Two containers of water a day; in quest of environmental sustainability and public health for the rural poor

Water quality, multiple uses and water division in the Lege Dini watershed area, Ethiopia; Towards a Multiple Use System Approach

M.Sc. Thesis by Pauline Scheelbeek

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Master thesis Irrigation and Water Management submitted in partial fulfillment of the degree of Master of Science in International Land and Water Management at Wageningen University, the Netherlands

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Preface and Acknowledgement

During the four years studying at the Wageningen University, I had learned a lot about the importance of water, irrigation and integrated watershed management, all focused on agricultural use of water and the problems it can bring along. However during my Bachelor-thesis and internship I came across another burdensome problem, that both the rural and the urban population are facing; inaccurate access to proper drinking water sources. While searching for a thesis project I preferred a topic that would combine these uses into an integrated resource project. In that time the International Water Management Institute was searching for two students to conduct a pilot study in Ethiopia to identify and tackle the initial thresholds of their new MUS-project. This match led to the cooperation between IWMI and the Wageningen University and gave me the chance to involve myself in a very interesting research.
During this thesis research I've broadened my knowledge about the health aspects of water enormously and I came back to the Netherlands enthusiast about Ethiopia, my research and this particular work field in which I would prefer to find a job after graduation.
Writing this report was somewhat delayed by the fact that I decided to enroll in some compulsory courses at the same time; however these courses provided me from new ideas for this thesis report.

This research would not have been completed without the help of people around me. First of all I would like to thank all translators, drivers and field assistants who helped me to collect the information needed. Special thanks to Aklilu Alemu and Radju Muhammed, who besides translations, explained a lot about the Ethiopian culture and norms and values. Also thanks to the staff of the HCS, especially Belehu Negesse, Tefary Gezahegn, Zemede Abebe, Mesfin Sahele and Tadesse Defabachew and the friendly and helpful staff of CRS, Ann Bousquet, Amsalu Gebreselassi, and Hazel Simpson. Also I would like to thank my external advisors Wim van de Hoek and Flemming Konradsen for their valuable contribution.

In the laboratory of Alemaya I was provided with excellent help of Dick Montijn. Without him I could not have done the water analysis. Thank you very much.

Furthermore I would like to thank all colleagues of IWMI; Krishna Prasad, Seleshi Bekele, Phillip Lampierre, Nigist Wagaye and also Kai Sonder for his contribution to the maps we made from the area. I also want to thank Stephanie Good for her company during the stays in Addis Ababa and my family and friends for their positive support from the Netherlands.

In Dire Dawa I received important information from two persons that although the language barrier was big became great friends; Antenneh Sanew and Girma Yohannes. Together with them, Dire Dawa was a very nice place to stay.

Two persons were very important during my stay in Ethiopia. First of all I want to thank Martine Jeths for her contribution and critical view on our fieldwork which forced me to think about my fieldwork from different points of perspective and the nice company in Dire Dawa. And secondly I want to thank Andres Verzijl for his support and great help during his stay in Ethiopia. Without him I would not have managed to complete all interviews and get valuable answers from male respondents. Thank you very much!

Last but not least I want to thank my second reader Harm Boesveld and my supervisors Eline Boelee and Frans Huibers for all their recommendations, ideas and discussions, which inspired me a lot while writing my proposal, doing the fieldwork and writing this thesis research. I was very pleased with your supervision!

Summary

Access to clean drinking water, proper sanitation and sources of a satisfying quality and quantity for livestock watering and irrigation is the key-factor for an arid region to become and/or to stay self sufficient. The quality of drinking water has a direct effect on human health, since contaminated water is causing for example diarrhea, which on its own is responsible for 5.000.000 deaths per year.
In rural areas, families often depend on livestock and agriculture. Taking care with choosing and applying a certain water source is therefore very important. Contaminated water will sicken the livestock while irrigation with improper irrigation water, can lead to yield reduction and irreversible damage to the soil. The United Nations realize the importance of water and adopted this issue in Millennium Development Goal 7.
The International Water Management Institute (IWMI) developed a strategy called the Multiple Use System Approach, to contribute to the solution of the worldwide water problem. According MUS designers and management organizations should take into account multiple water uses while designing a delivery system. Especially in rural areas nobody needs the water for just one use, but always a combination of uses. Therefore water delivery should be combined as well.
In arid areas with small sources, MUS supports a multiple source for multiple use approach; clean water sources should be used for drinking water and contaminated sources for uses with a lower water quality requirement. This means that villagers with access to clean drinking water should share the drinking water with their neighbors instead of using surpluses for livestock and irrigation.
Proper sanitation is another prerequisite for a healthy environment. If human and animal excreta are spread all over the communal areas and compounds, pathogen transfers via the diverse pathways are likely to occur. Besides from that, excreta can end up in water used for drinking, livestock or irrigation, which can lead to diseases, reduced harvests etc. Education about sanitation and hygiene within the household will increase the awareness of the local population and will stimulate them to take care of these issues.

In this research the possibilities of MUS are explored in a case-study watershed; the watershed of Lege Dini. The health situation in this area was poor. Many people suffered from diseases like diarrhea, vomiting and less frequently malaria. Clean drinking water was available in five out of eleven villages and inhabitants without access to tap water were forced to drink water from contaminated well and ponds. The quantity of water was also not sufficient for all domestic and agricultural uses. This made it impossible for the area to become self-sufficient. Although many NGO's and other development agencies were active in the area, the aid-service was poor coordinated. The result of this was that although the operating organizations invented good and effective solutions for the water and health problems in Lege Dini, these were unfortunately not widely adopted. Only the participants of an education program were often willing to change their habits. An annual assembly of development organizations, in which the plans and projects for the coming year would be discussed, would eliminate the communication and coordination problems.

By investigating the water sources, two turned out to be suitable for drinking water. The discharge of these two sources was also sufficient for the whole population of Lege Dini. Other sources were suitable for livestock and irrigation. The EC-level is rather high for irrigation, but since there is no other source available, irrigators should select tolerant species like tomatoes to grow on their plots. Most farmers mention that they see irrigation and selling cash crops on the market as one of the opportunities towards self-sustainability.

Since the tap water from one of the sources defined as drinking water source is used for livestock as well, new sources (near the homestead) have to be created, to assure the owners of the livestock to have sufficient water for their animals. The possibilities for additional water sources were diverse. Rainwater could be collected by installing rainwater harvesting installations on the roofs of some houses. This water can be stored for drier periods, or as emergency stock. Just outside the villages, water harvesting ponds can be created, as water source for animals. If properly cleaned and protected by a fence this water could be used as emergency stock for drinking water as well. This has to be accompanied by a protection project for the vegetation cover of steep slopes around the villages, since livestock sources near the homestead takes along an increased risk of overgrazing.

Another amount of water than can be created is by reusing wastewater. This can be used for e.g. irrigating the crops, or if the family doesn't own land, for extra hygiene inside the household. After irrigation and livestock, the main destination of an additional amount of water was said to be hygiene by the respondents.

The MUS-approach seems to have positive effects on the health situation in Lege Dini and contributes to the goal of self-reliability. A healthy environment is the basis for fewer diseases and therewith more manpower for farming and other income generating activities.

A threshold for implementing MUS worldwide will be the distance between village and source in the case of 'multiple sources for multiple uses'. The walking distances for remote villages in order to obtain clean drinking water will be too large. A threshold for 'multiple uses in one system' will be the cooperation between ministries of health and ministries of agriculture, which is difficult to establish in a bureaucratic setting.

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1. Introduction and Background

The Universal Declaration of Human Rights recognizes the inherent dignity and the equal and inalienable rights of all human beings (UN, 1948). One of these fundamental rights is the access to proper drinking water and sanitation.
Around one sixth of the more than 6 billion people in the world lack the access to improved sources of water and about 40% don't have access to improved sanitation services according to a WHO publication of the year 2000. Five million people still die each year as result of a diarrheal disease, which is mainly caused by improper sanitation and lack of clean drinking water.

Besides drinking water, water for livestock and irrigation is a very essential element for survival especially in developing countries like Ethiopia. Without livestock the transport and tillage possibilities of the rural population are very restricted. In semi-arid and arid areas without irrigation, the harvest is insufficient for the farmer to make a living, and cash crops can not be cultivated. Since water resources are very scarce in these regions, the division and sustainable use of water is crucial for the development of rural and urban areas.
The United Nations recognizes the problems and admits the importance of sufficient drinking water, sanitary facilities and sustainable water management. Therefore this issue is adopted in one of the eight Millennium Development Goals that were set in 2000 (MDG 7, UN, 2000).
This research tries to contribute to the improvement of the water and food security in the world by analyzing the possibilities for an integrated approach to multiple use of water (MUS-approach) in eastern Ethiopia. In this analysis limitations and opportunities will be identified and possibly tackled, contributing to a widespread implementation.

This research is a MSc. thesis research within the Master program of International Land and Water Management (specialization Irrigation and Water Management) at the Wageningen University. It was conducted in Ethiopia under supervision of Dr. F. Huibers, lecturer at the Wageningen University and Dr. Eline Boelee, researcher Irrigation and Health at the International Water Management Institute in Addis Ababa Ethiopia.
The study was conducted as part of the Multiple Use System Project (MUS-project), which will be explained in detail in chapter 4. The MUS-project has five lead partners; the International Water Management Institute (IWMI); IRC, International Water and Sanitation Centre, Delft; Mekelle University, Ethiopia (MKU); International Development Enterprises (IDE) and Khon Kaen University, Thailand (KKU).

The Catholic Relief Service (CRS) office in Ethiopia with its national partners is currently the most important implementing partner in the project. CRS had selected the Lege Dini integrated watershed development project, implemented by its partner the Hararghe Catholic Secretariat (HCS), as the first field site for the MUS project in Ethiopia. CRS and HCS provided logistical support to this study, such as transport field assistants, drivers and translators. In addition the International Livestock Research Institute (ILRI) seconded a field assistant to the project.

The field location was visited once before the study by a researcher of IWMI. One of the disadvantages of the location was the fact that the irrigation component of the area was rather small. The focus of this research therefore switched during the preparation phase from a focus on irrigation as one of the multiple uses of water towards especially drinking water and water for livestock.

2. Introduction on Ethiopia

2.1 Facts about Ethiopia

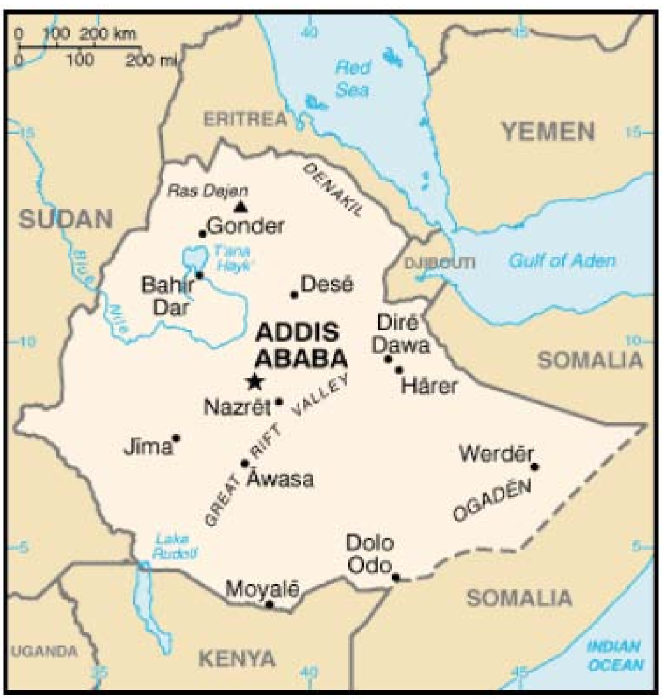
The Federal Democratic Republic of Ethiopia counts a population of 67.9 million inhabitants that is sharing the 1,127,127 square km of land (CIA, 2004). This population lives roughly in three agro-ecological zones (Caldwell, 1992): the *dega,* which is the area located at an altitude of 2300 meter and higher, the *weyna dega*, with an altitude ranging from 1500 to 2300 meter, and the *kolla*, located in the lowlands between 500 and 1500 meters.

The country is predominantly agrarian with 85% of the population living in rural areas. However, the total amount of arable land is just 10.71% of the total surface and land under permanent cropping only 0.75% (CIA, 2004).

The climate differs with the altitude of the country. In the highlands the temperature is always low, while in the lowland the temperature can reach tropical ranges. Ethiopia has two main seasons; the *keremt* (wet) and *bega* (dry). The wet season extends from June to September and provides the necessary rain for productive and domestic purposes. The annual rainfall distribution varies from less than 100 mm along the Somalian border to 2400 mm in the highlands of southwest Ethiopia.

The population is relatively young; 44.7% of the total population is younger than 14 years old. The average life expectancy is at birth is 46 years old (WHO, 2005), which is a result of the high child mortality in the country (about 15%).

Ethiopia's economic situation is very poor; the country belongs to the three poorest countries in the world. The GDP per capita in 2003 was less than 98 dollars (Worldbank, 2005). The CIA calculated a GDP/capita purchasing power parity, which meant for Ethiopia a GDP of US$ 700 per capita. (CIA Fact book, 2005). The gross national income (GNI) is about US$ 90 per capita in 2003. (Unicef, 2003) The country has been under food-aid since many decades, but the maximum loads of grain Ethiopia received during the two major famines in 1973 and 1984/5. Till now many regions in Ethiopia are still dependent on food aid (Jayne et al, 2000). From all households 49% still has a food deficit of 2.7 months average. (Worldbank, 2005)



Map 1: Ethiopia and neighbouring countries

Seven important ethnic groups can be distinguished in the country; The Oromo is the largest ethnic group, which covers 40% of the total population. 32% belongs to the Amhara and Tigre group, 9% is Sidamo, 6% Shankella, 6% Somali, 4% Afar, 2% Gurage 2% and 1% belongs to other small ethnic groups. Besides the diversity in ethnic groups, the country is divided in three religious groups. Almost 50% of the population is Muslim; almost 40% Orthodox Christian and 12% is Animist.

Amharic is the official language in Ethiopia, while English is the major foreign language taught in schools. The literacy is low; half the male population is not able to read and write, while 61% of the women are illiterate. (Unicef, 2000)

2.2 Agriculture and Productive Uses of Water

The most commonly cultivated crops in Ethiopia include a variety of cereals, pulses, oilseeds, and coffee. The most important field crop is grain, such as Teff, wheat, barley, corn, sorghum and millet. Teff is an indigenous grain of Ethiopia and is a basic ingredient for the staple food '*injera'* a sort of unleavened bread in the form of a pancake. Pulses are the second most important element in the national diet and a principal protein source. They are boiled, roasted, or included in a dish known as *'wot'*. (Major Staple Crops, 2004)

Picture 1: Harvested Teff is conserved in large heaps. The edible parts are stored inside, while the stalks can be seen from the outside

The Ethiopian Orthodox Church traditionally forbids consumption of animal fats on many days of the year. As a result, vegetable oils are widely used, and oilseed cultivation is an important agricultural activity. The most important oilseed is the indigenous *Niger* seed (neug), which is grown on more than 50 percent of the area devoted to oilseeds. (Major Staple Crops, 2004)

Ensete, known locally as false banana, is an important food source in Ethiopia's southern and south-western highlands. The consumption of vegetables and fruits is relatively limited, largely because of their high cost. Common vegetables include onions, peppers, squash, and a cabbage similar to kale. Fresh fruits, including citrus and bananas, as well as fresh and frozen vegetables, became important export items, but their profitability is marginal. (Major Staple Crops, 2004).

Less information is available about the major crop of the eastern part of Ethiopia; Chat (Chata Edulis), a mild stimulant evergreen tree. It grows under wide climatic and soil conditions, and tolerates drought for several months, which makes it suitable for the unreliable Ethiopian weather conditions. The cultivation is believed to start in Ethiopia in the early 14th century. The farming system has shifted from mono-cropping in the beginning to intercropping of maize and sorghum between rows of chat. The cultivation of chat in many times increases the household income and many farmers in the east of the country have improved their life standard. However increased income has not resulted into an increased investment in cereal production for the local market and the problem of food deficit remained at national level.

