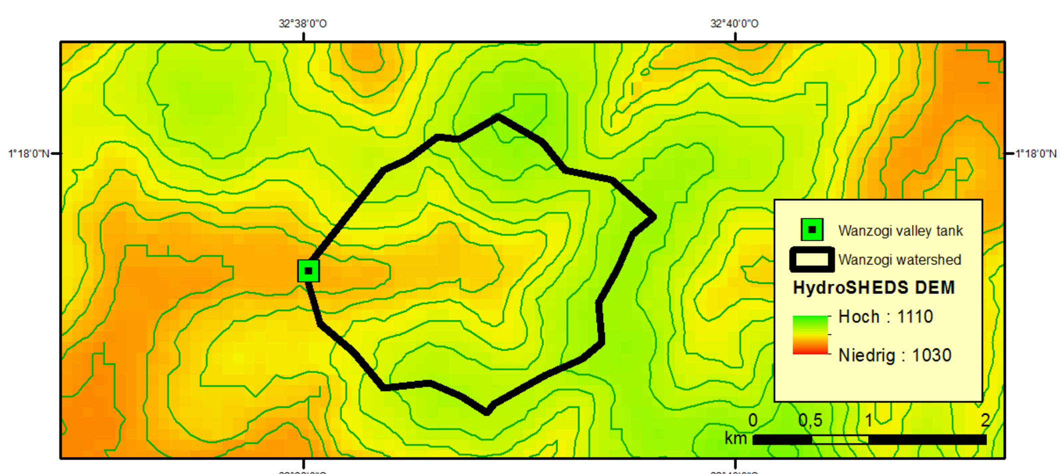
Figure 14: Precipitation data for Wanzogi



Determination of the watershed

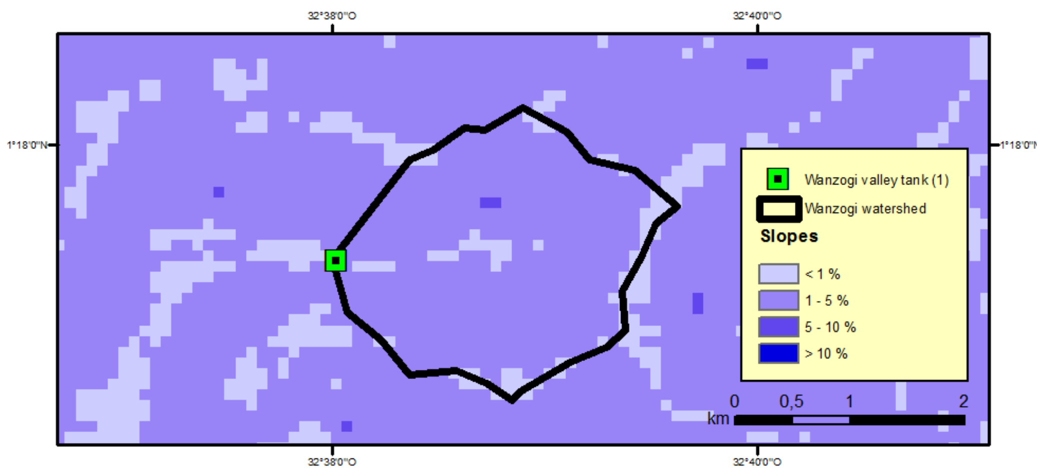
The HydroSHEDS DEM allowed calculating the size of the Wanzogi watershed, which was determined to equal 4.127 m². The watershed is displayed in Figure 15.

Figure 15: DEM of the Wanzogi watershed



Surface soil in this catchment area is loam towards the south east and in the inflow area and clay in the rest of the catchment. According to the Soil Atlas of East Africa (Jones et al. 2013) the soil is classified as haplic ferralsol. Over 90 % of the area has slopes between 1 % and 5 % and the remainders are flat (see Figure 16). The pasture condition has been classified as poor according to Ritzema (1994: 125). Ritzema (ibid: 128f) also defines the antecedent moisture class of the soil used in this study, depending on the 5-day antecedent rainfall.

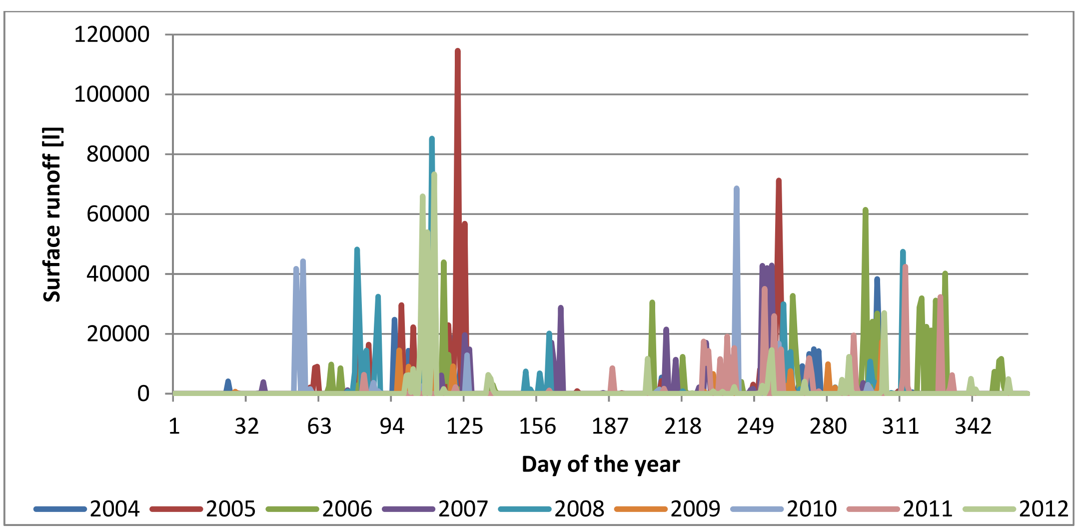
Figure 16: Slopes of the Wanzogi watershed



Surface runoff

The result of calculating the surface runoff with the SCS curve number method is shown in Figure 17:

Figure 17: Seasonality of surface runoff



The seasonal changes in runoff are evident, and as the farmers stated, the long dry season at the beginning of each year is the biggest challenge for watering livestock. For all years observed, this dry season was longer than the one around mid-year. Due to the impossibility of calibrating the model, the absolute runoff numbers are likely to be exaggerated. Onyando and Sharma (1995: 374) have shown that not calibrating an SCS/CN model in similar conditions in Kenya led to a runoff overestimation by a factor 10. Considering the volume of the valley tank, even this overestimation suggests, that the area is frequently flooded during the rainy seasons. This fact was confirmed by the locals.

Due to the unreliable runoff totals, it is not possible, to make absolute statements about the amount of water draining into the valley tank. However, these values allow estimating the length of the dry season and thus the needed amount of water in order to avoid the tank running dry before the beginning of the rains. A closer look at the long dry season of the years 2004 – 2012 is presented in Table 9.

Table 9: Length of dry seasons 2004 – 2013

	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13
Start	26.11.	18.10.	22.12.	23.10.	08.11.	31.10.	26.10.	30.11.	23.12.
End	05.04.	28.02.	08.03.	08.02.	19.03.	07.04.	22.02.	22.03.	10.04.
Days	129	133	76	108	130	158	119	113	107

For the estimation of the length of the dry season, only calculated runoff events of more than 1000 m^3 were considered. There are little rains sometimes even during dry season, but these don't lead to significant runoff events. Taking into account that 2009 was an exceptionally dry year (with many cattle dying), the valley tank should provide water for about **130 days**. That equals just over four months and is sufficient to cover the water demand during long dry periods.

4.1.4 Evaporation

Data base

Both datasets, NASA and FAO, have restrictions and thus need to be examined and validated.

NASA dataset

NASA provides all necessary climatic datasets on their homepage. Data is available from 1983 till present, with changes of the procedure of data collection in 2008 and 2012. Data from between those two years differ significantly from data before and after. Since the latest data for 2013 follow the same curve shape and magnitude as data from before 2008, it was decided to omit 2008 to 2012 and use a data series from 2000 until 2007 (see Table 10). NASA data is available on a daily basis and provides all necessary parameters for calculating E_p with the Penman equation.

Table 10: Comparison of NASA data series

Data series	Correlation	Difference Ep
2013 & 2000 – 2007	0.95	19.47 mm/year
2013 & 2008 – 2012	0.78	452.71 mm/year

FAO dataset

The FAO uses the database of its own Agrometeorological Group. Meteorological and solar data is collected from meteorological stations all around the world and can be interpolated for any location using the New_LocClim application. The FAO provides several different meteorological parameters as well as readily calculated E_p.

The principal difference between the two datasets is that NASA data is satellite based and provides solar and meteorological data where surface measurements are sparse. On the contrary, FAO data is based on readings from meteorological stations. Consequently the error depends on model inaccuracy for NASA data and interpolation errors for FAO data. A problem with interpolation arises, when looking at the weather stations surrounding Wanzogi. Only two of them, Soroti and Lira, are situated in a similar climatic region. The station at Namulonge (as well as others nearby) is situated close to the shores of Lake Victoria and therefore significantly influenced by the lake climate; Mubende is at a much higher altitude and Masindi is already beyond the cattle corridor to the northwest. The meteorological stations surrounding Wanzogi are displayed in Table 11.

Table 11: Meteorological stations surrounding Wanzogi

Weather station	Distance to Wanzogi	Direction
Namulonge	85 km	South
Masindi	110 km	Northwest
Mubende	160 km	Southwest
Lira	110 km	Northeast
Soroti	120 km	East

Data adjustments

Calculating the correlation coefficient for the Wanzogi weather data in relation to the weather data at the meteorological stations displays evidence for the above stated problem. For FAO data the New_LocClim standard interpolation method was used, the results are displayed in Table 12 and Table 13.

Table 12: Correlation of NASA data at Wanzogi and the surrounding weather stations

Station	Min Temp.	Max Temp.	Humidity	Wind	Radiation	Ep
Namulonge	0.76	0.95	0.88	0.86	0.95	0.93
Masindi	0.93	0.95	0.95	0.74	0.90	0.93
Mubende	0.68	0.79	0.71	0.63	0.84	0.72
Lira	0.95	0.96	0.95	0.84	0.98	0.99
Soroti	0.98	0.94	0.93	0.93	1.00	0.98

Table 13: Correlation of FAO data at Wanzogi and the surrounding weather stations

Station	Min Temp.	Max Temp.	Humidity	Wind	Radiation	E_p
Namulonge	1.00	1.00	0.99	0.99	–	0.99
Masindi	0.74	0.94	0.81	-0.33	–	0.87
Mubende	0.67	0.97	0.85	-0.20	–	0.94
Lira	0.67	0.97	0.85	-0.20	–	0.94
Soroti	0.49	0.97	0.84	0.01	–	0.95

For NASA data the dataset at Wanzogi corresponds best to Lira and Soroti, which was expected considering that these locations are in the same climatic region. However, the FAO dataset interpolation based on the nearest weather station in Namulonge shows different results. The high average correlation and particularly high correlation with Namulonge weather data do not consider the climatic variability in between these locations. Hence for this study due to the difficulty to define proper interpolation methods, interpolated data is discarded. NASA data does not depend on interpolating from local weather stations and is thus assumed to provide data independent from variations in local climate.

Nevertheless FAO data is trustworthy at the location of the weather stations, as it is derived directly from those stations. Comparing data fetched at these five locations shows that the estimation of E_p with NASA data leads to significantly higher E_p than with FAO data.

Correlation between FAO and NASA data is good at Lira and Soroti but questionable at the other stations (Table 14). In general the NASA estimates are higher than FAO weather station data. Lira and Soroti values, the only ones from fairly similar climatic conditions, reveal what the dimension of deviation / overestimation and consequently the correction factor for NASA data should look like.

Table 14: Correlation and mean deviation of NASA and FAO data

Station	Correlation	Mean deviation [mm/day]
Namulonge	0.75	0.69
Masindi	0.63	0.83
Mubende	0.51	-0.03
Lira	0.97	1.05
Soroti	0.95	0.94

The high correlation of NASA data at Wanzogi, Lira and Soroti and the high correlation of NASA data and FAO weather station data at Lira and Soroti suggest that the curve shape of the NASA data at Wanzogi is appropriate. However, the absolute values are too high and therefore need to be corrected. For this operation, the mean deviation for each month at Lira and Soroti was proportionally deducted from the curve at Wanzogi.

Figure 18: Corrected NASA data at Wanzogi

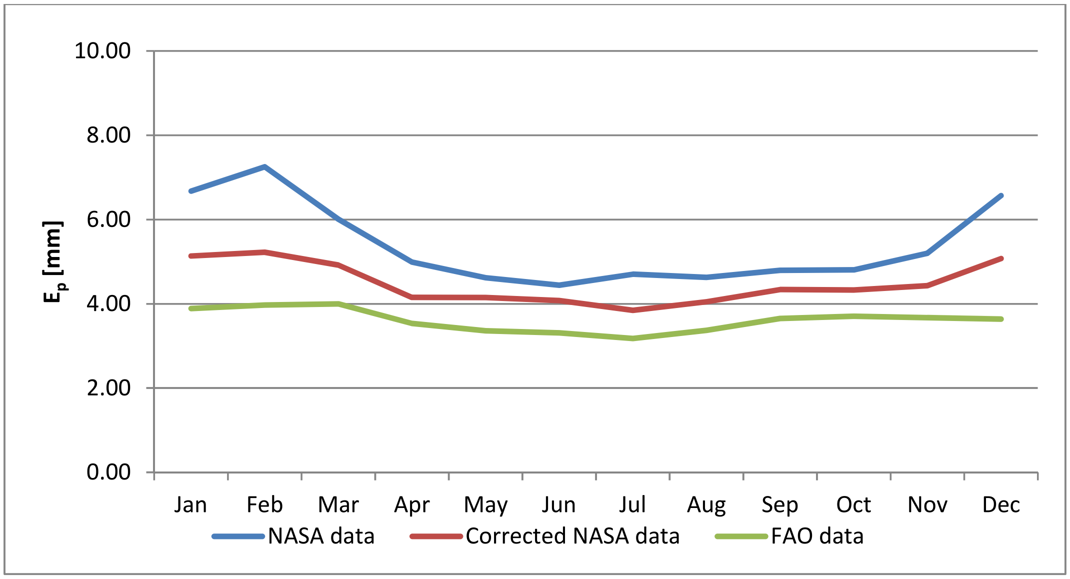
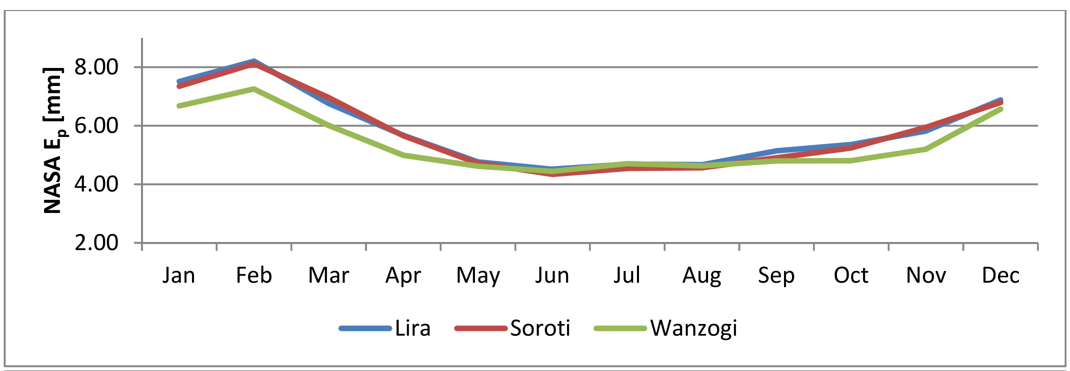
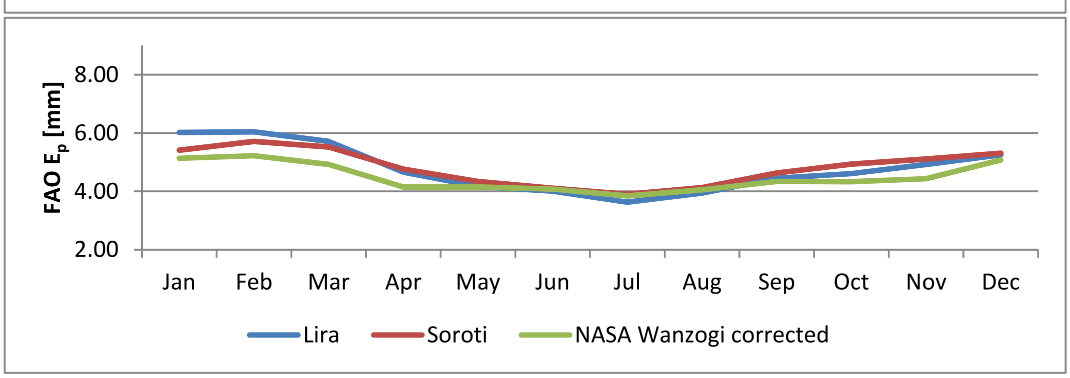


Figure 18 shows that the corrected NASA data at Wanzogi is still significantly higher than the interpolated FAO data, but well below the original NASA estimates. Figure 19 visualizes the correlation of NASA data for Lira, Soroti and Wanzogi as well as the correlation of FAO data at Lira and Soroti and the adjusted Wanzogi data.

Figure 19: E_p at Lira, Soroti and Wanzogi. NASA data and FAO data





Evaporation pan

Pan data is only available for July – November 2013. The pan coefficient used to transform E_{pan} to E_p of 0.9 is consistent with previous work done in equatorial regions of Africa (Riou 1983, Shanin 1985, Taylor and Howard 1999). Data derived from the pan seems questionable at times, as daily evaporation drops to less than 1 mm for certain days. However, the pan values are used to assess the calculated Penman evaporation.

Table 15: Penman E_p and pan E_p for 2013 in mm/day

Month	FAO	NASA	NASA corrected	Pan	Difference NASA corrected, Pan
July	3.18	4.88	3.98	3.81	0.17
August	3.37	4.77	4.18	3.70	0.48
September	3.65	5.41	4.90	4.68	0.22
October	3.71	5.14	4.63	4.59	0.04
November	3.67	5.32	4.53	4.41	0.12

Figure 20: Calculated and measured E_p at Wanzogi

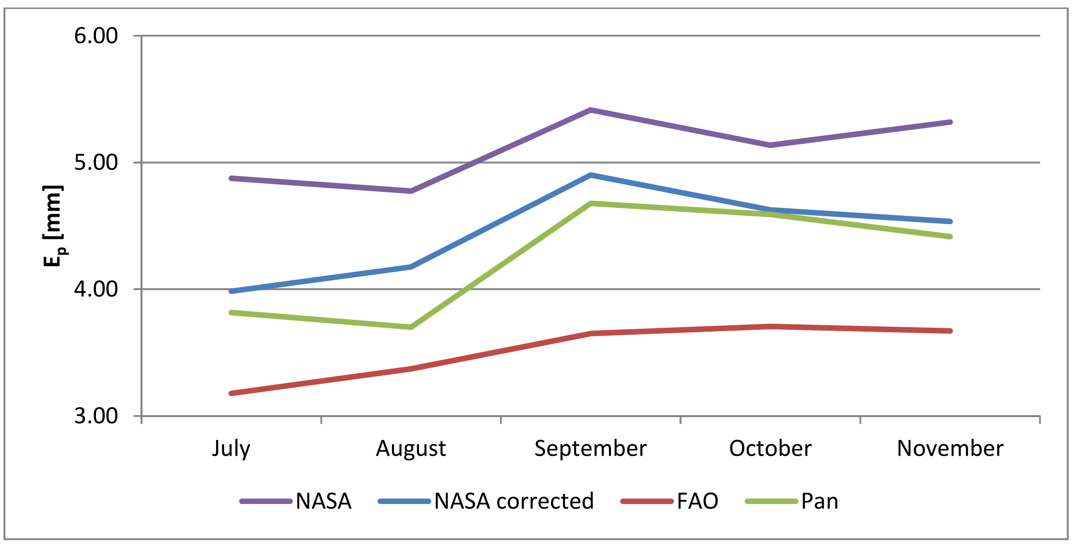


Table 15 and Figure 20 show that the pan evaporation is in between the calculated NASA E_p and the FAO E_p. Considering that the pan values are probably too low due to unknown reasons, the corrected NASA data series seems to be appropriate to be used for calculating the water balance. FAO data based on the standard interpolation needs to be discarded.

Evaporation rate

The calculated evaporation rate equals 1632 mm/year with peaks in the long dry season at the beginning of each year. This is lower than the estimated 1800 by Dagg et al. (1970: 65), but fits well with the results of Taylor and Howard (1999: 58). Using just FAO data, uncorrected NASA data and pan data, the corresponding evaporation totals are 1315 mm/year, 1948 mm/year and 1432 mm/year respectively. Table 16 shows the calculated average E_p for each month of the year.