Irrigation has so far not been very important in the agricultural development of Ethiopia. Its irrigation potential cannot be determined since the data about irrigation are unreliable. In the study of Teshome (2003) however the country's potential is estimated at 2.5 million hectares, while currently 197, 100 hectares are under irrigation. Nearly half of this area is irrigated on the small-scaled traditional way. Farmers often have very small irrigation plots and up-scaling will not be possible in this type of irrigation. Since drainage is barely taken present in some areas, the soil is degrading and sodicity and salinity problems occur.

From all potential rainfall, only 3% remains in the country, the rest is lost in the form of run-off to the lowlands of neighboring countries (CIA, 2004). In some areas roof catchment-

installations are promoted, but like the situation described before, this is often very small-scaled.
Crops that receive irrigation are mainly vegetables and other cash crops, which can be sold on the market. Cereal crops like sorghum and maize are almost never irrigated.

2.3 Domestic Water Uses, Sanitation and Health

Ethiopia has a predominantly rural population. The health status of the inhabitants is low compared to other low-income countries, while the population growth is very high in comparison. The health problems are mainly the result of the widespread poverty along with low education levels, poor access to good quality drinking water, absence of sanitation facilities and inadequate access to medical services.
Ethiopia has many times affected by outbreaks of drought, famine, diseases and conflicts, which have helped to preserve some of the worst demographics, food insecurity and health conditions in the world. In 2000, 26.3% of the Ethiopian population lived well below the poverty level as defined by an income of less than $1.00/day (Rural Poverty Portal). More than 80% has to make a living from less than $2.00/day (Rural Poverty Portal). Ethiopia has a long history concerning periods of drought, which mainly affected the northeastern region of Ethiopia; Wollo, Tigray and Shewa. On of the most intensive drought periods took place in 1971-1975 and caused 250,000 people to die and in Wollo and Tigray half of the livestock was lost (Webb et al., 1992).
About 70% of the health problems are of direct result of nutritional problems. (Begashaw, 2002). The most common diseases that occur are the acute respiration infection, nutritional deficiency and diarrhea. Other frequently occurring diseases are malaria (especially for children under five) and HIV/AIDS.
The capacities of the hospitals and medical facilities are by far not able to provide all inhabitants with medical services; one medical doctor has to serve 47,976 persons a nurse 8460 and a health assistant 8847. (Begashaw, 2002)

UNICEF conducted research in 1990 and 2000 and compared the percentage of the Ethiopian population with access to drinking water sources. While the percentage of rural people that had access was going down, the percentage of urban people stayed more or less equal.

Access to improved drinking water sources in % of the total Ethiopian population		
	1990	**2000**
Rural	17%	12%
Urban	80%	81%
Total	25%	24%

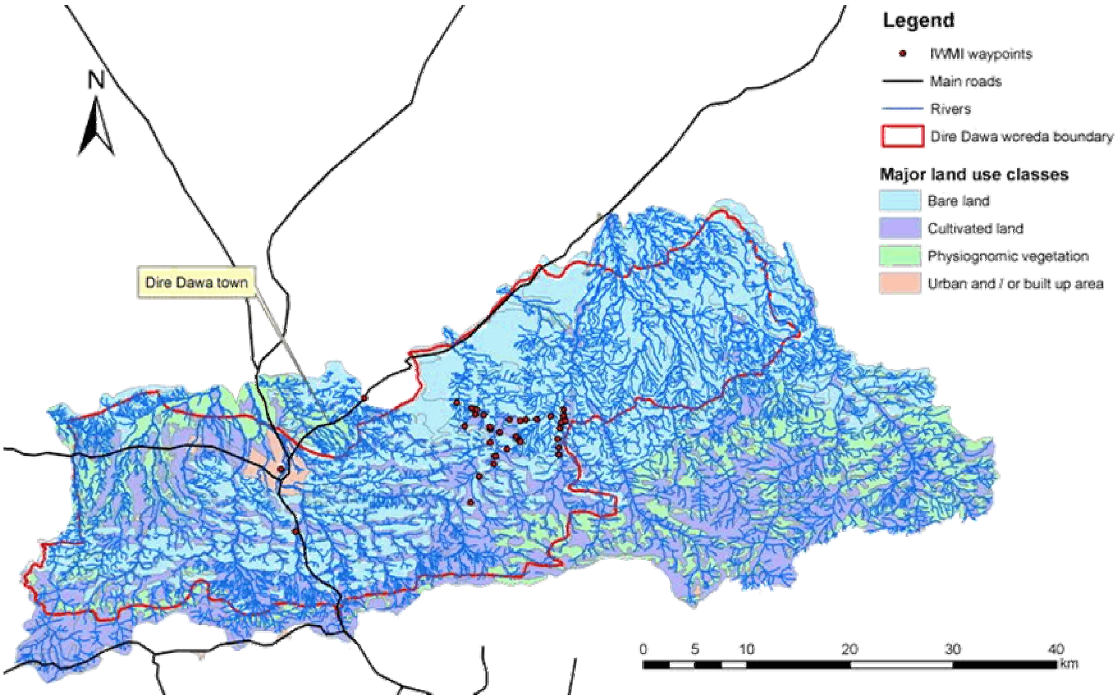
Table 1: Percentage of population in 1990 and 2000 with access to improved drinking water sources in Ethiopia. Source: WHO-UNICEF, 2001

Picture 2: Water tap in Lege Dini. These taps are installed by UNICEF

According to official estimates (2004) 32% of the Ethiopian population has access to adequate drinking water in 2004. Adequate water supply is defined by the FAO as 20 liters per capita per day within a range of 2 km from their homes (FAO, 2004). Only 17% has got access to adequate sanitary facilities, which is the major cause of infections and diseases like diarrhea. Diarrhea is accountable for 46% of child mortality. Health programs however pay little attention to sanitation problems and usually focus on drinking water.

3. Description of the Research Area

Lege Dini, the Peasant Association (PA) where this research was conducted is situated in the Eastern part of Ethiopia in the *Woreda* (district) of Dire Dawa. The area covers 9,300 hectares and the population is estimated at 270 families, which means about 1,600 heads. Since a lot of visitors use the resources in the area, the population estimated to use the water resources is 3,875. (HCS, 2002)



Map 2: Location of the research area. The waypoints are symbolising the villages and enlarged in map 3

The altitude ranges from 1,100 meters to 1,600 meters above sea level and the annual rainfall, although unreliable, fluctuates between 420 and 650 mm. The average day temperature is 26 to 30°C. Due to the topography (rugged and undulated land) only 210 hectares are suitable for cultivation. The average cropland per household is 0.78 hectare. (HCS, 2002)
Lege Dini includes 10 villages and most of its inhabitants are agro-pastoralists. Two villages (Lallo and Kore Chafe) are seasonal villages. In these villages, most families travel around with their livestock during the dry-season and come back to their villages in the rainy-season. The major crops cultivated by the farmers are maize and sorghum. In some villages papayas are grown on small plots. The livestock owned by the people in Lege Dini mainly exists of camels, cows, oxen, donkeys, sheep and goats. The farmers cultivate about 30% of the required food-production; 70% is coming from the aid-organizations. (UNICEF, 2005). All villages in Lege Dini are dependent on the aid-projects provided by the government, different NGOs and UNICEF. The projects are mostly food-for-work projects wherein amongst others water-harvesting ponds, terraces, wells and roads have been constructed (UNICEF, 2005).

The water sources in the area are diverse. Four villages (Ajo, Iddo, Iddo Bolo and Halo) have access to water that is pumped up from a borehole and stored in a reservoir. From this reservoir pipelines lead the water to fenced water points with taps inside the villages. One village (Kora) has access to a spring that is lead via pipelines to a fenced tap. Inhabitants of other villages that do not have access to clean drinking water sometimes buy their water in Ajo or Kora as well. In general the health situation improved a lot if compared to the situation before this borehole and spring.

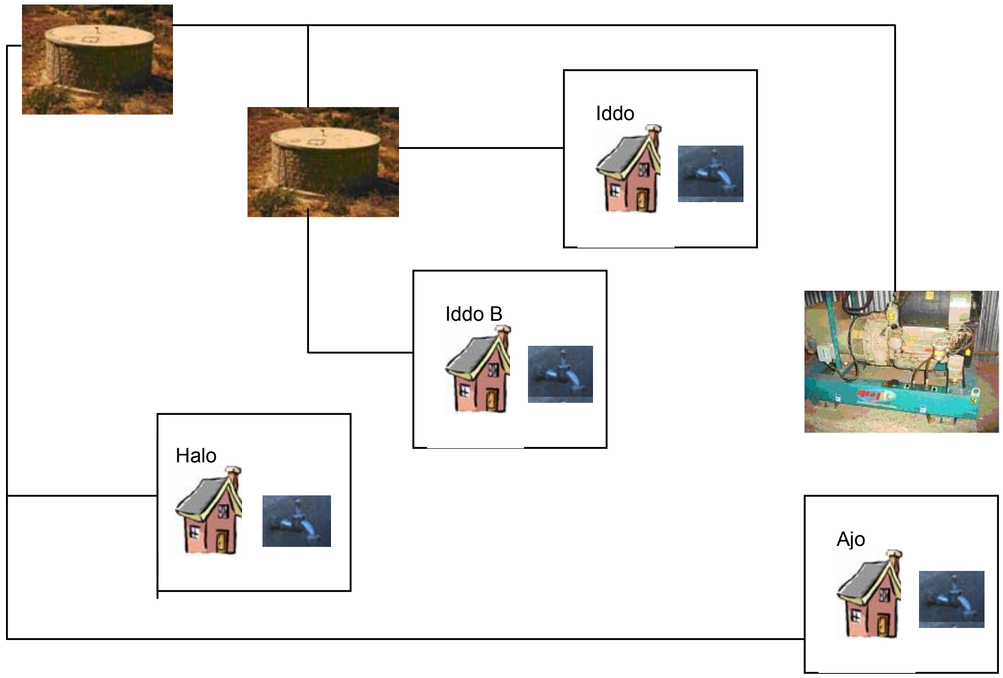
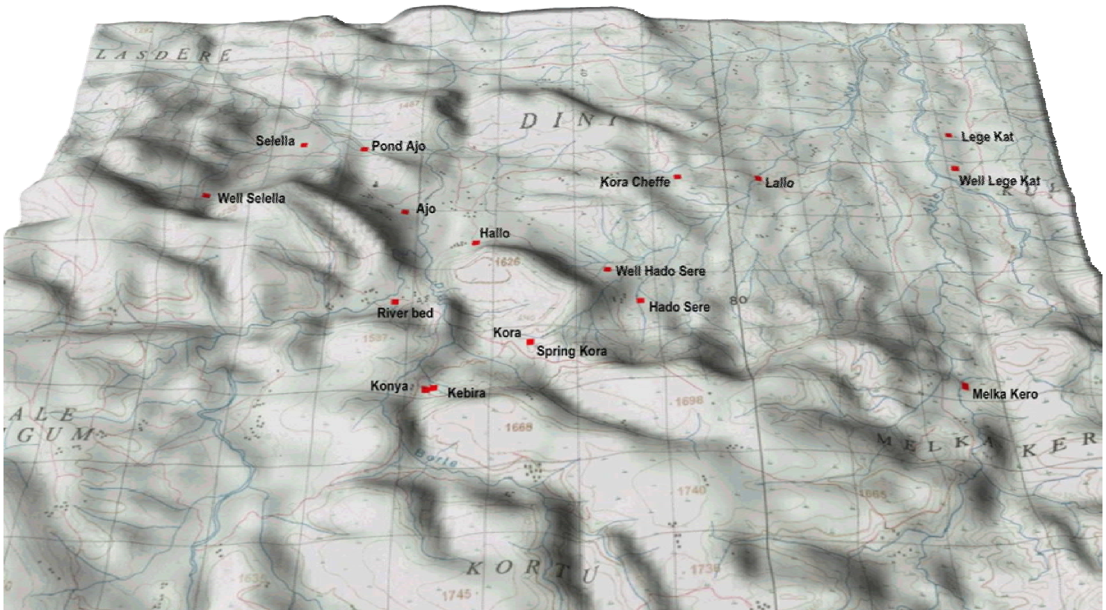


Figure 3: Schematic overview of the water delivery system of the borehole in Ajo

Near each of two villages (Hado Sere and Selela) a well is situated where water can be collected. Three other villages (Kore Chafe, Lallo and Konya) have no water source in or near their villages and rely on the sources of neighboring villages.
Livestock water sources can be found inside and outside the PA. In some villages, livestock drinks from the same source as the farmers, but mostly the animals are herded to a pond or well. Smaller animals, like goats and sheep, often receive water from the household containers or wastewater.

Irrigation is not applied frequently and most crops are cultivated rainfed. There are two common ways of watering plants. The first one is surface irrigation by digging a small canal from the washing or drinking place to the fields. In that way wastewater will be used for irrigation. The second way of watering is by drip irrigation. The USAID tin cans that brought cooking oils as part of food are tied to a branch of a tree or a bush and are used to store the water for each crop. In the bottom of the can, the villagers made a lot of tiny holes that regulate the water supply to the crops. Irrigation is only applied in the villages with good access to water (the villages with the tap-installation); hence the wells and ponds are barely used as irrigation source. Mostly tap water and in smaller amounts wastewater is used for watering of especially papaya and vegetables.



Map 3: The villages of Lege Dini in a relief picture

The PA of Lege Dini is part of the Water Sector Development Project. The WSDP set up targets concerning urban and rural water supply. The targets are divided into short-term, medium-term and long-term targets, which indicates that the target has to be reached within 5, 10 and 15 years respectively. The existing situation in 2001 was that in the region of Lege Dini and surroundings 91.000 people form the total rural population. In that year, the WSPD was covering 37% of this area, which meant that 34.000 persons were served by rural water supply. For the Dire Dawa region, where Lege Dini is situated, these targets are mentioned in the table below (WWDSE, 2001).

End 2006			***End 2011***			***End 2016***		
Total rural pop. (x1000)	*Rural coverage %*	*Rural population to be served (x1000)*	*Total rural pop. (x1000)*	*Rural coverage %*	*Rural population to be served (x1000)*	*Total rural pop. (x1000)*	*Rural coverage %*	*Rural population to be served (x1000)*
102	49	50	112	66	74	120	90	108

Table 2: Short-, medium- and long-term targets of the WSDP to serve the rural population with (drinking) water. Source: WWDSE, 2001

The Water Sector Development Program, as well as the MUS-project distinguishes different types of water demands. The important sectors for this research are (WSDP, 2002):

1. Domestic Water Demand (DWD). The design standard that is adopted for rural areas in Ethiopia is 15-25 l per capita per day. At the end of 2006 the domestic water demand is projected on 15 lpcd, at the end of 2011 this will be 20 lpcd and at the end of 2016 it is planned to provide 25 l water per capita per day.
2. Livestock Water Demand (LWD). The water demand for livestock is only calculated in case there are no streams, lakes, ponds etc. in the vicinity where the livestock can drink. In case potable water schemes are to be used for livestock, an amount of 3 lpcd is estimated. In the highland rural areas the average LWD was considered to be 20 liter per Livestock Unit (LU), with an average of 1.7 LU per person. In the lowland rural areas, LWD was estimated on 25 liter per LU, with an average of 3.0 LU per person. (WSDP, 2002)

These targets are used for calculating the total amount of water needed in Lege Dini for multiple uses.

4. Multiple Use Systems

4.1 Introduction

In the last decades a lot of effort has been put into tackling poverty. Different plans and projects were developed to create possibilities for dealing with the problems this poverty brings along. One of the possibilities for change was irrigated agriculture. Irrigation made it possible to harvest a higher yield and start cultivating other types of crops (such as cash crops) creating more economic support for the farmers (Chaturvedi, 2000).While with these irrigation projects, the yields (and also income) of the farmers did increase, in conventional irrigation system planning the designers only focused on the productive uses of water, hereby missing important opportunities. Practice shows that the water from these irrigation systems is often used for other purposes than merely agricultural crop production, especially in places where there is poor domestic water supply but a good irrigation infrastructure (Van der Hoek et.al, 2001). In many cases these multiple uses of water are informal and often considered illegal.