Table 16: Calculated average E_p at Wanzogi in mm/day

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
$\mathbf{E_p}$	5.13	5.22	4.92	4.15	4.15	4.08	3.84	4.05	4.34	4.33	4.43	5.07

4.1.5 Seepage

Considering that the soil at the bottom of the valley tank is (loamy) clay, which was determined by Percy Kyazze and also stated by the District Engineer, the approximate seepage rate is in the region of 0.25 – 10 mm/day. Readings of the water level taken in June and July 2013 suggest that apart from evaporation and consumption about **4 mm per day** are lost due to seepage.

4.1.6 Calculating the water balance

Table 17 displays the terms of the water balance. The 130 days of a long dry season are calculated starting on November 16th, but the real starting and end of course vary for each year. Precipitation has been added into the calculation as direct rainfall into the valley tank, since there is no other inflow and runoff remains zero. It has to be noted again, that all these values have some variability in them and are based on assumptions that might or might not apply for a certain year. Yet it pictures well the dimensions of the factors of the water balance during a particularly long dry season and gives an insight in the adequacy of the existing infrastructure to cover the needs.
According to these results, the Wanzogi valley tank is just big enough to cover the demand of the estimated 1500 head of cattle for a dry season of 130 days with the calculated evaporation and seepage rates. With the above stated assumptions, there would be enough water to water the cattle for 9 more days or 139 days altogether.

Table 17: The Wanzogi water balance

	Unit	Nov	Dec	Jan	Feb	Mar	Dry Season
Length of dry season	days	15	31	31	28	25	130
Evaporation losses	mm/day	4.43	5.07	5.13	5.22	4.92	5.02
Seepage losses	mm/day	4.00	4.00	4.00	4.00	4.00	4.00
Total losses	mm	126	281	283	258	223	1172
	m^3	151	337	339	309	267	1406
Precipitation	mm	27	54	25	41	70	219
Livestock Demand	m^3	0	6	185	615	918	1724
Available water at the end of month	m	2.33	2.16	1.84	1.23	0.34	
	m^3	3063	2798	2310	1446	362	

4.2 Analysis of design and management

4.2.1 Design

Soil Erosion Risk

Spatial distribution of the SER

Figure 21 displays the spatial distribution of the valley tanks in the focus of this investigation and their respective calculated watersheds. The obtained SER and its determinants K, LS and C were calculated for each of these watersheds to draw conclusions on where the potential for improvement is the highest considering design and siting of a new water source. The Kainamura watershed comprises the Wanzogi watershed; the Kalungi watershed is small and barely visible in this map. All water resources with the exception of Nakasongola are in the same landscape. The Nakasongola resource is not a valley tank but a valley dam and thus is situated in slightly steeper environment. Table 18 lists details about size and distribution of those watersheds.

Figure 21: DEM and watersheds

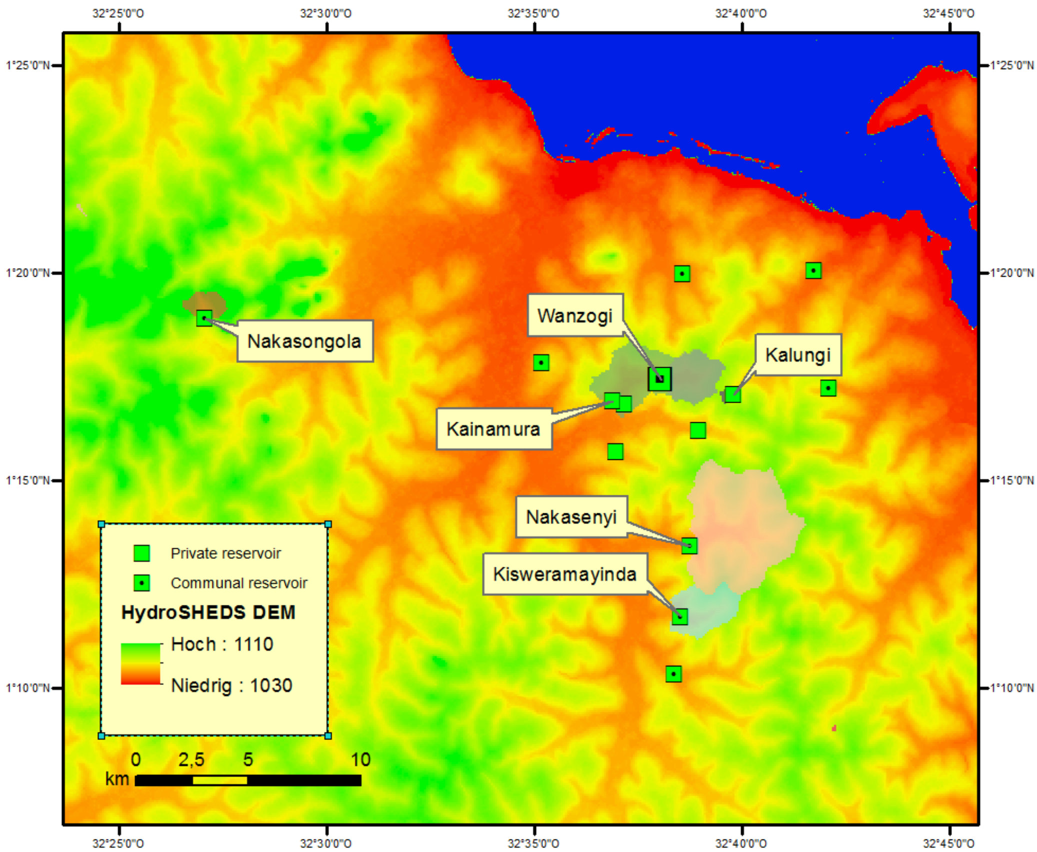
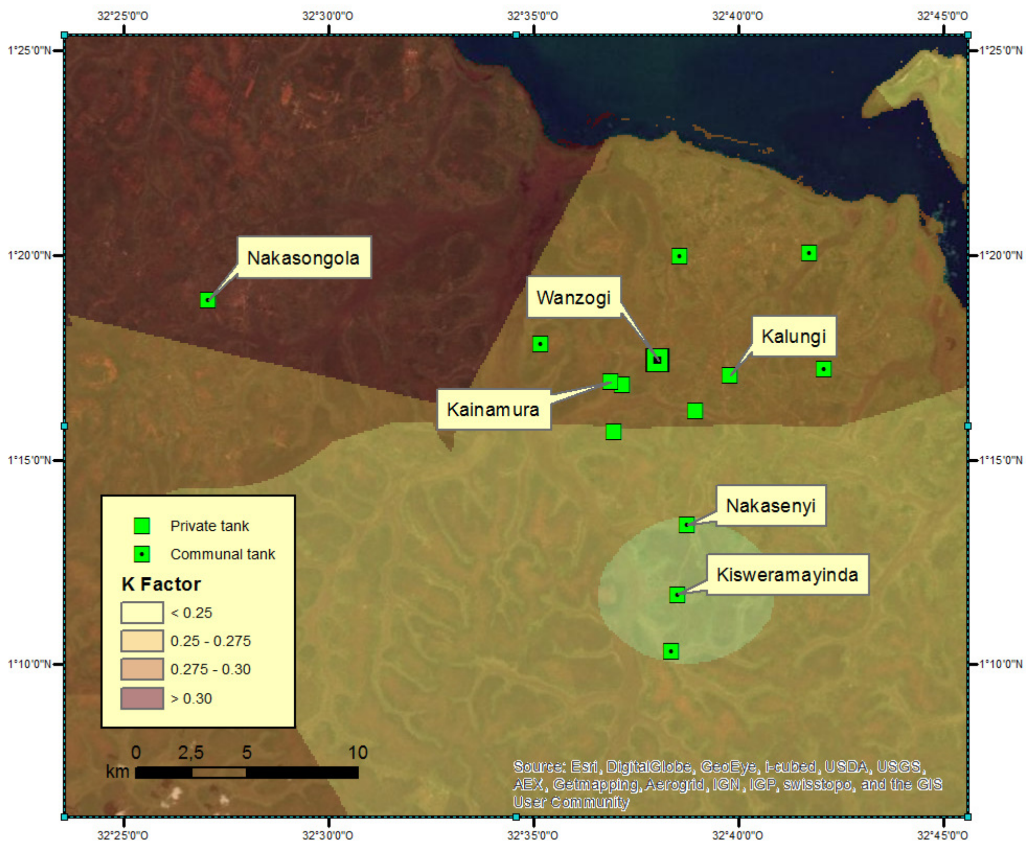


Table 18: Watershed details

Resource	Longitude	Latitude	Watershed Area	max. Elev.	min. Elev.
	[deg]	[deg]	[km²]	[m]	[m]
Wanzogi	32.635	1.290	4.13	1091	1057
Kalungi	32.663	1.285	0.28	1090	1073
Nakasenyi	32.646	1.224	29.21	1103	1053
Kisweramayinda	32.642	1.195	5.05	1103	1055
Kainamura	32.615	1.281	11.30	1091	1049
Nakasongola	32.451	1.315	1.80	1251	1078

Soil erodibility was interpolated using Kriging for the whole catchment based on the samples taken at the sites. The K factor distribution is illustrated in Figure 22.