On the other hand when it comes to solving poverty problems, people are inclined to focus on save drinking water. Safe drinking water is indeed a primary need of everybody and is recognized as a basic human right. A drinking-water delivery system will increase the health situation of the poor, since it provides besides drinking water, also possibilities for better hygiene and sanitation. However, drinking water alone will not create direct economic benefits for the farmers. Taps and other facilities will often be installed without realizing that water for productive uses does improve the financial situation of the farmer and therewith his capacity of tackling his problems the poverty brings along.

Especially in the rural areas, all individuals need their water for multiple uses that all require different qualities, quantities and timing. In case of multiple sources with different water qualities, already in the design phase the possibilities for different sources for different purposes should be considered.

Besides from the infrastructure that is seldom suitable for multiple uses, the management of water is often divided over several sectors. Water for domestic use is supplied by the drinking water and sanitation or health sector and water for irrigation often by the agricultural sector. This makes it very complicated to merge multiple uses (and sometimes multiple sources) in one system, since in this case projects need to be organized not only practically but also institutionally. Different sectors need to cooperate with each other and that will only be possible if there exists insight in the fact that different uses can not be seen independent from each other.

Another problem that has to do with this integration of sources is the access to safe drinking water and forms part of the seventh Millennium Development Goal of the United Nations; '*Reduce by half the proportion of people without sustainable access to safe drinking water'* (UN, 2000).

In an area with several water sources this addition 'safe' becomes very important. In many rural areas drinking or irrigation systems are constructed from the nearest source to a certain village. As described above, the water is often (legally or illegally) used for all domestic and productive purposes. Problems start to occur if the system that was meant for irrigation, indeed serves water of an 'irrigation quality', unsuitable for drinking. If people are allowed to collect some water from these canals for domestic use, the water they drink will not be 'safe' for drinking, but people may be unaware that the water needs further treatment before consumption. Such a situation may occur in one village, while in the neighboring village a drinking water system is used for irrigating the crops. If at an early stage the quality of the different sources is determined, it will be possible to establish what source can be used for what purpose. If the opportunities are there, sources can be shared in order to provide access to safe drinking water for all people, while sources from lower quality can be shared for livestock, irrigation and other productive uses.

4.2 Success factors of Multiple Use Systems

Recently the discussion is started among scholars and institutions that promoting multiple use water supply systems might be the way to provide the poor with sufficient water and so create new opportunities for tackling poverty.

The International Water Management Institute, together with IRC, NRI, MKU, KKU and IRD created the MUS-project in order to examine how to implement these supply systems in areas where water is a scarce resource. The definition of MUS as used by the project is '*A multiple-use system (MUS) is the sum of the institutions, services, resources and infrastructures that allow communities to effectively and inclusively manage their water resources and the domestic and productive uses of water.*' (Anonymous, 2004). In this definition, three types of systems can be distinguished that are listed below.

- Productive Plus-systems are originally designed for delivering water for irrigation or other productive purposes, while in practice the water is also used for domestic uses, such as laundry, bathing and cooking. Also seepage water from canals that is reused for domestic use can be considered productive plus
- Domestic Plus-systems are designed to provide domestic water for drinking and sanitation, whereby the water is also used for other domestic and productive uses such as watering the home garden, brick making, laundry, livestock and food processing (e.g. beer)
- Multiple Use Systems; these systems are designed for all desired uses (domestic and productive) in a certain area

One of the advantages of the MUS-approach is its efficiency at different levels. First of all it creates a favorable situation at the economic level. If multiple uses are considered in the design phase, a more efficient infrastructure can be created that merges these multiple uses. A merged system will have an economic advantage, since creating a system for all uses will be probably less expensive than several systems that each serves a single use.

Another level where efficiency will be achieved is with regard to water quality. If the MUS-approach succeeds in implementing the 'multiple sources for multiple uses-idea' all water sources will be used efficiently in their own category; clean water sources only for drinking water and more contaminated sources for uses that require a lower quality. This reduces the requirements for treatment.

Furthermore the MUS-approach will contribute to the improvement of human health by promoting safe drinking water for all.

4.3 MUS -project

As described in chapter 2, water is a very scarce resource in large areas of Ethiopia. Especially people living in the rural areas are strictly limited in their water use on both productive and domestic level.

The Ethiopian economy is largely based on agriculture. The sector provides 50% of the GDP, 85% of the export and eight out of ten persons find a job in agriculture. (Werfring, 2004) Almost all crops are grown on a rainfed basis; less than 5% receives irrigation. There are different types of irrigation, but traditional smallholder is mostly applied in about 63,000 ha. (Werfring, 2004) As a consequence, Ethiopian agriculture is very vulnerable to droughts and erratic rainfalls.

Like many developing countries, Ethiopia with the help of foreign aid-organizations is trying to tackle the problem of poor access to clean drinking water. At the moment however Ethiopia is still far from reaching the Millennium Development Goals on this point. According to official estimates only 24% of the Ethiopian population has access to safe (and enough) drinking water, according to the FAO standards of at least 20 liters per capita per day within a range of 2 km from their homes (FAO, 2004).

To contribute to the improvement of the Ethiopian situation, the MUS-project will design, test and promote models, guidelines and tools that provide an efficient way of delivering water for both domestic and productive uses. Furthermore the project searches for ways of upgrading existing systems. Since one of the project goals is to fight poverty research will be done on how small-scale productive uses of water at the household level can be promoted in order to reduce this poverty. The official title of the MUS-project is *Challenge Program Project CPWF-28: Models for Implementing Multiple-use Systems for Enhanced Land and Water Productivity, Rural Livelihoods and Gender Equity*. It is part of the Challenge Program Water and Food (CPWF-28) of the CGIAR. The project wants to contribute to achieving three out of the eight UN Millennium Development Goals:

- Development Goal 1: Eradicate extreme poverty and hunger
- Development Goal 3: Promote gender equality and empower women
- Development Goal 7: Ensure environmental sustainability *(CPWF-28, 2003)*

The project will be executed in eight countries spread over five river basins, including Ethiopia in the Nile basin.

IWMI’s development partner for the MUS-project in Ethiopia is CRS (Catholic Relief Services). CRS is working with several Catholic missions throughout Ethiopia. One of them is the Hararghe Catholic Secretariat (HCS) in the eastern part of the country. This mission has a special office focusing on development work in Dire Dawa town. Lege-Dini is one of the sites where HCS has development activities related to natural resource management and where they have tried to establish a multiple use system. CRS has selected this site for IWMI to use it as one of their learning sites in the MUS-project.

5. National and International Guidelines

Guidelines can help to define to what extent something is safe and what the risks are if the maximum values are exceeded.
In this chapter, some (inter)national guidelines are presented, that are helpful in this research and are guidelines that are established or followed by organizations involved. Since the research is conducted in a developing country, such international guidelines are usually too strict. In developing countries there are many factors influencing water quality after delivery to the users at the water point. Therefore it is not worth to invest millions in meeting those guidelines exactly.

5.1 United Nations Millennium Development Goals

In the year 2000 the United Nations agreed upon the United Nations Millennium Development Goals. All United Nations Member States have pledged to meet these goals by the year 2015. For this research the following goals are important (UN, 2000):

1. ***Eradicate extreme poverty and hunger***
   - Reduce by half the proportion of people living on less than a dollar a day
   - Reduce by half the proportion of people who suffer from hunger

3. ***Reduce child mortality***
   - Reduce by two thirds the mortality rate among children under five

7. ***Ensure environmental sustainability***
   - Integrate the principles of sustainable development into country policies and programs; reverse loss of environmental resources
   - Reduce by half the proportion of people without sustainable access to safe drinking water and basic sanitation.

The importance of proper sanitation is internationally recognized. This led to the international agreement that drinking water projects must be accompanied by a sanitation part.
Due to the inadequate sanitation, lack of access to drinking water sources and low hygiene standards, many developing countries, including Ethiopia have a very low human health status. The most frequently occurring diseases as a result poor sanitation are listed in table 3.

Disease	Morbidity	Disability, mortality	DALY
Diarrheal diseases	1.5 billion new cases per year	5 million deaths per year	100 million DALY’s
Cholera	500 000 new cases per year	20 000 deaths per year	
Typhoid fever	500 000 new cases per year	25 000 deaths per year	
Roundworm	1.3 billion people infected	10 000 deaths per year	10 million DALY’s
Hookworm	700 million people infected		1 million DALY’s
Trachoma	146 million people with active infection	6 million people blind	3 million DALY’s

Table 3: The global public health importance of some diseases associated with domestic water supply, sanitation and hygiene behaviour. Source: WHO (2002)

In this research the Millennium Goals will be used as a guideline. The recommendations given at the end of this research are meant to contribute to accomplishment of these goals.

5.2 Guidelines of the Ministry of Water Resources of Ethiopia

Although Ethiopia has various (drinking) water resources, they are not equally distributed over space and time and not optimally used. The country therefore has suffered a lot from periods of drought (WWDSE, 2001).The Ethiopia Ministry of Water Resources has made a systematic inventory and identified measures in order to optimize the use of water resources all over Ethiopia and created the Water Sector Development Program (see chapter 3). This program, if funded, will operate in a time span of 15 years and started in January 2002. Priority projects have been identified and a detailed implementation plan was worked out using the basin master plan studies (WWDSE, 2001).

The WSDP considered two perspectives by defining their priorities and goals: the point of view of resource development for multiple uses and meeting the national and regional development objectives by creating optimal conditions for successful planning and implementation of the WSDP (WWDSE, 2001). The resource development goals for different uses based on the Water Resources Management Policy that are relevant for this research are listed below.

1. ***Making clean drinking water available to the larger segments of the society***
2. ***Making water available for livestock in critical areas such as the nomadic areas.***
3. ***Expanding irrigated agriculture to the maximum possible extent.***

5.3 USAID guidelines

USAID is the development organization from the United States of America, which provides a lot of development programs for Ethiopia. Under their program 'Food for Peace' (the so called title II projects) in Ethiopia involves sanitary activities in rural areas are carried out. To comply with the new environmental regulations in the United States, guidelines were formulated for Rural Water and Sanitation Projects in Ethiopia. These guidelines are specific for the Ethiopian situation and hence more practical than the WHO guidelines which are general for all over the world.
Since the guidelines of USAID are less demanding than the guidelines of WHO, it will be likely to reach these goals first. The WHO guidelines can therefore be seen as the second stage of development for safe drinking water and sanitation.

The guidelines of drinking water quality compared with the WHO guidelines in 2002 are listed in table 5.

Organism or Chemical	WHO International Guidelines 2002	Title II Projects Maximum Allowable Level
E.coli	0	50 / 100 ml
Arsenicum	0.01mg/l	0.05 mg/l
Fluoride	1.5 mg/l	3.0 mg/l
Nitrate as NO_3	50 mg/l	50 mg/l

Table 4: Drinking Water Guidelines of the WHO, the Title II project standards.

6. Theoretical Framework

In urban areas water is usually centrally treated and distributed through a network, which makes the tap water suitable for multiple purposes, like drinking, cleaning, cooking, etc. In rural areas this water treatment before distribution is often not financially feasible; this is why selection of the right water source is crucial.

Water sources are different in origin, available quantities and quality, making them suitable for different purposes: (Rottier and Ince, 2003)

- *Spring*; if adequately protected (see source protection below) it will normally produce good quality water. In case it has a low yield, a spring box and reservoir can be constructed to collect and store water and prevent pollution of the source.
- *Rainwater* harvesting; rainwater has a good quality, so, if properly stored and collected, the water should be of good quality. (Rottier and Ince, 2003) The catchment area (e.g. roof) should be as clean as possible. Since rainwater harvesting is usually a seasonal activity, it can't be the only source in the area, though there are good methods for storage.[1]
- *Deep and shallow well*; tapping water from a deep, usually confined, aquifer; this can be considered of good quality though it should be tested for chemical properties. The underground structures however are very difficult to maintain.
- *Hand-dug wells* into shallow open ground water; this water is often from an intermediate quality. If protected, e.g. covered with a lid and a hand pump is attached, several risk factors or contamination will be eliminated.
- *Surface water*; this type of source is often contaminated or at risk of pollution. If it has to be used for drinking water it should be collected as far upstream as possible. Upstream sources of pollution should be identified and controlled as much as possible, but usually the water still needs treatment

To avoid health risks for people and animals it is important to use suitable water for all different purposes. The highest quality is required for drinking water, but also for other (rural) water uses like livestock drinking water, bathing water and irrigation a certain quality is needed. In this chapter three main rural water uses will be discussed, and for different water quality parameters the minimum, maximum or recommended value per water use will be given. Finally, treatment options will be discussed.

6.1 Drinking Water

Water that is directly ingested by human beings requires the highest water quality standards. Illnesses that can occur by drinking contaminated water are very diverse, but most of the times symptoms like diarrhea and vomiting occur. At any given time, about half the population in the developing world is suffering from a disease associated with water supply and sanitation. About 400 children below age 5 die per hour in the developing world from waterborne diarrheal diseases (Gadgil, 1998). If you take the current situation in Ethiopia, under five mortality is about 171 per 1,000 live births. Diarrhoea is responsible for about 20 per cent of those deaths (UNICEF, 2004). The causes and effects of different contaminators are listed below.

[1] For further reading see: UNEP Source Book of Alternative Technologies for Freshwater Augmentation or the Global Development Research Centre (GDRC) http://www.gdrc.org

6.1.1 Fecal contamination

A high health risk is associated with the consumption of drinking water that is contaminated with bacteria and parasites from human and animal excreta. This is a major cause of diarrhea. The main pathogens *E.coli* bacteria and *Cryptosporidium* and *Giardia* parasites have been selected as indicators of fecal contamination of drinking water.

Fecal coliforms

A common indicator of contamination of drinking water with fecal material is the presence of thermotolerant coliform bacteria. *Escherichia coli* bacteria normally inhabit the intestines of all animals and humans, but a minority of the strains may cause human illnesses with severe cramping (abdominal pain) and diarrhea, especially in young children and elderly (Centre for Food Safety and Applied Nutrition, 2005).

Different sets of criteria for acceptable levels of contamination have been determined for the various uses by different organizations. Often rather elaborate stepped criteria are available depending on use and treatment.

The World Health Organization calculated the tolerable reference of pathogens, which indicates the maximum bacteria content per 100 mm. For *E. coli* this value is 100 thermotolerant coliform units (tcu). If more than 100 E. coli per 100 ml are found in a certain water sample, that water forms a potential risk for human health and should not be used for drinking water (WHO, 2002). After treatment, drinking water that is served to urban and rural areas for the purpose of drinking, should meet the strict guideline of 0 *E-coli*-colonies. For water destined to be used as a raw water source for a water treatment plan, (such as rapid filtration, chlorination etc.) an average loading of 1000 coliform units per 100 ml water is recommended by the WHO. The absolute maximum is 10,000 tcu per 100 ml water. Beyond this level, no treatment is possible. For simple treatments the water should have an average of 3-1,000 tcu per 100 ml depending on the treatment.

In their *Guidelines for Drinking Water Quality in Developing Countries,* the WHO takes into account that water treatment before consumption in developing countries is not always possible, thus the maximum allowable amount of *E. coli* without water treatment was therefore defined as 50 colonies per 100 ml.

Parasites: Giardia *en* Cryptosporidium

Ingestion of water and food contaminated by parasites can cause serious diseases. Frequently occurring parasites in Ethiopia are *Cryptosporidium* and *Giardia*. Also for *Giardia* and *Cryptosporidium* many guidelines have been defined. Most guidelines prescribe a standard of zero *Giardia cysts* and *Cryptosporidium oocysts* in drinking water, since a very small dose can already lead to serious symptoms.

Giardia is a protozoal parasite that is generally found worldwide in water and causes an intestinal illness called giardiasis. In Ethiopia this illness in generally found in Addis Ababa. Without proper treatment (antibiotics) the illness can last for months (Nevada State health).Giardiasis occurs throughout the population, but the symptoms, such as diarrhea, nausea, abdominal cramps, weight loss and dehydration, are severe on children and people with a low immune system (e.g. people suffering from AIDS or cancer). *Giardia* parasites produce cysts that are very resistant to harsh environmental conditions. Because the cysts are infectious when passed in the stool, or very shortly afterward, person-to-person transmission (e.g. via fecally contaminated hands) is possible. (WHO, 1991)

Studies with human volunteers have shown that even ingestion of one cyst may cause illness in contrast to most bacterial illnesses where hundreds or thousands of organisms may be necessary for an infective dose (Pathogens and Protozoans, 2005). *Giardia* is often found in feces from humans and animals such as dogs. Drinking water sources become contaminated when feces containing the parasites are deposited or flushed into water (Pathogens and Protozoans, 2005).

Cryptosporidium
The parasite *Cryptosporidium* is an intestinal parasite similar to *Giardia* and causes the disease of cryptosporidiosis. *Cryptosporidium* produces symptoms much more serious than *Giardia* but is much less frequent. Infection may cause serious diarrhea especially for children below the age of 5 years, and is particular severe for patients with a low immune system. Under normal conditions *Cryptosporidium* will disappear within a month. In AIDS-patients however, the number of people suffering from chronic cryptosporidiosis has been estimated on 40% in developing countries (WHO, 2002) In these patients the symptoms can become severe and life threatening.
Cryptosporidium also produces oocysts that are very resistant to harsh environmental conditions and can survive for a long time. They can remain viable for about 18 months in cool, damp or wet environments. They are quite common in rivers and lakes, and can be brought into the water with fecal material from domestic and wild animals (Fayer, 1997).

6.1.2 Chemical contamination

Drinking water quality can be affected in multiple ways by chemical contamination. Sometimes the chemicals occur naturally in the groundwater, such as fluoride or arsenic from geological origin, and sometimes they occur due to pollution from human activities such as leather tanneries, mining activities or flushing of agrochemicals. However this is of minimum importance in Ethiopian rural areas because of the absence of industry and limited access of farmers to agro-chemicals. Chemicals can have a severe effect on human health and drinking water should therefore be controlled from time to time on the presence of these matters. If the contamination level is too high and becomes a risk for human health, special attention should be paid to the selection of the best source of water for a certain purpose. Since chemical pollution can often not be removed from the source, prevention of ingestion is the best option Furthermore it is important to know if and to what extend the contamination can be avoided for a next time. In this subchapter some chemicals and their effects on human health will be described. Moreover possibilities for disinfection and protection will be described and the guidelines given by different institutions.

Electrical Conductivity
The Electrical Conductivity (EC) estimates the amount of total dissolved salts (TDS), or the total amount of dissolved ions in the water. For human health a high value of EC can be dangerous. High salt concentrations can result into hypertension and high blood pressure (WHO, 2002); however the taste of very salt water will already prevent people from drinking it.
The EC value of water is influenced by many factors, some are listed here below;

1. The length of the water course before canalizing determines the contact that the water is making with the soil before reaching the canal, lake or valve.
2. If there are polluting sources in the neighborhood of the water source, a sudden increase or decrease in EC-value sometimes occurs. (Lake Access, 2004) These

sources include amongst others point and non-point sources; fertilizers, insecticides and herbicides, etc.

3. Evaporation of water causes a concentration of dissolved solids in the remaining water and therewith a higher value of EC.

The WHO guidelines concerning salinity prescribe 200mg/l of sodium, or a Total Dissolved Solids (TDS) of 1000mg/l (WHO, 2002).

Nitrate

Nitrate is occurs naturally in the soil in organic forms from decaying plant and animal residues. Bacteria in the soil convert the various forms of nitrogen to nitrate, a nitrogen/oxygen ion (NO_3^-). This is desirable as the majority of the nitrogen used by plants is absorbed in the nitrate form. However, nitrate is highly leachable and flushes with the water through the soil profile. If there is excessive rainfall or over-irrigation, nitrate will be leached below the plant's root zone and may reach groundwater. One of the most frequently occurring sources of nitrate spreading is animal manure wherever animals graze, sleep or drink.

The primary health hazard from drinking water with nitrate-nitrogen occurs when nitrate is transformed into nitrite. Nitrate oxidizes iron in the hemoglobin of red blood cells to form methemoglobin. Methemoglobin does not have the oxygen-carrying ability of hemoglobin. This creates the condition known as *methemoglobinemia*, sometimes referred to as ‘blue baby syndrome’, in which blood lacks the ability to carry sufficient oxygen to the individual body cells. (Jasa et al, 1998)

The WHO recommended in the second edition of the guidelines for drinking water quality a maximum of 50 mg /l NO_3^-. (WHO, 2004)

Sulphate

Sulphate occurs naturally in several mineral salts in the soils, many of which are soluble in water and can leach to the groundwater. By pumping up groundwater, for e.g. irrigation, the sulphate will be spread out over the soils again. Sulphate occurs naturally in several mineral salts in the soils, many of which are soluble in water and can leach to the groundwater. Sulphate can be found in decaying plant and animal matter. Also in this case it is therefore important to protect the source and the direct upstream area from animals, since their excreta can leach to the watercourse as well.

If the Sulphate levels in the water are high, people will recognize an unpleasant taste while drinking. Due to sulphate reducing bacteria that change the sulphate into sulphide, the water will get an unpleasant odor (rotten-egg smell). (Anonymous, 2003)

Consumption of water with very high levels of magnesium of sodium sulphate can result into intestinal disorders, diarrhea and dehydration. If the concentration is higher than 500 mg/l SO_4^{2-} it can have a laxative working. However, people can adjust themselves to higher levels of sulphate. The WHO recommends a maximum of 250 mg Sulphate per liter, since higher levels make the water taste badly, which forms a threshold for people to drink the water. (WHO, 2004b)

Chloride

In most water sources chloride is in smaller or larger concentration present. In surface water the concentration are often low, while in groundwater this can be higher depending on the surrounding geology. By passing rocks and soils, the dissolutions of salts into the watercourse takes place. In drinking water chloride is not harmful for human health, as long as the concentrations do not exceed a certain value. However, people with a heart or kidney disease will be more vulnerable for the effects of chloride. Chloride may impart a salty taste in drinking water if it exceeds 100 mg/ l. If a sudden increase in chloride concentration will be measured, this can be the effect of a contaminating source. (InfoPEI, 2005)

pH

The pH of drinking water reflects its acidity. pH stands for 'potential Hydrogen' and can be measured on a scale from 0 -14. A pH value of 4 stands for example for $1 \times 10^{-4} = 0.0001$ mol H_3O^+ per liter, while a pH of 6 equals $1 \times 10^{-6} = 0.000001$ mol H_3O^+ per liter. The value seven indicates that the water is 'neutral'; free of acid or alkalinity. A value below 7 indicates the presence of acid and a value above 7 means that alkalinity is present in the water. (Water Systems Council, 2005)

In the groundwater the pH lies normally between 6 and 8.5. If water with a very low pH will be piped, the water can have a corrosive influence on the (metal) piping material and can leach these metals, such as copper, iron, lead, mangane and zinc into the drinking water. The water will taste very sour. High values of pH (levels above 8.5) are considered as hard; however they do not form a health risk. The disadvantage of water with a high pH value is that treatment such as rapid chlorination is less effective than in neutral water.

6.2 Water for Livestock

Livestock is to a smaller extent than human beings vulnerable to contaminated water. Both direct ingestion of poor quality water and food that had contact with or was irrigated by contaminated water can affect the health of animals. Smaller animals, because of bodyweight, are generally more sensitive to the contaminated water than larger animals. In the driest months of the year, the herders should take extra care of the drinking water that is given to the animals. Three reasons can be given for this increase in risk during these months:

- High evaporation and therefore increased salinity of the water sources
- Increased water intake by the livestock
- Increased water temperature; more optimal temperature for reproduction of harmful organisms

In developing countries, animals are highly valued and essential for farmers to be able to make a living, so water should be tested on the risk for different animals. Diseases and death among livestock will decrease or eliminate the possibilities of money generation by the farmers. Besides from agricultural products as milk and meat, livestock forms often a cheap option for labor and inputs in the form of traction power and manure. (Ayers and Westcot, 1985)

Two major factors that can affect the health of the animals are Salinity and Nitrogen.

The American National Academy of Science (1972) established that the salinity in drinking water for livestock should not exceed 5dS/m. Under certain circumstances and for different animal species, this rate can be exceeded. In the table below, different salinity rates are listed with their restrictions for use.

Water Salinity (EC) (dS/m)	Rating	Remarks
<1.5	Excellent	Usable for all classes of livestock and poultry.
1.5 – 5.0	Very Satisfactory	Usable for all classes of livestock and poultry. May cause temporary diarrhea in livestock not accustomed to such water; watery droppings in poultry.
5.0 – 8.0	Satisfactory for Livestock	May cause temporary diarrhea or be refused at first by animals not accustomed to such water.
	Unfit for Poultry	Often causes watery feces, increased mortality and decreased growth, especially in turkeys.
8.0 – 11.0	Limited Use for Livestock	Usable with reasonable safety for dairy and beef cattle, sheep, swine and horses. Avoid use for pregnant or lactating animals.
	Unfit for Poultry	Not acceptable for poultry.
11.0 – 16.0	Very Limited Use	Unfit for poultry and probably unfit for swine. Considerable risk in using for pregnant or lactating cows, horses or sheep, or for the young of these species. In general, use should be avoided although older ruminants, horses, poultry and swine may subsist on waters such as these under certain conditions.
>16.0	Not Recommended	Risks with such highly saline water are so great that it cannot be recommended for use under any conditions.

Table 5: Salinity levels and their impact on livestock and poultry. Source: Ayers and Westcot, 1985

Livestock poisoning by nitrates or nitrites should not occur with levels less than 100 mg/l. However nitrate levels lower than 100mg/l may cause heavy growth of algae in watering points, which in its place has negative health effects on the livestock.

6.3 Irrigation Water

If water of an unsuitable quality (e.g. grossly polluted water) will be applied for irrigation purposes, two major disadvantages can occur. First of all polluted crops can cause a health hazard for humans and animals and secondly the crops will be limited in their development, which decreases the income of the farmer. Besides from these main effects a third (side) effect can occur; leaching of pollution caused by irrigation water to underlying aquifers, which can be used to pump up drinking water.
Besides these disadvantages a positive influence of contaminated water can be its high concentration of nutrients. The farmer has to apply less manure in that way (Cofie et al, 2003).

6.3.1 Factors influencing human and animal health

If polluted irrigation water is poured or sprinkled over crops that are eaten raw and unwashed by humans or animals, it can form a health risk for them. If the water is contaminated with parasites or fecal coliforms people can be infected by these feces if they eat the crops raw without any treatment. Besides irrigation water, fertilizing vegetables with un-composted manure can cause the same contamination. *Escherichia coli* bacteria grow rapidly in several types of raw fruits and vegetables, particularly when stored at 12°C or above, which is a normal condition in tropical countries such as Ethiopia. (Centre for Food Safety and Applied Nutrition, 2001) In the same way other (chemical) matters, such as metals, can be ingested by the consumer.

Non-food crops or treated crops that are served with contaminated irrigation water will not form a health risk, but reduced yield of these crops can create a lack of income for the farmer (see next section). Due to leaching, the pollution, caused by improper irrigation water, can reach underlying aquifers. The size of the pollution and therewith the magnitude of the hazard for human health depends on different factors:

- The kind of pollution; some matters break down more quickly than others
- Structure of the soil; water storage capacity
- Rainfall; a lot of rain will leach the polluted water quickly towards groundwater level
- Depth of the root zone

6.3.2 Factors influencing crop growth

All plants need a certain amount of nutritious elements, mainly Nitrogen, Phosphorus and Potassium. If these elements are not (in a sufficient concentration) present in the water source applied, the crop will not optimally develop, which means yield losses for the farmer. When the water contains other elements, such as chemical pollutants, toxic matters or hazardous micro-organisms, plants will be infected and also lose yield, or even die.
Yield losses are a serious problem in developing countries, especially in absence of counter measures. If an area wants to become or stay self-sufficient, reduced yield should be avoided and growing circumstances should be optimized.

Electrical conductivity

Crops have different responses on irrigation water with a high salinity level. Salt in the soil or irrigation water decreases the water availability for the crop and will lead to decreased growth and yield losses on the short and on the long term. Salinity can directly lead to a reduced photosynthesis.[2] A long term effect can be reduction of leaf size, resulting in less light interception.

Ayers and Westcot (1985) distinguished four different classes of salt resistance in crops; sensitive, moderately sensitive, moderately tolerant, or tolerant to salinity in irrigation waters (see for example FAO, 2002). Vegetables are on average (very) sensitive to salt, however tomato forms an exception and is moderately tolerant to salt.

Salt Resistance in crops	Crop type
Tolerant	**Barley, millet**
Moderately tolerant	**Sorghum, Wheat, Tomato**
Moderately sensitive	**Maize, Papaya**
Sensitive	**Vegetables (like unions, etc.)**

Table 6: Some frequently grown crops in Ethiopia with their salt tolerance level. Source: Tanji and Kielen, 2002

Depending on the EC of the water and the resistance as described above the yield of the cultivation can drop down dramatically. For farmers this will result in food insecurity and probably an increased health risk. Therefore it is important to know, what the maximum

[2] For further reading see: Villa-Castorena, M., Ulery, A.L., Catalan-Valencia, E.A. and Remmenga M.D., 2003. *Salinity and Nitrogen Rate Effects on the Growth and Yield of Chile Pepper Plants*. Soil Science Society of American Journal, Madison, USA

allowable level of salt is to be more secure of sufficient harvest. In the table below the relation between salinity and yield reduction for the different classes is displayed.
Avoid very high values of EC and treating water with these EC levels is discussed in the drinking water sub-chapter above.

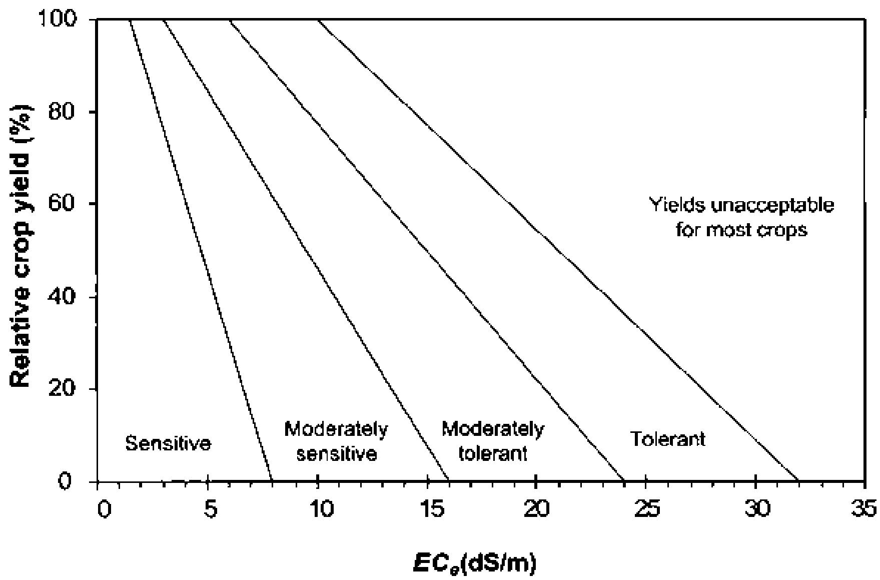


Figure 4: Yield reduction per salt level and per crop type. Source: Tanji and Kielen, 2002

Hardness
Water with a high magnesium or calcium carbonates content can damage the operational irrigation system, by forming a scale on the inside surface of various irrigation components and impede the irrigation itself (Pitts, *et al*. 1989). Plants will receive less water and are limited in their development and growth. In sprinkler irrigation systems hard water will leave white scale-like deposits on plant foliage that decrease the quality of plant material. However, in many developing countries like Ethiopia these sprinkler systems are hardly applied, since they are quite expensive.
Acidification is an effective method to reduce the amount of carbonates in water. The reaction that will occur is the following:

$$\boldsymbol{H^+} \text{ (from acid)} + \boldsymbol{HCO_3^-} \text{ (in the water) ------> } \boldsymbol{CO_2} + \boldsymbol{H_2O}$$

What kind of acid can be used depends on safety, costs, availability etc. In a poor rural context, the costs will be the limiting factor. (Bailey and Bilderback, 2005)
Keeping the pH stable and low (< 8.4) is another option to save the problem; it makes it impossible for carbonates to occur in the water. (Urban Watershed Project, 2005)

Nitrate
Nitrogen is an essential element for crop growth. Normally, the plant gets its nitrogen requirements from the soil, added fertilizers and irrigation water. However, an excess of nitrogen in applied irrigation water will cause damage to the crops and the quality of

production will be decreased. Grain crops will develop very fast in its vegetative stage and as a result forms very weak stalks. In the generative stage the development will be reduced, so they will process less grain. (Ayers and Westcot, 1985)
The concentration in most surface and groundwater sources is usually less than 5 mg/l NO_3^- but sometimes the groundwater measures unusual quantities that exceed 50 mg/l. Drainage water from below the root zone frequently has higher levels of nitrogen due to deep leaching of fertilizers. Wastewater, especially from food processing and domestic sources, is known to be high in nitrogen with values ranging from 10 to 50 mg/l (Ayers and Westcot, 1985). In rural areas in Ethiopia this is less common; however waste water from cooking is one of these sources.
Sensitive crops may be affected by nitrogen concentrations above 5 mg/l. Most other crops are relatively unaffected until nitrogen exceeds 30 mg/l.
If water with excessive nitrate content is the only source to irrigate with, an option for the farmer can be to change to a less sensitive crop, such as maize. Sometimes, the irrigation water can be used as a fertilizer as well and to avoid an excess of nitrate, applying fertilizer can be omitted. This is for example the case on farms around Addis Ababa, where farmers use urban wastewater for irrigation. Furthermore crop rotations can be planned to utilize residual nitrogen in the soil during the non-irrigation season. This may also be helpful in reducing the impact in succeeding years.
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Sulphate
Sulphate in irrigation water is considered beneficial to crops. However if present in high levels, it will cause salinity and permanent hardness, which can have negative effects on plant growth (College of Agriculture and Home Economics, 2005). Furthermore, very high values of sulphate can interfere with uptake of other nutrients. The removal/avoidance of sulphate from water is described in the drinking water sub-chapter.