Figure 22: Calculated and interpolated K factor



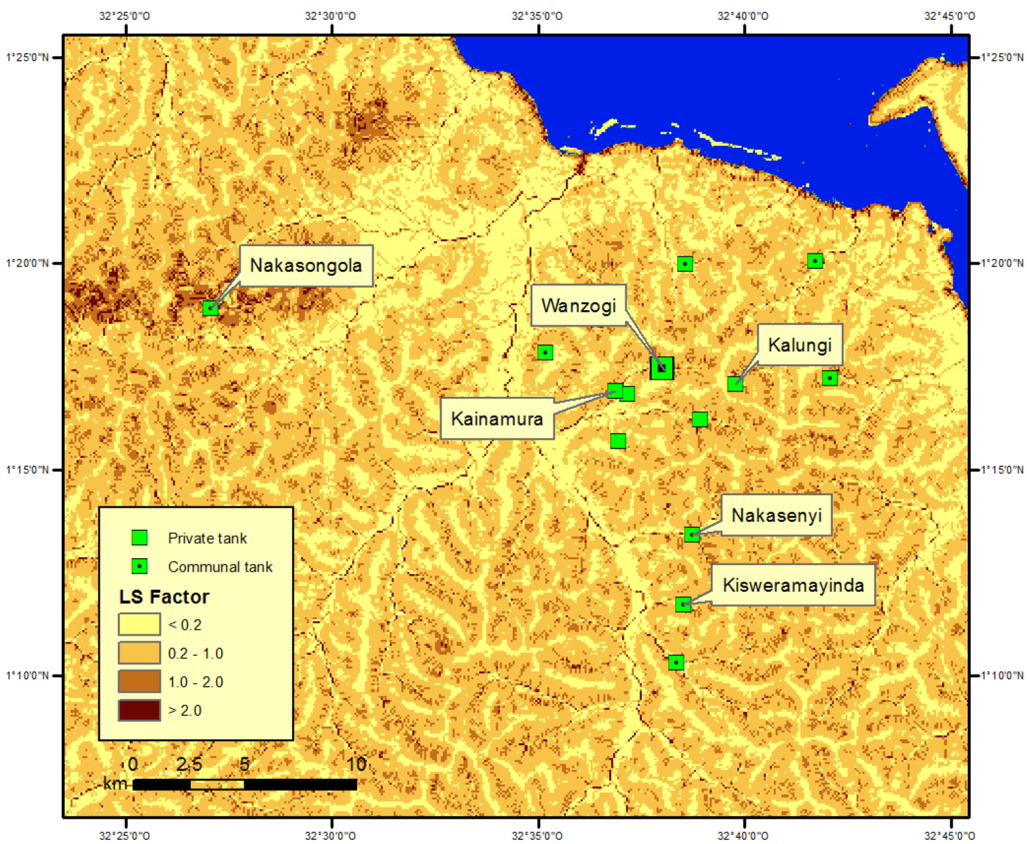
The K factor doesn't show much variation and lies within the margin suggested by the literature (Drake et al. 1999: 13; K ranges from 0.21 to 0.34). The watershed of the Nakasongola dam has slightly higher soil erodibility while Nakasenyi and Kisweramayinda are situated in less erodible terrain. Table 19 compares the calculated averages of the soil samples taken in the field and the values derived from the Harmonized World Soil Database (FAO et al. 2012).

Table 19: Soil parameters

	% Clay	% Silt	% Sand	% OM
Sample average	31	13	55	1.51
World Soil Database	33	20	47	1.79

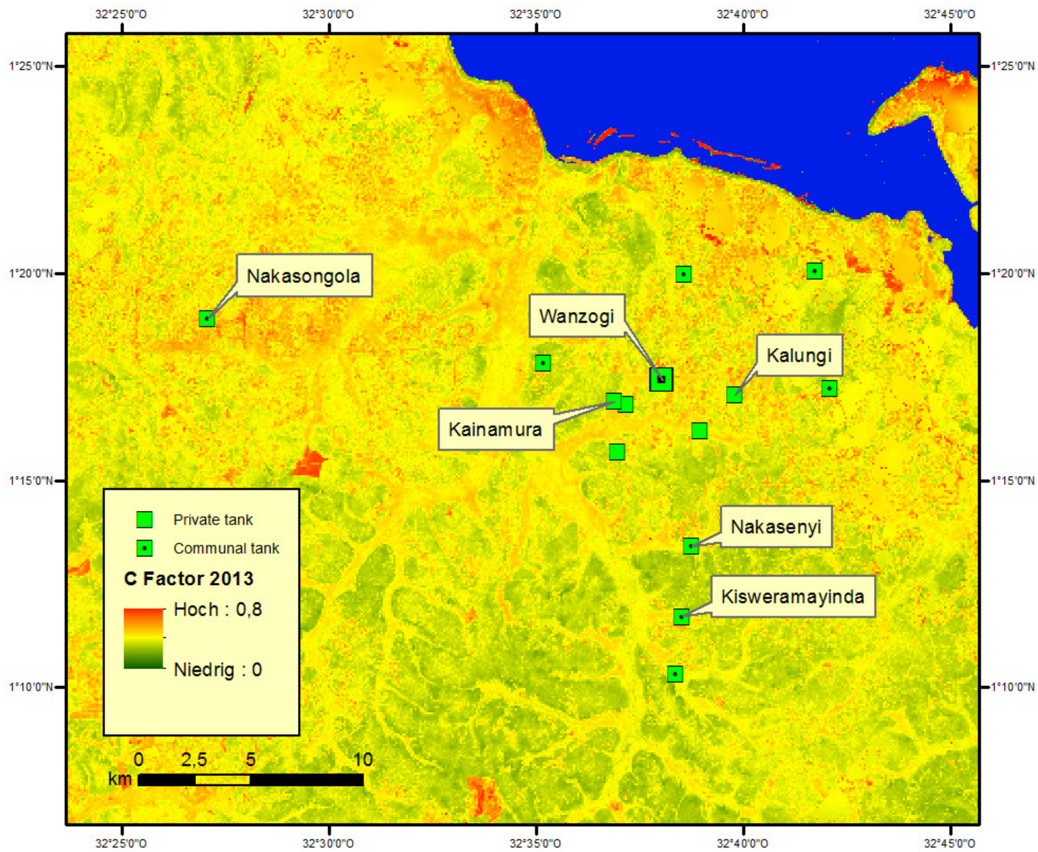
The LS factor is highly dependent on the slopes as the area is in general very flat. Figure 23 illustrates the LS factor distribution in the surroundings of Wanzogi. Again, Nakasongola is more exposed to unfavourable conditions, as that certain reservoir is situated in a hilly area with steeper slopes. For the other valley tanks, there is hardly any visual difference between the sites.

Figure 23: Calculated LS factor



The C factor was calculated based on NVDI extraction from Landsat images. Figure 24 displays the C factor for 2013. Green indicates a good protective vegetation cover while red displays bare land and settlements (The few intensely red spots northeast of Kalungi and at the coastline of Lake Kyoga are caused by cloud shadows. They don't affect any of the investigated watersheds). Yellow represents mainly pasture and agricultural areas.

Figure 24: Calculated C factor for 2013



Combining these layers leads to the SER displayed in Figure 25. From a visible inspection, it becomes evident that the Nakasongola reservoir is more exposed to soil erosion than the other reservoirs. The SER clearly increases with the steepness of the slopes and is low on the flat hilltops and in the valleys. The exception is the calculated flow path down at the very bottom of the valleys that bears a high SER due to the high amount of water routed through those cells.

Figure 25: Calculated Soil Erosion Risk

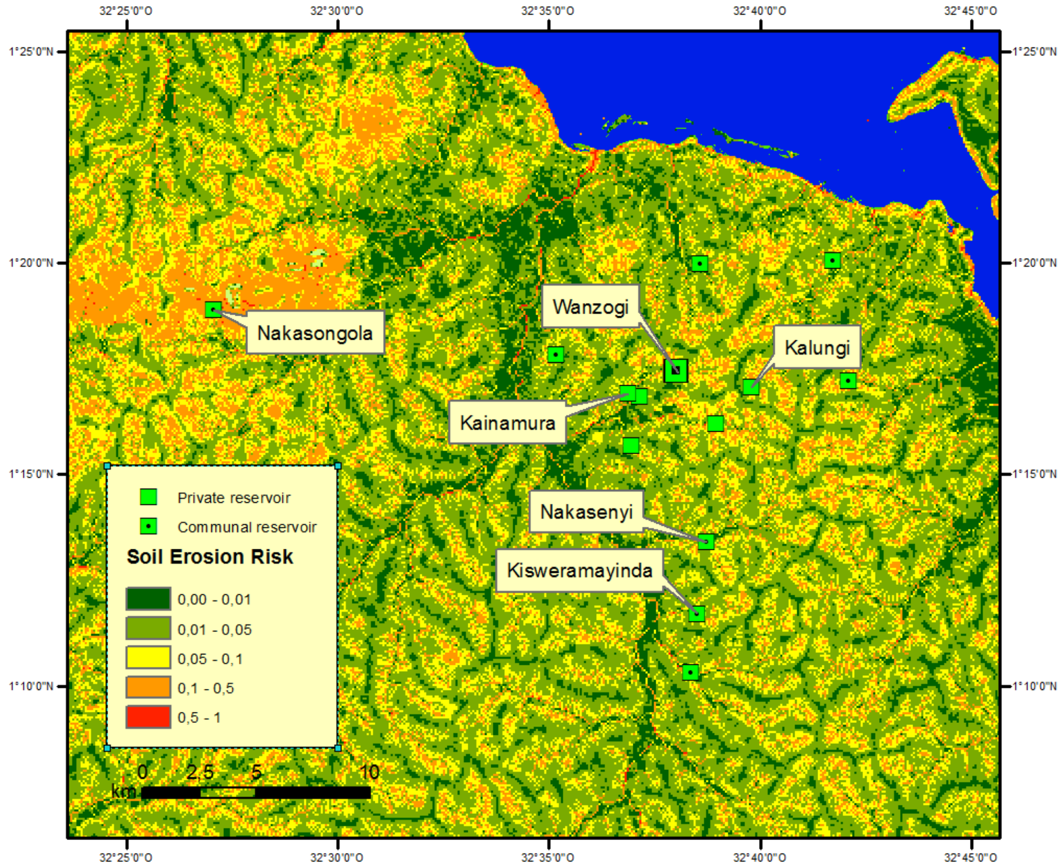


Table 20 summarizes the mean values for each factor in each watershed. The right column represents the standard deviation and indicates that the LS factor varies by far the most. While the high erosion risk in the Nakasongola watershed is due to having high values for each of the factors, it becomes evident that the length and slope factor contributes significantly more to the SER in this area than soil erodibility and land cover.

Table 20: Mean results for each catchment

	WAN	KAL	NSY	KIS	KAI	NAK	STD
K	0.288	0.289	0.256	0.242	0.288	0.311	0.023
LS	0.534	0.451	0.573	0.609	0.472	1.518	0.373
C	0.441	0.409	0.362	0.354	0.420	0.447	0.036
SER	0.070	0.058	0.053	0.052	0.057	0.203	0.054

Temporal distribution of the SER

The temporal change of the SER due to vegetation cover change was investigated only at the Wanzogi watershed. Landsat images used were taken on July 2nd 1985 and July 13th 2013 respectively and downloaded using the USGS Earth Explorer and USGS GLOVIS.

To verify the accuracy of the NVDI Landsat images, a supervised classification using the bands 5, 4 and 3 of the 2013 Landsat 8 images was performed. The training samples were derived from ArcGIS World Imagery as well as GPS readings taken during the time of fieldwork. Figure 26 represents the classification of the watershed; the area distribution of the classes is listed in Table 21.

Table 21: Distribution of land cover classes in the Wanzogi watershed

	Agriculture	**Scrub**	**Forest**	**Pasture**	**Settlement**
Area [ha]	46	294	1	66	6
% of watershed	11.25	71.25	0.18	15.89	1.43

Comparing Figure 26 (supervised land use classification for 2013) and Figure 27 (C values calculated with the NVDI for 2013) shows great compliance of the pattern of distribution from supervised classification and NVDI calculation. Consequently the C factor distribution determined with NVDI is considered representative for the Wanzogi watershed. However, due to the lack of adequate C values for each of the land cover classes, an absolute comparison was not carried out. Figure 28 illustrates the calculated C values for 1985. It is evident, that there was a major change in the vegetation cover between 1985 and 2013. The great forest degradation stated by the NFA (2005) is clearly visible and obviously charcoal burning and exhaustive livestock breeding do impact the SER massively. Table 22 sums up the calculated results of the temporal analysis.

Table 22: Mean results of temporal analysis

Parameter	**Wanzogi 1985**	**Wanzogi 2013**	**STD**
C	0.082	0.441	0.178
SER	0.015	0.070	0.026

Figure 26: Wanzogi watershed land use classification (2013)

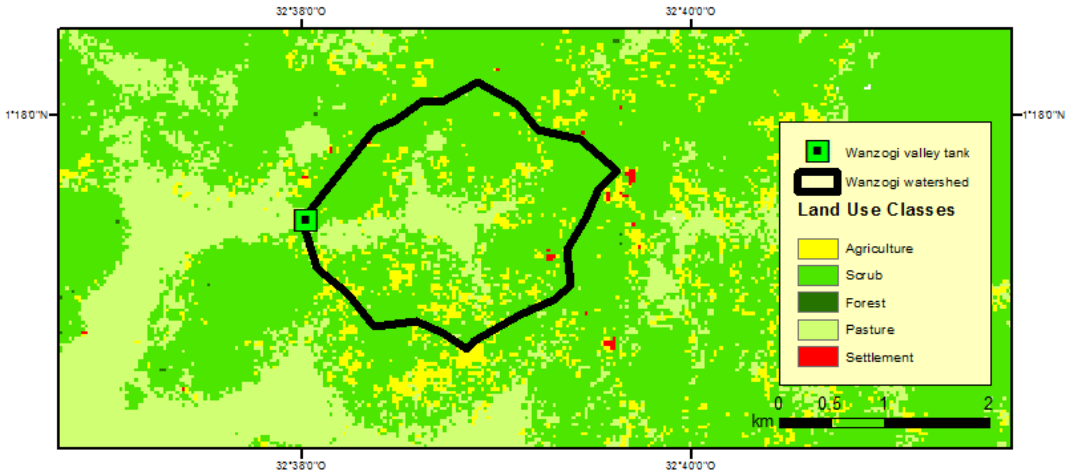


Figure 27: Wanzogi watershed C values (NVDI 2013)

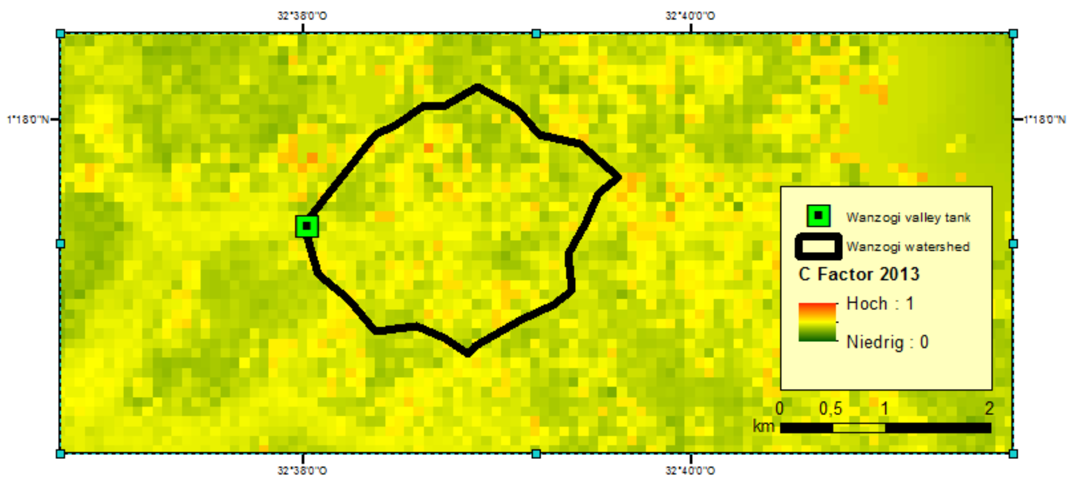
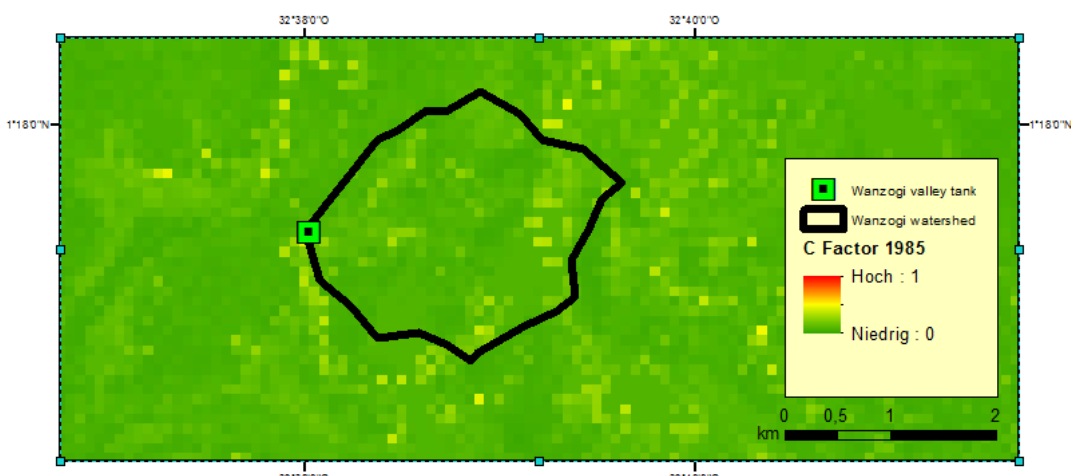


Figure 28: Wanzogi watershed C values (NVDI 1985)



Comparing spatial and temporal evaluation

Table 23: Deviation of K, LS, C and SER compared to Wanzogi 2013

	K spatial		LS spatial		C spatial		C temporal	
	min	max	min	max	min	max	Min	max
Location	KIS	NAK	KAL	NAK	KIS	NAK	WAN 85	–
Deviation	-16 %	+8 %	-16 %	+184 %	-20 %	+1%	-81 %	–

The Nakasongola reservoir is the only one that differs with a significantly higher SER from Wanzogi (see Table 23). This fact is due to the location of the reservoir in Nakasongola, which is the most distant one and has a very different topography. Similar conditions cannot be found in the Wanzogi parish or the near surroundings and thus the 184 % increase of the LS factor in Nakasongola in comparison to Wanzogi are not transferable to the design and siting of the Wanzogi water resource or a new water resource in that area. At the surrounding reservoirs, K, LS and C are up to 20 % lower than at Wanzogi, indicating that there is room for better design and siting of the water source considering the surface soil condition, topography and present vegetation cover.

However, the main difference is presented by the temporal evaluation of the C factor. In 28 years, the SER has increased by a factor 5 due to the change of land cover / land use. This results in increased soil erosion and reduction of the volume of the valley tank due to siltation and sedimentation. The spatial variance of the SER and its determinants is minor in comparison to the increase of SER caused by the temporal change of the land cover.

Resource protection

Proper protection of the valley tank avoids contaminants entering the water resource. Protective measures include inflow area protection, fencing and the restriction of direct access to the water body of animals and humans. The six sites investigated in this thesis have protective measures as shown in Table 24.

Table 24: Resource protection measurements

Location	Fence	Inflow area protection	Direct access humans	Direct access animals
Wanzogi	Barbed wire & young plants	Fenced inflow area [~0.5 ha]	–	–
Kalungi	–	–	Cleaning vehicles etc.	Direct access possible
Kisweramayinda	Barbed wire & fully grown plants	–	Taking water for domestic use (jerry cans)	–
Nakasenyi	–	–	Entering the water body to serve the animals	Direct access possible at certain spots
Kainamura	Barbed wire	–	–	–
Nakasongola	–	–	Laundry etc.	Direct access possible

To evaluate the resource protection measures, the water quality was assessed. Mean values for each of the parameters during the time of research were calculated and are displayed in Table 25.

Table 25: Mean water quality parameters

Parameter		WAN	KAL	KIS	NSY	KAI	NAK
pH	[]	6.74	6.73	6.89	6.62	6.73	6.73
TDS	[ppm]	35.90	30.80	33.40	66.00	35.30	70.10
Turb.	[NTU]	6.50	571.42	3.29	103.28	245.94	8.51
Nitr.	[ppm]	0.00	0.20	0.50	–	0.26	0.00
Sulph.	[ppm]	0.00	0.00	0.00	–	0.00	0.00
FC	[CFU/ml]	4.50	11.50	1.00	9.00	2.50	13.00
TAB	[cnt/ml]	5,077,000	too turbid	5,740,500	12,329,750	too turbid	8,348,250
TB	[cnt/ml]	6,355,250	too turbid	7,331,500	14,328,250	too turbid	13,336,250

TDS total dissolved solids, FC faecal coliforms, AB total alive bacteria, TB total bacteria

Nitrates and Sulphates are clearly below the recommendations (44 ppm and 1000 ppm respectively). Also pH (recommended 5 – 9) and TDS (below 1000 CFU) are ecologically sound. Turbidity values vary greatly and possibly affect the water intake of livestock as cattle may reject taking too turbid water. High values for Kalungi and Nakasenyi are due to their severe pollution while the 245 NTU measured at the Kainamura valley tank reflect the recent excavation of that tank and thus the high amount of suspended fine material. It is expected that this value will decrease by a great margin for the second year of the reservoir's existence.

The literature recommends faecal coliforms to be below 10 CFU/ml (Table 6). While Wanzogi, Kisweramayinda and Kainamura are well within this limit, Kalungi, Nakasenyi and Nakasongola are potentially harmful for livestock watering from those sources. There are no recommendations for the bacteria count, but the numbers reflect and confirm what was measured by faecal coliforms. For Kalungi and Kainamura, readings of bacteria count with the flow cytometer were not possible due to the high turbidity.