Chloride
Although chloride is essential to plants in very low amounts, it can cause toxicity to sensitive crops at high concentrations. Like hard, high chloride concentrations cause problems if used in irrigation systems. It can have a corrosive effect in the pipes of such a system as well as in the outlets of e.g. sprinklers (Bauder et al, 2005).
The concentrations of chloride that can be applied to the crop depend on the vulnerability of the crop. Vegetables such as unions are very sensitive to chloride. An example of a moderately tolerant crop is maize, while wheat, sorghum and barley are tolerant to chloride. In the table below the effects of different amounts chloride on crops is shown.

Below 70 ppm chloride	Generally save for all plants
70 – 140 ppm chloride	Sensitive plants show injury
141 – 350 ppm chloride	Sensitive and moderately tolerant crops show injury
Above 350 ppm chloride	Severe problems for all crops

Table 7: Effects of chloride concentrations on crops. Source: Bauder et al, 2005

pH
The pH of irrigation water forms seldom a problem by itself concerning crops. Imbalances in the nutritional status of the water can be used as an indicator for unusual pH values. If water has a pH outside the normal range of 6.5 to 8.4, it may contain a toxic ion or have a low salinity-value.

The greatest direct hazard of an abnormal pH in water is the impact on irrigation equipment. Equipment will need to be chosen carefully for water with unusual pH levels. (Ayers and Westcot, 1985)

6.4 Other uses

The above three sub-chapters all describe hazards due to direct of indirect ingestion of contaminated water. There are, however, hazards in the water that have nothing to do with ingestion e.g. skin and/or blood contact (e.g. via wounds). This kind of contact can take place during bathing in the water or religious ceremonies or even by inhalation (e.g. *Legionella*). (European Union, 2005)
The most frequently occurring disease as result of bathing in contaminated water is Schistosomiasis. [3] Furthermore bathing brings another problem along; many people in Developing countries are not able to swim. Drowning of children, bit also adults is frequently occurring.
Another use that is not yet discussed has nothing to do with possible health risks; laundry and other cleaning purposes. For doing the laundry it is important that the dH value is not too high. In very hard water soap becomes inactive since the soap molecules are 'captured' by the alkali-ions and this will make the soap hydrophilic.
The hardness of water is defined as the concentration of alkali-ions. Hardness is indicated in *dH (Deutsche Härte)* that can be estimated by measuring the concentrations of the alkali-ions Calcium, Magnesium, Strontium and Barium (Ca^{2+}, Mg^{2+}, Sr^{2+} and Ba^{2+}). In practice, Strontium and Barium do not play a role, since only fragments of these elements can be found in the water. As water moves through soil and rock, it dissolves very small amounts of these minerals and holds them in solution. The values of dH range from 0° (very soft) to values over 50° (extraordinary hard). (Klee, 1993)

dH	***0-4 dH°***	***4-8 dH°***	***8-12 dH°***	***12-18 dH°***	***18-30 dH°***	***Above 30 dH°***	***Above 50 dH°***
Description	Very soft	Soft	Average	Relatively hard	Hard	Very hard	Extraordinary hard

Table 8: Explanation of dH values Source: Klee (1993)

For drinking water a value between 4 and 8 dH° will be estimated as 'favorable quality', since it has the best taste.
The WHO (2002) recommends 500 mg ($CaCO_3$) / l as a maximum, which is about 28 dH°.

6.5 Improving water quality

If clean water, according to the guidelines on fecal contamination, is delivered to the consumer's source, it does not necessarily mean that the water consumed is still safe. Many factors influence the water quality on its way from source to mouth. There are five important aspects that contribute to the pathways of fecal contamination:

- Protection of the water source
- In-house storage and treatment
- Hygiene standards
- Sanitary facilities
- Water quantity (per capita)

[3] For further reading see WHO, 2002

Fecal infection of consumers can be avoided or treated in many ways. Very important in case of tackling a water quality problem is blocking the pathogen pathways as described in the subchapter above. Besides from these pathways there are other factors involved in the protection of drinking water and its sources.

6.5.1 Protection of the water source

A lot of attention is often paid to the construction of a water source that can deliver safe water for a certain purpose. However after this construction the water (that is collected by the users) can still be contaminated.

A frequent source of "hidden" contamination is fecal contamination (parasites and coliforms) by (especially wild) animals. If people are aware of the fact that livestock dung should kept out of the water, they can choose to fence their water source. An important advantage of the fence is the fact that beside from the livestock it will keep away wild animals too. These animals leave their excreta near or in the water source and are not easy to control by humans without a proper protection of the source. This may involve not only a fence around the source, but also a cover on top. Also young children that are using the source as latrine will be kept away by the fence, moreover they are not able to fall in and drown (Lee and Bastemeijer, 1991).

The protection fence should not only cover the source itself, but also the area upstream of the source (about 10 meter), to avoid underground flows transporting the excreta to the source. (Rottier and Ince, 2003) The construction of latrines in the upstream area should be avoided (Lee and Bastemeijer, 1991). Still there will often be run-off coming down, which can be diverted by a ditch that should be dug close to the source. (Rottier and Ince, 2003)

Another way of protecting the source is to minimize the hand-water pathway by installing siphons, taps or buckets connected to a rope.

In case of extreme contamination, ponds and wells can be emptied and cleaned. Streams and springs can be blocked upstream, while downstream cleaning activities are executed.

The construction of the water source should be checked from time to time to avoid breakdowns of the system

6.5.2 Water treatment

Although there are many possibilities to avoid contamination, many people still face problems with fecal contamination of drinking water sources. This can be the result of a breakdown of a protection measurement or another factor that was overlooked at designing stage. If the source contamination cannot be stopped, water treatment should make the water suitable again for drinking purposes again. There are different ways of cleaning the water from bacterial contamination and some of them are listed below.

Filtration: There are three types of filters that can be used in developing countries to directly or indirectly reduce the fecal contamination in water; rapid sand filters, slow sand filters and carbon filters. Rapid sand filters reduce mainly larger micro-organisms and suspended solids. The filters do not by themselves remove fecal pathogens, but they can prepare water for other treatments like SODIS (Gadgil, 1998).

Slow sand filters are more effective and less costly than rapid sand filters. The water seeps through the filter at rates of 10 to 20 mm per hour, so a large area of land is required (Gadgil, 1998), or the filter should be very long. A limitation of the method is that the initial coliform concentration of the inlet water should not be too high; otherwise the filter can clog easily (Gadgil, 1998). Flushing can solve the clogging problems, although this should not be done too frequent, since the fauna in the filter should not be flushed away. This type of filtration is also very suitable for removing parasites.

SODIS, pasteurization and boiling: The boiling and SODIS methods that are described above can not only prevent people from drinking contaminated water, it can also treat contaminated water in order to make it potable again. In the oocyst-stage Cryptosporidium is very heat-sensitive; a temperature of 65 degrees Celsius inactivates oocyst in 5-10 minutes. Boiling is also possible; in that case 1-2 minutes is enough. (Pathogens and Protozoans, 2005)

Electrolytic Generators: Generators that produce sodium hypochlorite from salt water can be used to clean the water from fecal contamination. Nowadays these generators are sometimes affordable and available for use in developing countries (Reiff et al, 1996), although in Ethiopia this is mainly not the case.[4]

Chlorination: Chlorine is one of the most common disinfectants of the world. A small dose is already enough to disinfect water (with a normal pH) almost fully from Giardia. In water with a high pH disinfection with Chlorine can become impractical, since a very high dose will be required. In smaller communities in the developing world bleaching powder ($Ca(OCl)_2$) or NAOCl can be used, since they are safer to transport than gas. [5]

CSP (Ceramic Silver Pot) filter: CSP filters remove turbidity and harmful bacteria from water. This method is said to cost US$3-5 per family per year, which is about 0.10 - 0.15 Ethiopian Birr per day. If the contamination in an (open) water source can be removed by this kind of filters it is a very inexpensive option if compared to the 0.10 – 0.15 Ethiopian Birr people are paying currently *per container of 20-25 liters.* For further reading see (NWP, 2004)

Increasing or decreasing temperature: All bacteria and parasites have a certain water temperature that stimulates their maximum growing-speed. This temperature depends on the kind of organism. Bacteria in human bowels for example have the optimal temperature of 37°C. Termophile bacteria have an optimal temperature about 90 °C. Most of the time, cool storage decreases the multiplying-speed of the organisms.
An option of water disinfection is the SODIS method. By using solar UV-A radiation (sunlight) and higher temperatures (e.g. storing the water on iron roofs of a house where it is fully exposed to the sun) pathogens can be inactivated. This method is favorable in developing countries since it is a low-cost solution for improving drinking water. [6]
Another possibility of minimizing the amount of pathogens in (drinking) water is boiling the water by heating it for a few minutes on 100°C. In countries where fuel is scarce, sustainable options should be explored for boiling the water, e.g. solar-ovens.

Parasite removal: Besides from the measurements as described above, parasites can be removed from the water on various ways. In the table below, an outline of the possibilities is given as well as their efficiency and the most important determining factors.

[4] For further reading see http://www.cdc.gov/ncidod/dbmd/diseaseinfo/waterbornediseases
[5] For further reading on alternative chlorination see (Gadgil, 1998)
[6] For further reading see: Http://www.sodis.ch

Type of process	Removal efficiency (log10-units) Crypt.	Giardia	Most important efficiency-determining factors
Disinfection processes:			Dose, contact time, installation design disinfectant demand, temperature, pH (especially for chlorine
Chlorine	0	0 – 2	
Ozone	0 – 2	1 – 4	
Ultraviolet light	0 – 4	0 – 4	
Filtration processes			
Rapid sand filtration	0 – 1	0 – 1	Filtration rate, recycling of backwash water Presence of “Smutzdecke”, filter depth
Slow sand filtration	1.2 – 3.7	1.3 – 3.7	Filtration rate, filter depth, pore size, precoat thickness, filter integrity
Other processes			
Soil passage	2 – 5	2 – 5	Soil composition, residence time, travel distance, presence of sediment
Reservoir storage	0.5 – 2	0.5 – 2	Residence time, reservoir design, addition of coagulants, temperature

Table 9: Removal of *Cryptosporidium* oocysts and *Giardia* cysts by treatment processes (WHO, 2002b)

6.5.3 Protection, prevention and removal of chemical pollutants

In general some precautions to avoid chemical pollution can be undertaken; the site for a certain drinking water source should be selected carefully. The location of domestic water wells, the upslope area and adequate separation distances between wells and possible contamination sources are important factors in these. Proper well construction and maintenance also reduces potential drinking water contamination

Removing chemical pollutants from the water is not easy to do and can be very time-consuming and expensive. Therefore most methods of removing such pollutants are not applicable in a poor rural context. People who depend on this water are often forced to search for other water sources. From a MUS point of view, well-informed people can decide to use good quality water sources only for drinking water and chemically polluted sources for other uses like cleaning, bathing etc. Care should be taken by the removal of the waste water, since it can seriously (and sometimes irreversibly) damage the environment.

High levels of EC, dH and Chloride can be avoided by early interception of the watercourse (e.g. piping, canalizing), which minimizes the time and space that the water is in contacts with the minerals in soils and rocks. If possible the well could be reconstructed.

For water with very low pH levels piping is not advisable since that kind of water can have a corrosive effect on the (metal) piping material and will flush the metals to the water distribution points. Extreme low values can be neutralized by adding soda ash into the water. Although, this treatment saves the piping system from corrosion, it brings along an increased health risk. Water with an extreme high pH can be treated by an ion-exchange system, such as a lime-soda ash mixture. (Water Systems Council, 2005)

High levels of Nitrate, Sulphate, Chloride and dH can also be removed by distillation and/or ion-exchange techniques. These procedures are however very expensive and not applicable in developing countries. For high dH levels counts: If the water exceeds the standards to a certain extent, it is less expensive to use for example more soap than to remove the alkali-ions.
Carbon filters can also be used on household level, or on village level if there is a communal tap. The filters can be placed between tap and container or container and glass. They should only be applied at water sources that are microbiologically safe since they can remove especially waterborne chemical pollutants. (Gadgil, 1998)

6.5.4 Hygiene behavior and health education

In areas with a frequent water scarcity, the available water will in the first place be used for drinking water and water for livestock; cooking, cleaning etc. will be put on the second place. Since often there is not much water left, hygiene behavior, like washing hands, faces and bodies will be inadequate. For the most basic hygiene practices every person needs 2-6 liters water per day (Worldbank, 2005b). Poor hygiene standards can have various effects on health. Often these effects are unknown by the local population and therefore creating awareness is very important in this situation.
If one's body is not cleaned, everything that is touched will be contaminated as well. If hands are not washed after defecation, feces will be transferred to water, food or directly ingested.

Sanitary facilities

Sanitation is a wide concept, which involves the installation of latrines, materials to use them correctly (e.g. water) and the cooperation of the local population (Rottier and Ince, 2003). However it should be stressed that the sanitary behaviour of people is even more important; if they insist to use the latrine, constructing facilities does not make sense.
A latrine or other sanitary facility can help prevent fecal contamination of drinking water. Lack of these facilities or its improper use can have a huge impact on the water quality. If the excreta of humans and/or animals are left in the village, there is a chance that the feces follow one of the many pathways that finally cause ingestions of pathogens in the feces by human beings. Children for example, can come in contact with the feces and parasites by playing in the compound or touching animals. Also flies can transfer from stools to uncovered food items. Feces easily flow by subterranean transport to the watercourses that are serving the area for drinking water. Hence proper location of sanitary facilities and water points in relation to each other and the topography is crucial in preventing obvious contamination of the water source. The possible pathways are shown in figure 2.