The correlation of the protective measurements with the contamination (in this case FC) represents the impact of a protective measure on contamination prevention. For this reason, the protective measures at each water resource were rated ranging from 0 (no measure taken) to 1 (appropriate protective measure). Table 26 lists the results.

Table 26: Correlation of protection measures and FC

Location	FC	Fence	IAP	DAH	DAA
Wanzogi	4.50	0.80	1.00	1.00	0.80
Kalungi	11.50	0.00	0.00	0.00	0.00
Kisweramayinda	1.00	1.00	0.00	0.75	1.00
Nakasenyi	9.00	0.00	0.00	0.50	0.20
Kainamura	2.50	0.60	0.00	1.00	1.00
Nakasongola	13.00	0.00	0.00	0.00	0.00
Correlation	–	*-0.93*	*-0.24*	*-0.90*	*-0.98*

FC faecal coliforms, IAP inflow area protection, DAH direct access of humans, DAA direct access of animals

Correlation for direct access of animals is the highest and also direct access of humans and proper fencing clearly correspond to the amount of faecal matter in the water body. Inflow area protection shows limited effect on the water contamination, but this factor needs to be evaluated with more detail in the future and with a sample that contains more valley tanks with inflow area protection.

These results indicate that the infrastructure regarding resource protection is adequate at the Wanzogi valley tank. Proper fencing and restricting human and animal access to the water body directly prevents faecal contamination and consequently leads to healthier animals. The water quality at Wanzogi is easily within the recommendations, and if the protective measures stay in place, contamination should not be a problem at the Wanzogi valley tank.

Dimensions

The dimensions of the six water resources are shown in Table 27:

Table 27: Resource capacities

Location	Length	Width	Depth	Capacity
	[m]	[m]	[m]	[m³]
Wanzogi	60	21	2.5	3175
Kalungi	76	25	4	7600
Kisweramayinda	100	50	7.5	37,500
Nakasenyi	53	25	2.5	3313
Kainamura	43	12	3.75	1935
Nakasongola	200	120	2.2	52,800

Obviously the dam in Nakasongola and the Kisweramayinda valley tank are the largest ones, and, according to the locals, never dry up during the dry season. Yet those two water resources are at a too far a distance to serve as alternatives for the Wanzogi livestock farmers. The dimensions of the Wanzogi valley tank are well within the scope of other sources in that area and represent a medium-sized valley tank. All valley tanks are rectangular; only the dam at Nakasongola follows the natural shape.

The only location that has an issue concerning the dimension is the valley tank at Kalungi. The 0.28 km^2 of catchment area are not sufficient to fill the valley tank. According to the locals, this is due to the fact that over the past decades, the water has opened new drainage channels and now mainly bypasses the Kalungi valley tank. The poor water quality of this water body is – among other reasons – also due to the little amount of water it contains during the whole year. As a consequence, the dimensions and siting of a new valley tank are very important and the potential catchment area needs to be considered in order to avoid situations like in Kalungi.

Banks

Comparing the banks (slopes and vegetation) of the water resources shows that there is little difference between them (see Table 28). The only site that catches the eye is Kalungi with its highly eroded, steep and unvegetated banks. The slopes of the other valley tanks are about 2:3 which is higher than the suggestions by the literature (Pallas 1986; Liddicoat et al. 2011: 33). The Nakasongola dam (being not excavated) has natural banks. Reducing the steepness of the banks at the valley tanks could reduce erosion and as well the risk of humans and animals falling into the water body.

Table 28: Bank slopes and vegetation

Location	Bank slopes	Bank vegetation
Wanzogi	2:3	Grass
Kalungi	Eroded	Bare soil
Kisweramayinda	2:3	Grass
Nakasenyi	2:3	Bushes & Trees
Kainamura	2:3	Currently unvegetated, grass planned
Nakasongola	Natural	Pasture

Water delivery

In the October 2012 as part of the WATERCAP project, a new concrete trough was constructed at a distance of 30 m from the Wanzogi valley tank. This trough was meant to replace an older and broken concrete construction and provide the livestock farmers with a facility that makes it easier for them to water their animals. At the same time it keeps the cattle from directly accessing the valley tank. To fill the trough volume of 3.1 m^3, a fuel driven pump and pipes were also provided through the WATERCAP project.

A closer look at the facility has shown some issues that come with its implementation. During the long dry season at the end of 2012 and beginning of 2013 the locals constructed traditional troughs directly at the valley tank in addition to the large concrete trough (see Figure 29). This meant that the facility was being used, but at the same time the herdsmen were still directly accessing the valley tank to water their animals from the traditional troughs – within the fenced area. The reason for these actions was that the provided pump could not keep up with the consumption rate of the cattle at the concrete trough. Hence, this trough was constantly almost empty and the calves were not able to reach the water. Furthermore it caused the herdsmen to take much longer for watering their cattle which made them construct the additional traditional troughs. For the next dry season at the beginning of 2014, a new bigger pump will be organized to solve this problem. Half a year after the initial problems, during the short dry season of June and July 2013, the amount of cattle at the valley tank was low because many herdsmen still used small ponds on the farmland. Thus the amount of water pumped into the concrete trough was enough for that season's demand, yet due to mechanical problems the pump was out of use for almost half of that dry season. Since the distance from the trough to the valley tank is 30 m and carrying water with jerry cans is hard work, the herdsmen again shifted back to the use of their traditional troughs directly at the water body.

Figure 29: Local using a traditional trough standing inside the valley tank

Even though the livestock farmers stated that they appreciated the concrete trough and the relief from having to fill traditional troughs with jerry cans, the case of the Wanzogi valley tank shows that there are more issues to consider. The mechanical pump problems are probably the result of improper maintenance and use of the pump and thus might have been solved with a better familiarization and training to use this new technology. The too small dimensioned pump was a simple fault within the WATERCAP project, leading to the rehabilitation of the traditional structures. These traditional structures ignore the protective measures at the valley tank and cause the cattle being led into the fenced area.

Yet the described way of watering cattle using a concrete trough and some sort of pump to deliver the water is the one suggested by the literature (Pallas 1986). The trough being able to water about 40 head of cattle at once fits well for the local needs and outperforms the small traditional troughs by far. The problem is the acceptance of the new technology and technical issues that come along with the infrastructure. World Vision, currently building four new valley tanks in that area (Kazwama, Kisenyi, Wabigumba, Katanalya), does not use fuel driven pumps but rather stationary hand pumps similar to what the locals are used to from their boreholes. These valley tanks are not yet in use, but the implementation of an already known technology that does not need fuel input might be a better solution for this issue. However, only the future will reveal the performance of the World Vision infrastructure.

Table 29: Watering facilities

Location	Trough	Trough size	Water delivery system
Wanzogi	Concrete trough	3 m^3	Fuel driven pump
Kalungi	–	–	–
Kisweramayinda	3 concrete troughs	3 x 1 m^3	Broken treadle pump, fuel driven pump
Nakasenyi	Metal barrel (half) at one of five access points	0.3 m^3	Jerry cans
Kainamura	Wooden trough	0.2 m^3	Jerry cans, fuel driven pump planned
Nakasongola	6 concrete troughs	6 x 2m^3	Gravity system

The water delivery infrastructure at the six resources is displayed in Table 29. The gravity system implemented at the Nakasongola dam is surely the best system using the existing water head to deliver the water to the trough. However, this is not possible in the other locations. The treadle pump at Kisweramayinda broke down quickly and thus, fuel driven pumps are the ones being implemented currently. Yet the hand pumps used by World Vision should be considered a low-cost and low-maintenance alternative.

The sizes and types of troughs vary but proper installations should be made of concrete, because any other alternatives deteriorate quickly and tend to disappear from the site. Locations with no proper concrete trough usually feature animals watering directly from the water body. All troughs fulfil the maximum height of 0.5 meters to allow calves to reach the water, but the troughs at Kisweramayinda are only 0.53 m wide, which is less than the recommended 0.7 m by Pallas (1986). The trough in Wanzogi meets the suggested technical standards for watering livestock.

It becomes evident that the main issue at the Wanzogi valley tank is not the existence of proper infrastructure. From a technical perspective, all the taken measures are appropriate (once the new pump is in place) and support satisfactory water quality, abundant water quantity and good access to the water. Yet the issues come with adequate use of the infrastructure (operation) and proper taking care of its functionality (maintenance).

4.2.2 Operation and maintenance

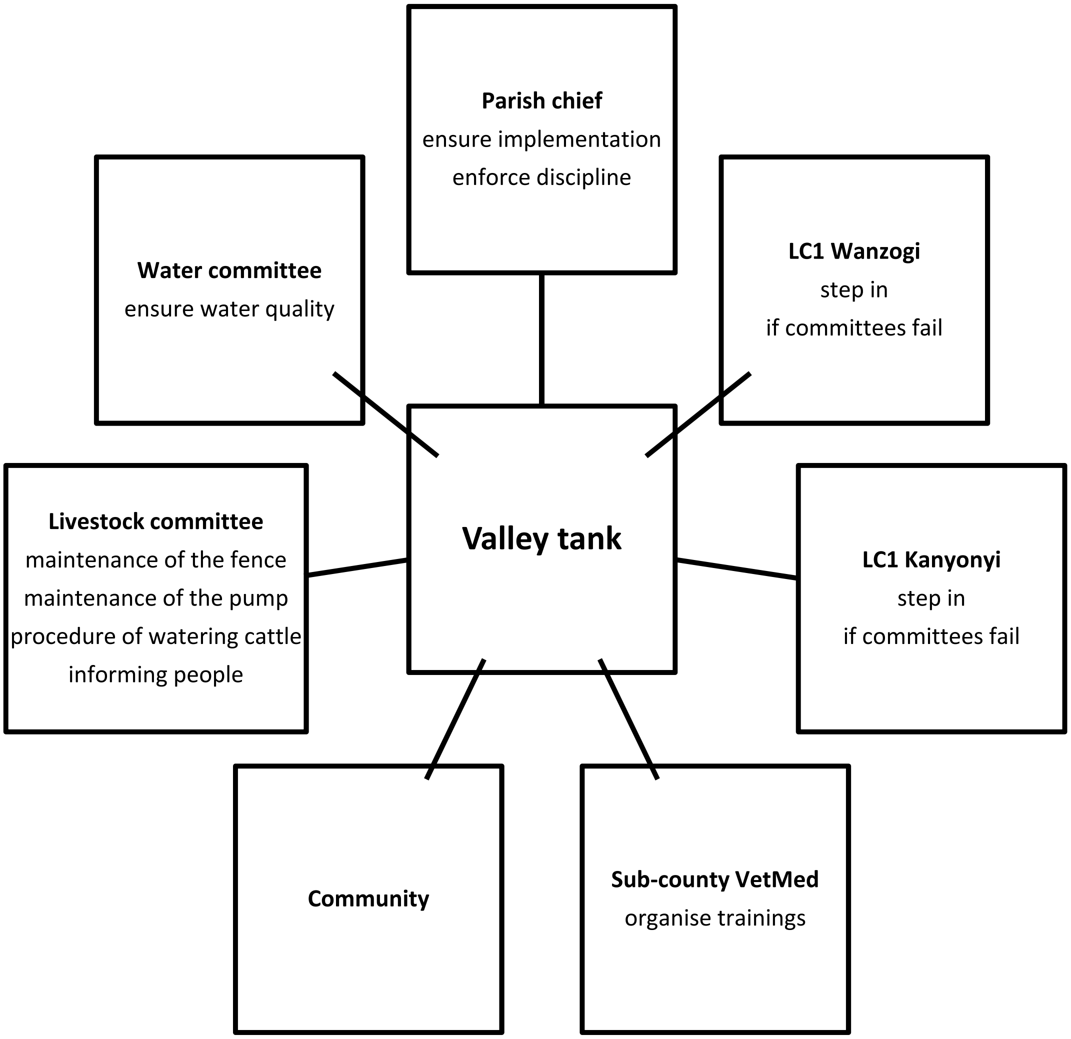
Responsibilities

Years ago a water committee was established to run the old small valley tank (before desiltation through the WATERCAP project). However, this committee failed to maintain the water resource properly, and consequently in 2011 a group of local livestock farmers formed their own livestock committee. The two committees competed with each other instead of working together and the share of responsibilities was not clear. The result was that O&M remained at a very poor level. To deal with this issue, during the fieldwork the clarification of responsibility sharing and reorganization of the committees was encouraged. In a group meeting, a concept of the livestock farmers' opinion on how responsibilities are to be shared was drafted and is displayed in Figure 30. This draft shows the inclusion of the village chiefs to step in if the committees fail to meet their duties and the right of the parish chief to take disciplinary actions in case of organisational failure at the valley tank. At this point in time, the idea was still of two separated committees for livestock and water.

As a consequence of these discussions, committee meetings took place in August/September 2013, and the organisational structure was discussed among the livestock farmers. Hence, the so-called "Wanzogi Water Users Committee" (WWUCO) was founded and put in charge of the valley tank as a Community Based Organization (CBO). The following goals of the committee were put on paper:

- Uniting herdsmen and water users in the Wanzogi parish
- Eradicating water contamination and disposals
- Having a united voice representing all herdsmen
- Fighting against uncertainties, myths and ignorance among herdsmen
- Causing a change in the livelihoods of the herdsmen
- Acquiring knowledge

Figure 30: Responsibilities as identified by the livestock farmers



The committee consists of 32 herdsmen. It is run by three executives, namely the herdsmen committee, the water committee and the maintenance and coordination committee. Each executive has a chair person and at least three others with official functions. The executives share the responsibilities for organizing the herdsmen and ensuring good livestock health (herdsmen committee), ensuring good water quality (water committee) and maintaining the infrastructure (maintenance and coordination committee). According to the district engineer, legal requirements demand that from 2014 on the officials of the WWUCO are elected every 2.5 years.

To become a member of the WWUCO, one has to

- be a citizen of Wanzogi parish
- pay a registration fee of 1000 Shillings per head of cattle for herdsmen or 2000 Shillings per dry season for domestic use (at the smaller domestic valley tank)
- pay for a litre of fuel for running the pump. Payment is done as a rotational shift.

Considering this structure of responsibilities, the locals have reacted to challenges in the past and reorganized themselves. However, the past has shown that the proper use of the infrastructure depends on whether the responsible committees do their duties or if they are mere abstract constructions, brought into existence to please financial donors.

One thing that was certainly lacking at the Wanzogi valley tank in the past was the existence of a monitoring body ensuring everybody is doing what he is supposed to do. The suggestion to the locals – which seemingly hasn't been implemented yet – was to install local leaders such as the village chairpersons or the parish chief as official monitoring instances ensuring that the responsible people in the committee meet their duties. This is coherent with the suggestion in the literature (Harvey and Reed 2006: 372f; Lockwood 2004: 12ff) that community managed resources should be provided with institutional assistance regarding technical issues and monitoring. Now it is up to the locals and the institutional authorities to put these structures in place.

The mere structure of the organization at the Wanzogi valley tank is probably the best organized in the whole area. The presence of the WATERCAP project and the financial contribution from outside the community has caused the locals to mobilize the herdsmen, organise themselves and to take on the issue as a community. Out of this process the WWUCO was born and lays the foundation for proper management of the valley tank. Yet the issue if this organizational structure will work properly in the future remains the decisive point. Details about the organizational structure of the neighbouring valley tanks are listed in Table 30.

Table 30: Responsibilities and organization

Location	Responsibilities	Financial Contribution	Domestic water use
Wanzogi	Committee	Maintenance, fuel	– (domestic tank next to it)
Kalungi	Private owner	Gather for maintenance, no financial contribution	✓
Kisweramayinda	Local chairman LC1	Organize themselves for maintenance	✓
Nakasenyi	Committee	–	✓
Kainamura	Private owner	–	✓
Nakasongola	Committee	Maintenance	✓

As concluded in the above results, Kisweramayinda and Kainamura valley tanks are ones with the best performance. Both of these valley tanks are mainly managed by one person in charge (even though for Kisweramayinda this one person – the local leader – brings many others along). The ones officially managed by committees (Nakasongola and Nakasenyi) are poorly run and face many challenges concerning the water quality. This indicates, that one responsible person in charge of a water resource can be the better solution than a committee not fulfilling its duties. And this also hints at the biggest challenge faced in Wanzogi, namely to make sure that the committee's performance is appropriate and accordingly the water resource is run well.

Maintenance

Fence

The new fencing around the Wanzogi valley tank has faced quite some challenges. The Lukoni planted along the barbed wire was attacked by hungry cattle and ceased to exist at the fence section near the trough. Furthermore some parts of the barbed wire became severely damaged during the weeks in July and August 2013 when the pump was not working and the animals were led inside the fence to take water from traditional troughs constructed right at the water body.

The big challenge for maintaining the fence is to keep the cattle away until the Lukoni plant is fully grown and able to resist the animals. Furthermore additional effort has to be taken to keep cattle at all times outside of the fenced area. The new organizational structures will hopefully deal with these issues, but again it all falls back to the question if the responsible people meet their duties.

Pump

The existing pump has been out of use for parts of July and August 2013 due to mechanical failure. A second, bigger pump will be acquired for the coming dry season. The pump is maintained with the money paid to the WWUCO and fuel organized by the herdsmen.

Trough

Heat expansion has caused minor cracks in the concrete trough. The locals used to fix them quickly. Continuous trough maintenance is essential to ensure that it is kept free of depositions and doesn't start leaking.

General maintenance

Removal of material blown into the water body was not observed during fieldwork. However, the amount of material in the water was very low so far.

Financial Contribution

Herdsmen (for the large valley tank) and domestic users (for the small domestic valley tank) contribute as mentioned above to finance maintenance. Financial resources are fairly high compared to the other valley tanks (of which some don't charge any contribution at all for maintenance) and thus the maintenance of the fence, pump and trough should not be a problem considering monetary issues - as long as people spot problems when they occur and take actions.

In order to acquire the new pump, each herdsman was charged with a certain amount of money and the WATERCAP project contributed part of the costs. In this process, the organisation of financial contribution seemed to work well among the livestock farmers.

Access

Humans

Humans are permitted to enter the fenced area and fetch water at the domestic use valley tank. They usually use jerry cans to fetch water directly out of the valley tank. This is a cause of contamination but more so the locals are concerned about people falling into the water and drowning. With the slopes being steep and most locals not knowing how to swim, this is a serious issue. It is the women and children responsible for fetching water and many husbands have stated their concern about their family's safety. The solution would be an infrastructure like a hand pump used at the World Vision valley tanks to fetch the water and the WWUCO has already stated their wish to do something about the issue. However, it is unlikely that funds for easing human access will be available in near future and thus the jerry can system will prevail as it does at most the water resources in the area.

Humans don't access the livestock valley tank except for placing the pipes for pumping water to the concrete trough. In comparison to most other water resources in the area, this is a definitely an improvement.

Animals

Technically animals are restricted from entering the fenced area – as long as the watering facilities work.

Animal watering

The organization of the locals to water their animals is well developed. The herdsmen bring their herds to the trough one after the other in order of appearing at the valley tank. During dry season when many herds water at the trough, they assign times of the day to everybody to make sure to distribute the herds throughout the whole day. The trough waters about 40 head of cattle at once, meaning that also the biggest herds (around 80 heads of cattle) can be led to the trough in one go as the surrounding area is big enough.

For the herds waiting, a resting area is available. However, this area is fairly small and supposed to be enlarged by the WWUCO in the future.

5 Conclusions and recommendations

5.1 Water balance

The calculation of the water balance is based on many assumptions that might or might not exactly represent the conditions of a particular long dry season. Hence, these results rather represent a general scheme of water availability and water demand during dry season, yet the exact numbers might vary from year to year. Water availability and evaporation are based on trustworthy meteorological data and thus representative for the area. However, the water demand depends on the exact number of cattle watering in Wanzogi and the extent of private water supply at the beginning of each dry season. These two factors are highly variable for each dry season and difficult to determine precisely.

With the valley tank volume equalling 3175 m^3 and the watershed covering 4.127 km^2, the long dry season from November till March was determined to be the crucial time of the year for watering livestock. Particularly long dry seasons last up to 130 days and the aim is that the Wanzogi valley tank provides enough water to cover the demand during this timeframe.

Considering the calculated amount of 1500 head of cattle for the cattle catchment area of the Wanzogi valley tank and the water demand curve as displayed in Figure 13, the available water will last for 139 days. That is long enough to cover the animals' water demand for 8 of the past 9 years of dry season. Only during the exceptionally long dry season of 2009/10 the demand would have exceeded the supply. The amount of cattle watering at the valley tank needs to be observed in the coming dry seasons in order to get a more exact picture of the demand and to be able to ensure that only the number of animals that the water resource is able to provide for will be led to the trough.

As part of this research, the question was raised whether evaporation or seepage impacts the water balance more significantly. The results have shown that during rainy season the magnitudes of the two variables are almost the same while during dry season evaporation is slightly higher than seepage (~5 mm/day and ~4 mm/day respectively). This conclusion is based on the determination of seepage from a water balance approach and not from direct calculation using soil and groundwater parameters.