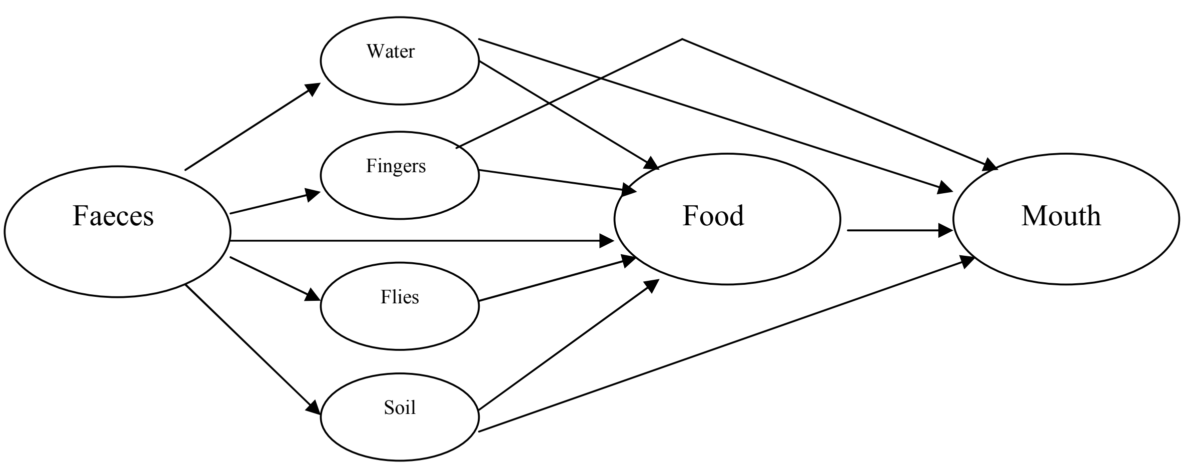


Figure 5: Possible *fecal-oral transmission routes of pathogens. (Source: Boot and Cairncross, 1993)*

Water quantity

Besides from quality, water quantity is an important factor to take into account. The often mentioned 'simple' recommendation about washing hands, before taking water out of the storage valve, become very complicated if the lack of water is actually the nucleus of the problem. A large part of the disease burden in developing countries is associated with these inadequate quantities of safe water for domestic use, lack of facilities to dispose of human feces in a sanitary way, and poor hygiene standards. The most important of the water-associated diseases is diarrhea, which causes high child mortality in many developing countries. For low-income communities the conventional approach to improve water supply has been to exploit shallow groundwater with low cost technologies.

Sufficient water supply is not only important if it comes to personal hygiene, but is also required for adequate cooking, washing cloths, and watering the crops and livestock. Without livestock or crops, the daily intake of food will drop down and a lack of water for cooking will stimulate people to eat uncooked vegetables and other products. The results of these trends are described above.

In-house storage

Although in some areas domestic water could be delivered in the close vicinity of the house or even inside the house, every household needs some space for storing water. During the wet season water will be delivered irregular or during a few hours a day and in the dry season the water delivery can be stopped for days, weeks or even months. All households, whether with connection to nearby water sources or not, will therefore be dependent on their storage capacities. Due to the climatological circumstances and for example a high daily temperature, water can be stored in traditional clay pitchers. The advantage of these pitchers is that they also provide the water from a cooling effect, since evaporation is possible through the pores in the clay.

Sometimes the water has to be stored for a very long period of time. In this period the water is exposed to hazard from outside. First of all it allows the possibility of fecal contamination inside the household. Children for example can put their unwashed hands in the water and cause a pathway for pathogen transmission. Secondly, the water can get polluted by dust and other materials that fall into the storage tank. Finally a hazard can be found in livestock and wild animals that come in contact with the water if this water is not stored on a safe place.

Health education

Health education about possible pathways can be a very effective tool in creating awareness of water contamination. By washing hands, looking after the hands, faces and feet from small children and removing animal dung from the compound, a lot of pathways will be eliminated. If given in a proper way (understandable, social acceptable, etc.) and involving as many people as possible, health education can really make a change in developing areas.

7. Problem Identification

7.1 History of the villages

The situation before settlement

The Area of the Peasant Association Lege Dini used to be a nomadic area. Nomads traveled around during the dry season and settled for a while during the wet season. Water sources that were used for drinking water and personal hygiene were found in the mountains or caught from the river and seepage wells. Sometimes the nomads sold their milk and other products on the market in a nearby town and bought other food item to take home.

The forced settlement of the Ethiopian Government

During the Dergue regime the Ethiopian government forced the nomads to settle down. Initially they were told that settlements would make it easier for the government to provide the necessary water and sanitary facilities. Later it became clear that the main reason behind the settlement was improved control over the population. The nomads had to face a critical situation; they had settled down in area where there were not enough resources to make a living.

In Lege Dini about 10 villages were settled with the total amount of *2500* inhabitants by the time of writing. The main problem in most villages is the water quantity and especially clean drinking water is not always available. Furthermore, also due to insufficient sanitary facilities, hygiene related diseases occur frequently. In this sub-chapter, the 10 villages will be discussed separately with their main problems addressed in this research.

7.2 The villages

Ajo

The main PA office of Lege Dini is situated in Ajo. This village is the host of most assemblies and meetings and guests normally visit this particular village.

The problems in this village are small in comparison with the others in the area. First of all there are several water sources within close distance to the houses. There is one borehole with a distribution point that has four taps in the centre of the village, opposite the clinic and one small tap inside the compound of the clinic. Water is pumped by a diesel fuel generator into two reservoirs and subsequently it flows into the distribution network in Ajo and to the villages of Halo, Iddo and Iddo Bolo.

Picture 3: The fuel generator that pumps up drinking water in Ajo

There is a big misunderstanding about which water is for whom. Although the designers (see designing paper in Annex) took into account the population of all surrounding villages, the water from Ajo is only used in the four villages that are connected to the piping system. Occasionally people from other villages buy their water in Ajo. The initial plan of DAP II was to implement first this water source, which would be shared by all villages in the PA till the moment that a second drinking water system would be installed. Unfortunately this was not (sufficiently) communicated to the users. The DAP II project is now cut back from 5 years to 2.5 years and it is not likely that the second water source will be installed soon (or within the 2.5 years scheduled).

The villagers of Ajo also set the rules about the amount of water a family can take for drinking. Leftovers are used for irrigation and livestock watering. There used to be a hand pump near the primary school, but it became inactive when the other sources were installed. Just outside the village there is a water harvesting pond. This pond is mainly used for livestock watering and eventually for drinking water in the driest period of the year. Sometimes it falls dry in May and June, just before the rainy season starts. According to the nurse from the PA the pond attracts a lot of malaria mosquitoes, but since it lies outside the village, risks are minimized.
In the village there are several latrines, but these are barely used. The two latrines near the clinic are locked and mostly school-children use this latrine by asking the key from the Nurse.
The health situation in the village of Ajo is moderate to good. Since there is enough clean drinking water, waterborne diseases are not occurring frequently. The crops that are grown are mainly sorghum and maize; there is a communal nursery where some vegetables are grown. All in all, the food pattern of the inhabitants is not very varied.
However during the visit in Lege Dini the diesel fuel generator broke down and caused major problems for the local inhabitants. Since there was no other option people started to drink the poor quality water from the water harvesting pond, which dried out quickly. Others went to the village of Kora to buy water from the spring system. After a week, Kora tried to provide water for the whole PA, but the source discharge was not enough for everybody. There was no emergency plan at all.

Selela

Selela is a small village in the mountains and half an hour walk to the village of Ajo. In Selela, the only water source is a well in the mountains, an hour walk from the village. This well is used for all purposes; drinking, personal hygiene, watering the animals, irrigation etc. On first sight the well looks contaminated and has a brown color. The people in the village of Selela have poor and small land and usually live from cattle herding.
Due to their small involvement in the cash economy, buying water in Ajo is for the inhabitants not possible. In the clinic in Ajo a lot of cases of diarrhoeal diseases come from Selela. Especially children under 5 years old are suffering from the low quality water. There are no sanitary facilities in Selela.

Picture 4: Inhabitants of Selela collect their daily amount of water at the well near their

Iddo, Iddo Bolo and Halo

The three villages Iddo, Iddo Bolo and Halo are also connected to the piped drinking water system from the borehole in Ajo. Although this water is clean, the villagers frequently use alternative sources. There are different reasons why the water from the tap is not enough for the families. First of all, the three villages are involved in a rotational system and receive water once per two days. Secondly the connecting pipelines break down frequently which results in contaminated water delivery and huge losses. Finally the fee for kerosene is very expensive for many villagers, so the ones that are able to pay for the water are forced to walk down and buy their water in Ajo. The animals are herded to different sources in the riverbed. The place that is most frequently mentioned by the people from Iddo, Iddo Bolo and Halo is ‘Malkakaro’. On account of the water harvesting pond in Ajo, Iddo, Iddo Bolo and Halo tried

Picture 5: Washing place in Halo; the waste water is lead to the communal papaya fields

to make their own ponds. However due to a lack of skills the ponds failed to conserve water. Furthermore the ponds were placed inside the villages instead of outside (like the Ajo example), which can bring along an increased malaria risk. Some families do have enough money to buy all water from the tap and divide use it for multiple purposes; domestic uses, personal hygiene, watering animals, irrigating papaya etc. The villagers are mainly agro-pastoralists and own a small area (ca. 0.5 hectares) per family. In all villages there are sanitary facilities, but these are never used, due to poor construction.
The health situation is moderate to good in the villages, with the highest number of diseases reported in Halo.

Hado Sere

The inhabitants of Hado Sere are not connected to the piped system, but own a well near the village. The water of this well has a very poor quality, something that is recognized by the farmers as well. Recently they emptied the well to clean it, because children, adults and even their cattle turned ill after drinking the water. Since the well is very deep (water is collected via a tin can and a rope) it is possible that animals fell into the well and couldn't come out anymore. Cattle cannot enter the area since the area around the well is fenced
The health situation improved a lot when people stopped drinking the water from the well. Now the main drinking water source is located in Kora, where there is clean water available from a mountain stream.
Hado Sere is one of the poorest villages in the area. Cattle herding in combination with cultivating very small plots is the main activity of the inhabitants. According to the inhabitants the village is barely visited by project staff from (amongst others) Dire Dawa. Due to lack of knowledge, the sanitation programs do not have effect in the hygiene standards in the village if Hado Sere. A dung-heap upstream of the water source and no latrines are examples of this.

Kore Chafe and Lallo

Kore Chafe and Lallo are the remotest villages of the PA of Lege Dini. The villages are not permanently inhabited since most people from Kore Chafe and Lallo are semi-nomads; they are used to travel around during the dry season and settle themselves in the villages during the wet season. A few families stay the year-round in the village. Their main water source is the river and if the riverbed falls dry, a hole is dug to collect water. The water is used for drinking and livestock water and small irrigation plots.
There is not much information about the health situation in the villages, but malaria seems to be the most frequently occurring disease.

Kora

Kora seems to be the most developed village of the PA. Although it is situated a larger distance away from the town of Dire Dawa, the development projects have been implemented abundantly. The village has several drinking water places, a separate laundry area and a reservoir for watering the animals. All water is coming from the same source: a small spring from the mountains. Near the village this spring is piped and leads to a 10.000 liter reservoir. The water is clean and illnesses due to water or food are hardly reported in Kora. The villagers don't have to pay a fee for the water. There are only some savings per family for financing operation and maintenance costs. Visitors from other villages do pay a monthly fee. Irrigation water is also coming from the spring. All villagers have some land, where mainly sorghum, maize and irrigated cash crops are cultivated. In the nursery on the communal grounds some experiments are executed. The cash crops are eaten by the villagers themselves and sold to other villages. Surpluses are taken to the market of Dire Dawa.

Since every water source is piped or stored in a closed reservoir, there is less surface water for mosquito breeding and therefore the malaria risk is slightly decreased in the area. Results of this decreased risk can be found in the administration of the clinic. Less than 5% of all malaria cases in the PA is coming from Kora. (See annex) The sanitary facilities are good, however not used by everybody. Most people say to use their latrine only, if it happens that they are in the close vicinity of the latrine if they have to go. Otherwise the mountains and the agricultural fields are used to defecate. The latrine is cleaned every day by the women of the village.

Picture 6: Papaya field in Kora; the cash crops are eaten by the villagers or sold on the Dire Dawa market

Konya

Konya is a village forty five minutes walk from Kora and does not have its own water source. All water is carried with 20 liter containers from Kora to Konya. For older people this is a tough operation and restricts them in the amount of water they can take home every day.

The people from Konya are agro-pastoralists and the small plots they have are mainly used for growing sorghum and maize. Inside the village there are now sanitary facilities.

There is not much information about the health situation in the village.

7.3 Limitations to a Multiple Use Systems approach

As described above there are a lot of differences between the villages. Some villages have access to multiple clean sources while others are dependent on one contaminated well. Sources are not used by all inhabitants of the PA due to the following reasons:

1. The drinking water sources are only installed in 5 out of 10 villages. For the surrounding villages (that are on average poorer than the villages with access to drinking water) it is a time consuming and physically tough operation to get their water in one of those five villages. Especially the families without donkeys or camels are very limited in the amount of water they can carry home. Since at several water sources people have to pay for the water, there is a problem of affordability as well.
2. The inhabitants of the PA differ of opinion whether the sources are meant for the whole PA or only for the villages they are installed.

In a multiple use system-approach water is shared for different purposes. E.g. the clean drinking water would be used for drinking water only and not for the surrounding irrigation plots, since people from other villages are falling ill due to contamination in their main drinking source. Other sources (wells, ponds, etc.) would than be used for cleaning, personal hygiene, watering animals, irrigation and other non-consuming activities.

The main problem in the PA of Lege Dini in reaching this ‘ideal’ multiple-use situation is mainly the distance between the villages and the limited possibilities to pump up ground water.

If the distance between villages is exceeding a full day walking, the MUS-approach cannot be implemented. People can not be forced to stay overnight in another village for collecting their basic needs in drinking water.

The tap system in and around Ajo is pumping up water from the aquifer. According to the authorities that installed the pump, the amount that is being pumped up every day is a sustainable amount and won't exhaust this water layer. The same counts for the spring system in Kora. According to calculations of the NGO's that installed the system, it operates on a sustainable basis. The accuracy of part of these calculations is somewhat questionable. Reason to doubt is the fact that, although the maximum amount of water that can be pumped up from in the aquifer is calculated to be just enough for the whole population of Lege Dini including population growth, a second borehole in the same aquifer is considered to cover the shortages that would occur. Furthermore all calculations are based upon estimations and assumptions. Although the reason was unknown by the time the author left, the pump was not operating (or dry-pumping) from the second week of January onwards, which can indicate a miscalculation.

The seepage wells that are dug by the villagers in the riverbed are also dependent on the groundwater level and aquifers. Exhausting of this water layer can lead to disastrous water shortage for the inhabitants.

7.4 Measurements

The four main uses of water in Lege Dini are drinking water, water for personal hygiene, watering the livestock and irrigating the fields.

As described in the theoretical framework, water should be available (quantity) and from a certain minimum quality to avoid (health) risks for humans, animals and the environment.

Since this study is no medical study, health risks will not be analyzed in detail, but the following topics will be explored:

1. The availability of water in general: What is the amount of water in the different sources and the difference in wet and dry seasons?
2. The availability of water suitable for multiple water uses
3. The quality of different source and the possible risk they form for humans, animals and/or the environment
4. The risks related to poor sanitation
5. The knowledge of the local people and the ways this can be improved.

8. Objective and Research Questions

According to the above theory, the objective of this research is to contribute to the improvement of the water and food security in the Lege Dini watershed area and therewith the improvement of health of its local population. Further more the concept of multiple sources for multiple uses will be examined and where possible improved in order to create possibilities for widespread implementation.

To reach this objective the following research questions are defined:

First Research Question
What is the required and available discharge of different domestic water uses?

a. *Which different water uses require a higher water quality than the water quality that is currently serving the area?*
b. *What are the required and available quantities of water in the dry season for the different water uses estimated by sub-question a?*
c. *What are the required and available quantities of water in the wet season for the different water uses estimated by sub-question a?*

Second Research Question
What are the possible risks of contamination?

a. *Where are the water sources located in the field?*
b. *Where are the human feces collected?*
c. *Where is the manure collected of the livestock in the field?*
d. *Does contamination of the different water sources and human and animal feces take place?*

Third Research Question
What is the local knowledge about potential risks of contaminated water?

a. *How is the health education provided in the area?*
b. *What are the hygiene customs in the area during the dry season?*
c. *What are the hygiene customs in the area during the wet season?*

Fourth Research Question
Can the available water be used for human consumption?

1. *What is the quality of the water in the borehole used for domestic water?*
    a. *What is the salinity, hardness?*
    b. *What is the iron, sulphate, nitrate and chloride-content in the water?*
    c. *Are Cryptosporidium spp. and Giardia spp. present in the water source?*
    d. *Does the water contain fecal coliform bacteria?*
2. *What is the quality of the water in the river?*
    a. *What is the salinity, hardness?*
    b. *What is the iron, sulphate, nitrate and chloride-content in the water?*
    c. *Are Cryptosporidium spp. and Giardia spp. present in the water source?*
    d. *Does the water contain fecal coliform bacteria?*
3. *What is the quality of the water in the shallow wells water?*
    a. *What is the salinity, hardness?*
    b. *What is the iron, sulphate, nitrate and chloride-content in the water?*
    c. *Are Cryptosporidium spp. and Giardia spp. present in the water source?*
    d. *Does the water contain fecal coliform bacteria?*

4. *What is the difference in water quality at the source if compared to the point of use?*
5. *Under which conditions domestic water is stored in houses?*
6. *What is the difference in quality before and after in-house storage?*

Fifth Research Question
To what extend is the MUS-project able to improve the water and food security?

a. *In what way does the MUS-approach influence the water and food security in the Lege Dini watershed area?*
    I. *What are the factors that have a positive influence*
    II. *What are the factors that have a negligible or negative influence*
b. *What changes, derived from the Lege Dini-case, can be applied to the MUS-approach to improve its positive results on water and food security in general?*

Sixth Research Question
What are the possibilities for change to improve the sanitation and water quality and security in the Lege Dini watershed area, within the boundaries of social acceptance and environmental opportunities?

9. Methods and Materials

9.1 Investigation of the Area

The first two weeks of this study were spent on exploring the Peasant Association of Lege Dini. All villages, water sources and roads were tracked using a handheld GPS in order to make a map of the area. Furthermore the heads of three villages were met and the purpose of the research was explained. Thereafter all villages with an own water source were visited and the inhabitants were interviewed about the organizational structure and rules and regulations concerning the water division.

The GPS-data were reproduced in a map of the area (see map 3). The information from the villagers was used for the selection of the sampling-sites and the definition of the themes for the sanitary survey.

9.2 The Sanitary Questionnaire

In order to get insight into the in-house water treatment practices and hygiene standards in the PA of Lege Dini and to understand the results of the quantitative water analysis, it is important to have a total overview of where and when the water is flowing, transported or consumed. With these data it will be possible to explain the origin of pollution. Therefore a survey was held among 12% of all households in the Lege Dini watershed area. All activities outside and inside the household that influence to a smaller or larger extent transmission routes were questioned and observed from November 2004 till February 2005.

From each selected household the responsible person for water affairs, mostly the oldest women, was interviewed. To get insight into the different perceptions and customs between men and women, from an additional 5% of all households the man was interviewed. The total number of families per village was taken from the lists in the clinic of Ajo.

Name of Village	No. of families	No. of interviews		No. and type of Water sources						
		Women	Men	Borehole	Tap	Water harvesting pond	Reservoir	Shallow well	Spring	Irrigation system
Ajo[b]	68	7	3	1	3[d]	1	1[d]			
Iddo[b]	20	2	1		1[d]		1[d]	1[c]		
Iddo Bolo[b]	19	2	1		1[d]		1[d]	1[c]		
Selela	21	3	1					1		
Konya	14	2	1							
Hado Sere	19	2	1					1		
Kora	54	6	3		2[e]		1[e]		1	1[e]
Kebira	21	3	1							
Halo	81	7	3		1[d]		1[d]			
Kora Chafe	[a]	1	1							
Lallo	[a]	1	1							

[a] Halo includes the families of Lallo and Kora Chafe.
[b] Ajo, Iddo and Iddo Bolo share one reservoir
[c] Shallow well in Ayalegungun
[d] Borehole water
[e] Spring water

Table 10: The total number of samples and interviews and their locations

The families were randomly selected. However in two villages the chief of the village selected the families and most of the time these were the houses close to the central water place or the family of the chief himself and houses of his relatives. This could have a negative impact on the validity of the research.
The questions were asked in an open form to avoid respondents to give the most ‘desirable’ answers by just conceding with the statements (see annex). Mostly the respondents were asked to explain their daily activities as a whole. The interviews were hold in the period from November 2004 till January 2005.

9.3 Water quality analyses

In order to understand the magnitude of the contamination, samples from all water sources were examined in the laboratory. Water samples were taken carefully (see protocol later this chapter) in order to be secure that the contents of each sample reflect the real composition of the water in the source.
Hence the samples from open wells were taken approximately 1 meter below surface level, using a heavy aluminum cup with a rope. First the cup was rinsed at least three times with water from the sample site to avoid mingling of the different samples. In streams, the bottles were hold in the stream with the opening in the upstream direction. If there was not enough discharge to fill up itself, the bottle was moved slowly in the upstream direction. If the sample was taken from a tap, first all extension pieces were removed from the tap. Since these pieces were replaced once in a while, measured values did not indicate contamination of the extension piece, but contamination of the water source. Unfortunately the contamination through the extension pieces was not measured. Then the tap was cleaned from the outside and two minutes heated with a burning wick. Thereafter the tap was opened for at least two minutes without touching it. The lid of the bottles were closed firmly and secured with tape to avoid leaking. Afterwards the samples were directly placed in an ice-box and stored under cool circumstances.

The laboratory facilities in the Dire Dawa were limited, including the sterilization possibilities. Due to the simple technological equipment, most values could not be measured exactly. Therefore most measurements are repeated various times and the average value is listed in the results chapter. For parasite analysis and electrical conductivity measurements, the Central Laboratory from the Alemaya University was used.

9.3.1 Thermotolerant coliforms
All water samples were analyzed on the presence of thermotolerant coliform bacteria. Every month samples were taken in the morning, before the villagers started to collect their water and before the livestock arrived to drink. In December, from three open sources, the samples were taken in the late afternoon as well to compare the results with the morning samples. Most people get their drinking water in the morning. The problem with the sources in Selela and Hado Sere is that there is only space for one person to collect water. If somebody is late, he/she will have to wait till the afternoon to get water. Therefore it was interesting to see the course of contamination during the day.
All samples were placed in an icebox immediately after the sampling and filtered within 12 hours.
Since the analysis was done for all thermotolerant coliforms it was not possible to confirm whether the coliforms were from human feces or from livestock dung. Observations were done in order to find the main contamination factor.

For the analysis of thermotolerant coliforms the membrane filter technique was used.
Before the analysis all materials were sterilized in a steamer (Prestige Medical Portable Steam Steriliser 7500 Series). Than, the samples were shaken and the lids were removed from the bottle. From each sample, 100 ml was filtered through a membrane filter (Gelman Sciences Sterilised Membrane). The membranes were placed in a sterilized dish and colored with a lauryl red solution. (Membrane Lauryl Sulphate Broth).
Than, the dishes were allowed to stay for 24 hours in a heated area inside a mobile water analysis kit (Oxfam DELAGUA-kit). After the 24 hours the dishes were removed and the colonies were counted. If the number of colonies exceeded 75 the next measurement was done with a two or four times diluted sample.

9.3.2 Electrical conductivity, pH and temperature
The electrical conductivity (EC) was measured by an Electrical Conductivity Meter. All samples were measured three times in order to get a reasonable average value. Since there was no portable EC meter available, samples were taken in small bottles and directly placed in an icebox. All samples were analyzed within 5 hours after sample taking.
The pH was measured with a pH meter (HACH Company). Before every measuring day, the meter was calibrated in a buffer solution (Color Coded Yellow) with a pH of 7.00 (±0.02, cat. 288 35-49). After each measurement the pH meter was rinsed by the buffer solution. All samples were measured three times.
The temperature was taken on spot using a thermometer (Cocmapen 21982).
The EC, pH and temperature were measured monthly.

9.3.3 Hardness (in mg $CaCO_3$ per liter)
For measuring hardness EDTA Tetra sodium Salt with a normality of 0.800 ± 0.004 from HACH Europe was used as titration liquid. From each sample 50 ml was poured in a clean 100 ml Erlenmeyer. By using 50 ml of the sample the digital multiplier was 2.0. Firstly 1.0 Buffer Solution Hardness 1 (pH 10.1 ± 0.1, cat. 424-32 HACH Europe) was added to the sample. Than one powder pillow with Permachem Reagents Man Ver 2 (Hardness Indicator, cat. 851-99, HACH Europe) was added. With a digital titrator (HACH Europe) the amount of titration solution merged with the sample was measured till the color changed from red to blue. All measurements were repeated three times and samples were taken from each source monthly.

9.3.4 Chloride (mg/l)
Chloride was also analyzed by titration. Silver-Nitrate ($AgNO_3$) 0.2256 ±0.0010 was used as titration liquid. To 50 ml of the samples one powder pillow HACH Chloride 2 indicator was added. When the color changed from yellow to red the amount of used titration liquid could be defined. The digital multiplier by 50 ml was 0.25. All measurements were repeated twice and samples from all sources were taken monthly.

9.3.5 Nitrate (NO_3^-) and sulphate (SO_4^{2-})
Nitrate and sulphate were analyzed once during the research, since the spectrophotometer was only available from late December till mid-January. Both nitrate and sulphate were analyzed on the spectrophotometer (HACH, DR/2000) using reagents (HACH Nitra Ver 5, cat. 14034 – 99 and HACH Sulfa Ver 4, cat. 12065-99 respectively).
Samples for nitrate and sulphate analysis were directly after taking placed in an ice box. To avoid leaking the lid was tightened firmly and secured with tape.

9.3.6 Parasite analysis

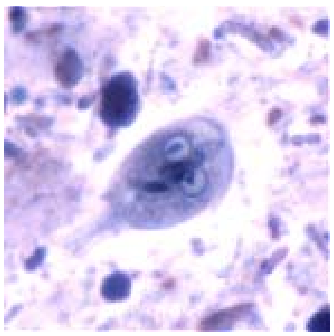
For analyzing the water on *Cryptosporidium* oocysts and *Giardia* cysts, water samples were collected from the five main water sources; a water harvesting pond, a bore hole, a river stream and two shallow wells.

The samples were collected in large 30-liter containers and after transportation the samples were directly placed in the refrigerator of the laboratory. The samples were taken in the morning in December 2004.

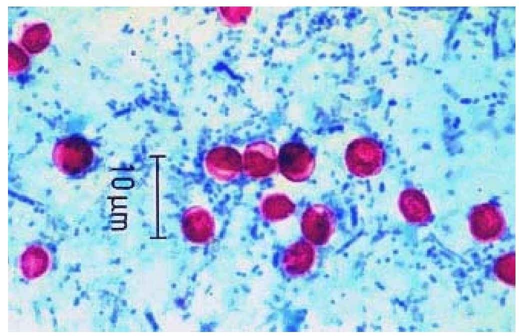
The samples were pumped with a small electric pump through a cylindrical filter (4µm). The residues in the filter were removed by scraping the surface of the filter. Then the filter was rinsed with distilled de-ionized water and scraped again.

The collected material was stored in small tubes (20 ml) and conserved in 4 ml of 10% formaldehyde.

After 1 month the 10 ml of the supernatant was removed from the tubes and centrifuged for 15 minutes at 200g



Picture 8 : *Giardia* cyst through the microscope (60X objective)



Picture 7: *Cryptosporidium* oocysts through the microscope (100X Objective)

On picture 7 and 8 *Giardia* cysts (left side) and *Cryptosporidium* oocysts (right side) through a 60X resp. 100X objective, like the ones found in water samples collected in the Peasant Association of Lege Dini can be seen.

<u>*Giardia* cysts</u>

Giardia cysts were analyzed using a light microscope with a 40X objective. From all sources two slides were prepared with a drop of the concentrated specimen. From each slide 25 fields were randomly selected. The number of positive fields and the amount of cysts per field were reported.

<u>*Cryptosporidium* oocysts</u>

For analyzing the *Cryptosporidium* oocysts the Ziehl-Neeilsen staining was used. First the solution from the 20 ml tubes was centrifuged with a solution with a higher gravity. The solution used for this purpose was sucrose with a specific gravity of 1.105 and this was pipetted in a centrifuge tube. On top of the sucrose 5 ml of the water sample was layered. After centrifuging for 15 minutes at 200g, a cloudy layer became visible at the interface of the tube. This layer was removed by a pipette and used to prepare 2 slides for each source. When the smears were dry the Ziehl-Neeilsen method was applied. With a 100X objective the slides were examined in an oil-immersion. From each slide 25 fields were randomly examined. The number of positive fields and the amount of cysts per field were reported.

9.4 Sample locations

The five main water sources in Lege Dini were examined both in time and space.
In terms of space the water was sampled at different points on its way from source to final consumption. For all sources this is a different route. In the table below the different points of sampling are listed. The containers in which the water is transported to the houses of the villagers were examined as well.

Main Locations:	SUB LOCATIONS :	Remarks:
Selela well	Well morning/afternoon/containers	Before activity/in late afternoon
Ajo borehole	Reservoir (1) morning/afternoon Reservoir (2) morning/afternoon Tap water Ajo Tap water Iddo Tap water Iddo Bolo Tap water Halo containers	Might not give water
Ajo pond	Well morning/afternoon containers	Before activity/late afternoon
Hado Sere well	Well morning/afternoon Container	Before activity/late afternoon
Kora river stream	Upstream Cave Upstream Reservoir Upstream tap Downstream tap Irrigation channel containers	Most upstream part possible

Table 11: sample locations of the water samples collected in Lege Dini

The water pathways are different for each source:

- <u>Ponds, wells and other open water sources</u>
  For ponds and wells the chain is very short; first the water is collected from the pond or well in containers. Secondly the water is carried in the jerry cans to the houses of the villagers. In or near the houses it is consumed or used for domestic and productive uses. The in-house storage is not different from this; water is conserved in the containers. In these sources the water will be examined in the open water source and in the container.
- <u>Rivers, springs and streams</u>
  Since rivers are streaming, these water sources renew themselves in time. Double measurements in morning and afternoon are therefore not useful. In streaming water sources it is more important to compare upstream quality and downstream quality. Since there exists a pipe-system to conduct the water from the stream to the village, this system will be analyzed too. In the case of rivers and other steams the water was sampled at the following locations: In the most upstream part where it is possible to

take a sample, in the reservoirs, at the taps, in the containers and from the irrigation canals downstream.

- Boreholes
  The borehole in Ajo serves many villages; the chain is therefore very long at some locations. Each part was sampled to find the contaminating sources of the serving water. In the case of boreholes the water was sampled at the following locations: in the reservoirs, at the taps (in Ajo, Iddo, Iddo Bolo and Halo) and in the containers

The results were analyzed and compared in order to make an adequate diagnosis of the quality of the water. If the water in the main source is already unsuitable for drinking water, some treatment must be applied in order to increase the quality. If the water quality decreases along the chain, recommendations about transport and in-house storage and treatment should be made.

9.5 Acceptability aspects

Besides from all guidelines and goals, water quality is not only a matter of numbers and values. The local population will not be likely to use water that is smells, looks poor and tastes bad. Furthermore, contaminations that were overlooked by investigating the sources can be stressed by the people themselves when asked about the quality of their water sources. Therefore the rural population of the Lege Dini watershed area has been interviewed in order to understand their point of view and perceptions. As described in chapter 4.3, specific characteristics can indicate different kinds of contamination. Further research is required to quantify the origin of contamination. If despite the color the water turns out to be suitable for domestic uses and drinking water, still a solution should be found to improve the appearance and thereby the acceptability and use of the water. Even if scientifically proven that there is no health risk involved, drinking colored, smelly and bad tasting water is not desirable.

9.6. Exploring suggestions for improvement

The final objective of this research as defined in chapter 6 is to contribute to the improvement of the water security of save drinking water in the Lege Dini watershed area and therewith the improvement of health of its local population.