Whether or not the water in the valley tank is enough to cover the water demand highly depends on the number of animals led to the water resource. The Wanzogi valley tank has little reserve and was not designed to cover demand from outside Wanzogi parish. Hence, if other communal valley tanks run dry early and herdsmen bring their cattle to Wanzogi from distant areas, the valley tank will not be able to provide for all the animals. It is the task of the operational committee to ensure that the valley tank is only used by the number of cattle it is able to sustain. Water is a very limited resource in this area of Uganda and there is much temptation to sell water to neighbours in need during long dry seasons. According to some locals this has happened in the past, and caused the valley tank to run dry early.

From a water balance perspective, in accordance with the mentioned assumptions the Wanzogi valley tank is an adequate infrastructure to cover the demand of the local livestock. For deeper insight into the water balance at Wanzogi, the presently conducted study by Percy Kyazze will reveal more exact data on the seepage rate. Combining the results of the two studies will give a better picture of the water balance. For better determination of the water demand, a proper livestock census in Wanzogi parish is essential. Unless a census is performed, all the calculations will be based on estimates. Follow up research on the real water availability during dry season over a series of years should be used to verify (and if necessary adapt) the assumptions stated by this study.

5.2 Design and O&M

The study on soil erosion and siltation has clearly shown that the temporal variation of the vegetation cover has the highest impact on the soil erosion risk (SER). The SER for the Wanzogi valley tank has increased by a factor 5 between 1985 and 2013 while spatial differences due to slopes, soil erodibility and vegetation cover are within 20 %. Reducing the production of charcoal and the corresponding cutting down of forests could significantly reduce the potential of reservoir siltation. Though unlikely, a change in the behaviour is essential for soil protection. This can only happen with institutional guidelines put in place by local and governmental authorities. Reports (NEMA 2010, NDC 2009, NFA 2005) have shown that a general awareness of the problem of forest degradation is present, but currently the economical need to burn and sell charcoal as well as to breed livestock exceeds environmental considerations.

Siting of the resource due to slopes and soil erodibility does not have a major impact on the SER. The only issue that has to be considered when excavating a new dam is the size of the catchment area. The case of the Kalungi valley tank, which never fills completely during rainy season due to the too small catchment area, proves that siting is an issue. For the Wanzogi parish, the siting of the valley tank is appropriate.

The correlation of protective measures at a water resource and the amount of faecal matter in the water is > 0.9. Hence, fences and the restriction of humans and animals to access the water body directly are very important to ensure good water quality and safe drinking water for the cattle. Water resources with a lack of protective measures have shown to provide water with dangerous contamination for humans and animals. Evaluation of the water quality parameters considered by this study has shown that the water of the Wanzogi valley tank is adequate for watering livestock.

Infrastructure to deliver water such as troughs and pumps are important if proper resource protection is in place. Portable troughs such as trunks and barrels usually go hand in hand with animals watering directly from the water body. The only sites where the animals did not access the water body were equipped with proper concrete troughs and pumping facilities such as in Wanzogi. The design of the Wanzogi valley tank meets all the standards suggested by the literature (as described in chapters 3.6 and 3.7) and conclusions drawn from the comparative analysis. Protective measures are in place, the dimensions are well designed and the water delivery facilities are appropriate. The only issue that does not correspond to the suggestions in the literature are the bank slopes that should be less steep to prevent bank erosion and people from falling into the water.

This research has shown that in order to ensure the functionality of the design, adequate management of the water resource is crucial. Only the future will reveal if the resource is run properly and the fence and watering facilities will last. With the newly organized organisational committee WWUCO, the structures are in place. Additionally the new laws requiring re-elections of committees managing communal resources every 2.5 years will help to bring new dynamics into the organisational structures and can be considered a first step of governmental authorities' reactions to the challenges faced. However, the past has revealed that the success of the project depends on people meeting their duties. The community management model suggests that a stronger connection to the local governments that provide technical assistance and monitoring is necessary to assure that the structures continue to work well. Especially a monitoring system is essential to ascertain that the problem of slack responsibilities doesn't occur again.

Follow up work at Wanzogi is important as part of the monitoring of the system. Having the infrastructure in place does not guarantee a functioning project and assisting the locals with technical help and guidance for their management structures could ensure that these structures and the facilities don't get lost over time. As the community management model has shown, many projects face challenges years after implementation. Having people, e.g. from Makerere University, assist the local livestock farmers in their management of the resource could ensure that the task doesn't get lost over time and additionally might produce further insight in the water availability and water demand as well as organisational challenges.

Concluding this study, the hypothesis has been validated. As long as the management structures work properly, the Wanzogi valley tank provides sufficient water to cover the current local livestock water demand.

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7 Annex

7.1 Abstract

In the beginning of 2013 a valley tank in the Wanzogi parish in central Uganda was desilted and enlarged as part of the Austrian sponsored WATERCAP project. Additionally, the valley tank was equipped with pipes, a pump and a concrete trough to facilitate watering animals. In the context of this thesis, the Wanzogi infrastructure was assessed regarding water availability, design and management. The underlying conceptual model for this research is *community management*, implying that the local community owns the infrastructure and is responsible for operation and maintenance as well as decisions on future development.

From a water balance approach, the valley tank holds sufficient water to cover the demand of the estimated 1500 head of cattle using the resource during long dry seasons of 130 days. However, there is little spare water for additional animals watering at the valley tank and the management structures need to make sure that the number of cattle led to the water source is within the limits that the water source is able to provide for. The siting and design of the valley tank are appropriate in light of the recommendations in the literature and the lessons learned from other valley tanks in the region. The water quality of the Wanzogi valley tank is well within the suggested recommendations for watering cattle. The study on soil erosion and sedimentation has shown that the main factor in an increased soil erosion risk is the dramatic degradation of the vegetative land cover over the past decades. To deal with this issue, alternatives to this location's economically essential businesses of charcoal burning and extensive stock-breeding need to be provided.

The infrastructure can be considered technically appropriate for its purpose and the major challenge that remains is proper operation and maintenance. Hence, the organisational structures are essential to ensure the project's sustainability. First steps have been taken, and with the recent formation of the Wanzogi Water Users Committee (WWUCO), responsibilities are clearly defined. Yet, the past has shown that the mere existence of organisational structures does not necessarily lead to a properly managed infrastructure. As a result of this thesis, establishing monitoring instances at an institutional level seems to be crucial to make sure all the involved parties meet their duties. To guarantee project success follow up work is needed to support the local committee and ensure that the infrastructure is operated and maintained properly.

7.2 Zusammenfassung

Durch das von der österreichischen Entwicklungszusammenarbeit finanzierte WATERCAP Projekt wurde Anfang 2013 in Wanzogi in Zentraluganda ein Reservoir zur Tränkung von Rindern neu ausgebaggert. Zusätzlich wurde auch ein Betontrog errichtet, sowie eine Pumpe und Leitungen zur Verfügung gestellt, um die Tränkung der Rinder zu vereinfachen. Im Rahmen dieser Diplomarbeit wird die errichtete Infrastruktur in Wanzogi in Bezug auf Wasserverfügbarkeit, Design und Management untersucht. Der theoretische Kontext dieser Diplomarbeit ist *community management*, die lokale Gemeinde ist selbst Besitzer der Infrastruktur und gleichzeitig verantwortlich für Betrieb und Instandhaltung.

Die Analyse der Wasserbilanz hat ergeben, dass das Reservoir genug Wasser für etwa 1500 Rinder während besonders langen Trockenzeiten von 130 Tagen fasst. Gleichzeitig wurde aber festgestellt, dass die Reserven für längere Trockenzeiten oder zusätzliche Rinder aus der Umgebung sehr gering sind und daher sichergestellt werden muss, dass die maximale Anzahl an Rindern nicht überschritten wird.

Standortwahl und Design des Reservoirs sind angemessen bezogen auf Empfehlungen aus der Literatur und verglichen mit anderen Reservoirs in der Region. Die Wasserqualität in Wanzogi ist geeignet zur Tränkung von Rindern. Eine Untersuchung des Bodenerosionspotentials hat ergeben, dass der ausschlaggebende Faktor für zunehmende Bodenerosion und Verschlammen des Reservoirs die fortschreitende Abholzung der Wälder in den letzten Jahrzehnten ist. Um dem entgegenzuwirken, müssen Alternativen zur Erzeugung von Holzkohle geschaffen werden, die für die Menschen wirtschaftlich unerlässlich ist.

Die Infrastruktur ist zur Tränkung von Rindern technisch geeignet und die größte Herausforderung ist der Betrieb und die Instandhaltung des Systems. Das bedeutet, dass die organisatorischen Strukturen wesentlich sind um die Nachhaltigkeit des Projektes zu gewährleisten. Ein erster Schritt wurde durch die Bildung eines Komitees getan wodurch die Verantwortlichkeiten klar definiert wurden. Die Vergangenheit hat aber gezeigt, dass die Existenz solcher Strukturen nicht notwendigerweise zu gut gemanagter Infrastruktur führt. Ein Ergebnis dieser Diplomarbeit ist die Notwendigkeit der Einrichtung von Kontrollinstanzen, um sicherzustellen, dass alle Beteiligten ihren Pflichten nachkommen. Um den Erfolg des Projektes zu gewährleisten, ist in jedem Fall eine Nachbereitung notwendig um das lokale Komitee zu unterstützen und sicherzustellen, dass die Infrastruktur angemessen betrieben und gewartet wird.

7.3 Curriculum Vitae

Personal details

Name:	Christian Scherer
Date of birth:	25.07.1986
Nationality:	Austria

Education

2009 – 2014	Individuelles Diplomstudium „Internationale Entwicklung“ (“International Development”)
2012 – present	Master’s degree „Kulturtechnik und Wasserwirtschaft“ (“Environmental Engineering”)
2009 – 2012	Bachelor’s degree „Kulturtechnik und Wasserwirtschaft“
Feb. – June 2011	ERASMUS students exchange, Valencia, Spain
June 2005	Matura (A-levels) at HTL Villach

Internships and practical experiences

2005 – 2007	GBA ships e.V., technical staff member
2008	Centro de Formación “Granja Hogar”, alternative civilian service (teacher), San Ignacio de Velasco, Bolivia
July – Sept. 2010	Amazon Fund, internship – water supply project, San Luis Grande, Bolivia
2012 – present	Vermessung Fuchs-Stolitzka (surveyor’s office), surveyor

Language skills

German	native speaker
English	fluent (written and spoken)
Spanish	fluent (spoken)