To reach this objective a clear problem definition and a quantification of the water quality has to be followed by an analysis of bottlenecks, causes and implications. Since the bottlenecks, causes and consequences of these causes will be known after completing the fieldwork, this can lead to practical solutions, opportunities, recommendations and designs for change.

It is important that these conclusions contain useful and practical information specific for the situation in Lege Dini. For example the recommendation to wash your hands before eating will be useless if the water deficit is the nucleus of the problem. All designs and recommendations for change only make sense if they are defined in accordance with local norms and values.

A part of the problem may be covered by health education (see results chapter), for other problems more stringent options should be found. People from Lege Dini are very open towards education programs. They often ask for supplementary information and are actively involved in the programs that have been executed in their villages. This can be used as a powerful method to reach a lot of people in the area.

In cooperation with Martine Jeths (Jeths, 2006), who focuses on institutional possibilities and coping strategies joint conclusions and recommendations will be drawn for the Lege Dini area.

9.7 Limitations of the research and recommendations for further research

A few limitations should be mentioned that showed up during this research. First of all there was a problem interviewing the male part of the population, since they were not likely to talk with women about sanitary issues. At the end of December and in the beginning of January a male assistant took over these interviews and came up with valuable reports. The women that were interviewed were likely to exaggerate the situation a little, in hope of additional help from the researcher. Furthermore, both men and women were selected by the chief and were mainly the families with the largest land holdings. Since the fellow inhabitants found the interviews very interesting, they often sat together in a circle around the interviewee and the researcher, which made the respondent sometimes a bit uncertain about his/her answers and showed sometimes hesitation to speak out his/her true feelings and thoughts.

Sometimes people were in a hurry; in that case, the interview was stopped and another respondent was completing the questionnaire. The data of one interview are sometimes coming from two different persons.

The laboratory facilities in Dire Dawa were limited. There was minimal equipment for sterilization and the estimation of thermotolerant coliforms by staff of the HCS was sometimes questionable. Sterilization of bottles and containers was not possible. By repeatedly rinsing the bottles with water from the selected source, the sample in the bottle was as pure as possible.

There was no data available about the aquifers in the area. This can be from great importance to the people of Lege Dini. If the aquifer is structurally exhausted, trying to become self sufficient in the way the people are trying now, will be useless.

10. Results

10.1 General impression and observations

During the interviews it became clear the there was no uniformity about rules and regulation in water delivery. Everybody was mentioning other systems of division and collection. Also the development organizations contradicted each other. For a detailed description of the organizational structure see Jeths, 2006.

10.2 Results of the water analysis

10.2.1 Thermotolerant coliforms

The amount of coliforms exceeded in many water sources the maximum allowed values in Developing Countries according to the WHO drinking water guidelines and the DAP II project guidelines for drinking water. However for livestock and irrigation purposes the values are acceptable, on the condition that the irrigated crops are not eaten raw. Especially crops that are irrigated by pouring the water over the leaves and stem should be treated first before eating if high levels of thermotolerant coliforms are found.

	Name/Type Source	**Sept**	**November**		**December**		**January**	
			morning	***afternoon***	***morning***	***afternoon***	***morning***	***afternoon***
1.	*Selela Well*	*	**63**	*	**148**	**172**	**276**	*
2.	*Ajo Pond*	*	**100**	*	**148**	**204**	**200**	*
3.	*Ajo Tap*	4	**75**	24	17	*	25	*
4.	*Reservoir 1*	*	0	*	0	*	2	*
5.	*Reservoir 2*	*	0	*	0	*	(a)	(a)
6.	*Iddo Tap*	*	1	2	0	*	(a)	(a)
7.	*Iddo Bolo Tap*	*	21	20	16	*	(a)	(a)
8.	*Halo Tap*	*	10	12	11	*	2	*
9.	*Hado Sere Well*	*	49	*	**165**	**187**	**310**	*
10.	*Kora Spring*	*	0	*	0	*	1	*
11.	*Kora Reservoir*	*	0	*	0	*	1	*
12.	*Kora Tap Up*	*	2	*	3	*	2	1
13.	*Kora Tap*	17	1	*	2	*	2	7
14.	*Kora Irrigation canal*	*	17	*	4	*	6	7
15.	*Lega Cat seepage well*	*	*	*	63	*	**216**	**164**
16.	*Containers*	*	*	*	**213**	*	34	*
	* No data a. Pipe system was broken down							

Table 12: Average thermotolerant coliforms per 100 ml, measured from samples taken from 16 different sites in the PA of Lege Dini. Data from September are measured by the HCS.

As shown in table 12 the open wells and pond have the highest concentration of thermotolerant coliforms. Closed sources like the tap system in the villages around the borehole show a stable value during the day. However over the study period an increase in thermotolerant coliforms per 100 ml in the open sources was measured. This can be the result of the declining water table in the open sources.

From the clinic in Ajo, a lot of illnesses (mostly diarrhea) are reported from late November till the short rainy season and from Late March till the large rainy season, these are the periods

that the water in those wells is becoming scarcer and therefore the contamination more concentrated.
The tap and the spring system are more or less stable. The coliform concentration increases a little along the system, but does not exceed the limiting values for coliforms as defined by WHO/DAP II.
The containers (average of different measurements) show an increased concentration of coliforms per 100 ml both in Kora (closed system) and Selela (open well).

10.2.2 Giardia and *Cryptosporidium*
Since *Giardia* and *Cryptosporidium* parasites do not have a large influence on crop growth and animal health, drinking water guidelines are used as comparison. Again attention should be paid to irrigation water if the crops irrigated are consumed raw. Especially animals, but maybe also children, may eat part of a crop just after irrigation. The parasites can still be active by that time.
Since a small dose of *Giardia* and *Cryptosporidium* can already cause an infection, the guidelines prescribe the value of 0 cysts/oocysts.

	Name/Type of source	***Giardia* cysts per 30 liter (2x 25 fields)**	**C*ryptosporidium* oocysts per 30 liter (2x 25 fields)**
1	*Selela Well*	**21**	5
2	*Ajo Pond*	**21**	7
3	*Ajo Tap*	6	2
4	*Hado Sere Well*	**23**	**10**
5	*Kora Spring*	3	1

Table 13: Amount of *Giardia* cysts and *Cryptosporidium* oocysts per 30 litres from 5 different sources in the PA of Lege Dini. The values are the sum of de number cysts/oocysts found on 2 smears.

Giardia cysts were found especially in the open wells and ponds. The seasonal variation was not measured.
The *Cryptosporidium* oocysts also occurred mainly in the open sources. However in the closed sources (tap system and spring) the values exceed 0.

10.2.3 Temperature
The temperature measurements showed values between 17ºC and 38ºC. For some types of bacteria, 37/38 degrees (body temperature) is the favorable temperature to multiply. The water temperature for the sources in Ajo and Kora shows an increased value along the system with increased exposure of the distribution system to the sun. In the reservoirs the temperature is still about 22ºC, while the tap water sometimes exceeds 36ºC.

	Name/Type Source	September T (°C)	November T (°C)	December T (°C)	January T (°C)
1.	*Selela Well*	*	21	21	19
2.	*Ajo Pond*	*	17	23	20
3.	*Ajo Tap*	28	26	23	26
4.	*Reservoir 1*	*	21	22	23
5.	*Reservoir 2*	*	24	24	(a)
6.	*Iddo Tap*	*	28	28	(a)
7.	*Iddo Bolo Tap*	*	29	30	(a)
8.	*Halo Tap*	*	27	27	26
9.	*Hado Sere Well*	*	26	28	26
10.	*Kora Spring*	*	19	19	19
11.	*Kora Reservoir*	*	23	23	23
12.	*Kora Tap Up*	*	**34**	**33**	**34**
13.	*Kora Tap*	32	29	30	33
14.	*Kora Irrigation canal*	*	**35**	**37**	**37**
15.	*Lega Cat seepage well*	*	*	24	24
16.	*Containers*	*	*	21	**38**
* No data (a) Pipe system broken down					

Table 14: Morning temperature (in °C) of 16 samples from water sources in the PA of Lege Dini. The values from September are measured by the HCS.

Irrigation water with temperatures higher than 20°C can cause damage to the crops when applied by sprinklers or poured over the leaves. The leaves of sensitive crop can turn yellow resulting in yield reduction. Temperatures over 36.7ºC can therefore decrease the farmers' income a lot. Furthermore colder water holds more dissolved oxygen than warm water, which benefits the development of the crop.

10.2.4 pH

All measured pH values lay within the normal range of 6.0 – 8.5. This means that according to this parameter, the water is suitable for drinking, irrigation, watering livestock and other uses like bathing.

10.2.5 dH

None of the measured dH values are exceeding the WHO guideline of 500 mg $CaCO_3$ per liter. Still some values are just below this 500 mg (28 dH) and will cause the drinking water to have a bad taste (like calcium).

10.2.6 EC

According to table figure 3 from chapter 6, sensitive crops will be reduced in yield by these values of electrical conductivity. Especially unions and other vegetables that are grown in the nursery will be limited in their development. Farmers that are cropping moderately sensitive crops like papaya and maize will also face small yield reductions. The EC levels in the water sources will not have a negative health impact on livestock in the area. If animals are accustomed to the water sources, diarrhea and other diseases will not occur (Alabama Cooperative Extension System). Water sources with values above 500 µS form a hazard for poultry. The water source of Ajo would be an excellent opportunity for poultry.

	Name/Type Source	**Sept**	**November**		**December**		**January**	
			Mean EC (µS)	***Standard dev. (σ)***	***Mean EC (µS)***	***Standard dev. (σ)***	***Mean EC (µS)***	***Standard dev. (σ)***
1.	*Selela Well*	*	579	2.9	634	3.1	689	1.0
2.	*Ajo Pond*	*	266	1.5	266	4.3	266	1.5
3.	*Ajo Tap*	791	663	5.6	639	3.2	622	2.6
4.	*Reservoir 1*	*	612	6.7	588	1.5	576	0.6
5.	*Reservoir 2*	*	558	7.5	540	2.3	(a)	(a)
6.	*Iddo Tap*	*	658	1.5	646	2.5	(a)	(a)
7.	*Iddo Bolo Tap*	*	642	4.0	622	1.5	(a)	(a)
8.	*Halo Tap*	*	648	6.7	628	2.6	624	5.1
9.	*Hado Sere Well*	*	670	1.0	687	5.6	704	6.1
10.	*Kora Spring*	*	605	4.4	542	5.7	508	6.1
11.	*Kora Reservoir*	*	595	4.2	585	4.6	567	3.2
12.	*Kora Tap Up*	*	573	4.9	566	1.5	540	8.0
13.	*Kora Tap*	509	555	1.5	512	3.5	500	2.1
14.	*Kora Irrigation canal*	*	561	2.6	550	2.1	544	0.6
15.	*Lega Cat seepage well*	*	*	*	613	7.8	599	0.6
16.	*Containers*	*	*	*	638	4.3	494	5.7
	* No data *(a) Pipe system broken down*							

Table 15: EC values (in µS) and standard deviation of 16 samples from different water sources in Lege Dini. Values from September are measured by the HCS.

10.2.7. Chloride

The examination on chloride in the different water sources showed some values that exceeded the standard of 70 mg/l, which indicates risk for damage to the crops. Especially sensitive crops, like vegetables, can be damaged if irrigated by water from the tap system in Ajo. The highest values measured were from water samples collected at the seepage well of Lega Cat (123 mg/l Chloride). This water can damage all crops, may even destroy the entire yield of sensitive crops and can cause irreversible damage to the soil.

For human health the values are not indicating a risk. However, the water from Lega Cat will taste very salty. It is drunk, mainly by the inhabitants of Lallo and Kore Chafe, but better tasting water has their preference.

	Name/Type Source	November Av. Cl. content (mg/l)	standard dev. (σ)	December Av. Cl. content (mg/l)	standard dev. (σ)	January Av. Cl. content (mg/l)	standard dev. (σ)
1.	*Selela Well*	50	1.0	53	1.0	52	0.6
2.	*Ajo Pond*	26	2.1	36	0.6	38	1.0
3.	*Ajo Tap*	**80**	0.6	34[b]	0.6	64	3.2
4.	*Reservoir 1*	**76**	1.5	**70**	2.5	62	0.6
5.	*Reservoir 2*	**70**	1.5	**72**	2.1	(a)	(a)
6.	*Iddo Tap*	**77**	1.0	**74**	2.1	(a)	(a)
7.	*Iddo Bolo Tap*	**82**	2.3	**84**	1.5	(a)	(a)
8.	*Halo Tap*	**76**	1.5	**82**	2.9	**75**	2.1
9.	*Hado Sere Well*	53	3.2	58	1.2	50	0.6
10.	*Kora Spring*	53	2.1	51	1.0	43	1.2
11.	*Kora Reservoir*	48	0.6	56	2.1	49	2.6
12.	*Kora Tap Up*	44	1.2	57	1.5	50	2.9
13.	*Kora Tap*	47	0.6	54	2.9	47	1.5
14.	*Kora Irrigation*	45	1.2	55	0.6	48	3.2
15.	*Lega Cat well*	*	*	**122**	1.5	**116**	2.1
16.	*Containers*	*	*	54	1.5	46	0.6
	* = no data						

Table 16: Chloride values (in mg/l) and standard deviation of 16 samples from different water sources in Lege Dini. Values from September are measured by the HCS.

10.2.8 Nitrate

The nitrate measurements show higher values in the borehole system of Ajo and in the seepage well of Lega Cat. For drinking water there is no problem because the values are low. Higher values can cause blood disorders, like the blue baby syndrome. However values above 30 mg/l Nitrate can cause damage to all crops. Due to the excessive vegetative grow, weak stalks will be created that are unsuitable to support the grains etc. For livestock the water is, according to this parameter, safe.

	Name/Type Source	December Average Nitrate level (mg/l)	standard deviation (σ)	January Average Nitrate level (mg/l)	standard deviation (σ)
1.	*Selela Well*	6.0	0.5	6.3	0.3
2.	*Ajo Pond*	7.5	0.5	8.5	0.5
3.	*Ajo Tap*	23.5	0.5	25.2	1.0
4.	*Reservoir 1*	21.8	0.3	22.7	0.8
5.	*Reservoir 2*	22.7	1.3	(a)	(a)
6.	*Iddo Tap*	23.7	1.0	(a)	(a)
7.	*Iddo Bolo Tap*	21.0	1.5	(a)	(a)
8.	*Halo Tap*	22.0	0.5	23.0	0.5
9.	*Hado Sere Well*	5.5	0.5	6.3	0.6
10.	*Kora Spring*	8.3	1.3	9.3	0.8
11.	*Kora Reservoir*	8.5	0.5	10.5	0
12.	*Kora Tap Up*	10.0	0.5	10.0	1
13.	*Kora Tap*	9.3	0.3	11.8	0.3
14.	*Kora Irrigation canal*	10.0	0.5	10.8	1.0
15.	*Lega Cat seepage well*	**34.8**	2.1	**39**	1.3
16.	*Containers*	6.0	0.3	11.1	0.6
(a) Pipe system broken down					

Table 17: Nitrate values (in mg/l) and standard deviation of 16 samples from different water sources in Lege Dini.

10.2.9 Sulphate
All measured values were below the standard of 500 mg Sulphate per liter. Therefore there is no hazard for humans, animals and/or the environment according to this parameter.

10.3 Results of the survey and secondary data
The survey was divided into three main topics. First of all there were questions about awareness of water, sanitation and hygiene and the organizational structure around it. Secondly there were questions about the quality and quantity of in-house use of water and water for animals and irrigation. Finally some questions were asked about the future and desires of the farmers.

10.3.1 Awareness and organization
The respondents were asked about whether or not they knew who was representing their village, on what topic and for which organization. More than one third of all people interviewed didn't know anything about the system of representatives. The two groups (people that know and people that do not know the representatives) were also asked about their knowledge on topics that were launched in the villages in the form of education programs according to the NGO's and GO's in and around Dire Dawa. From the people who knew about the representative and his/her relation to certain organizations, 80% was also able to give a short outline of projects and education programs that had been executed in their PA.
However from the people that did not know about the representatives of their village, only 23% was able to recall the information given in projects and education programs. The other 77% either did not know about any meetings or did not find it useful to participate.

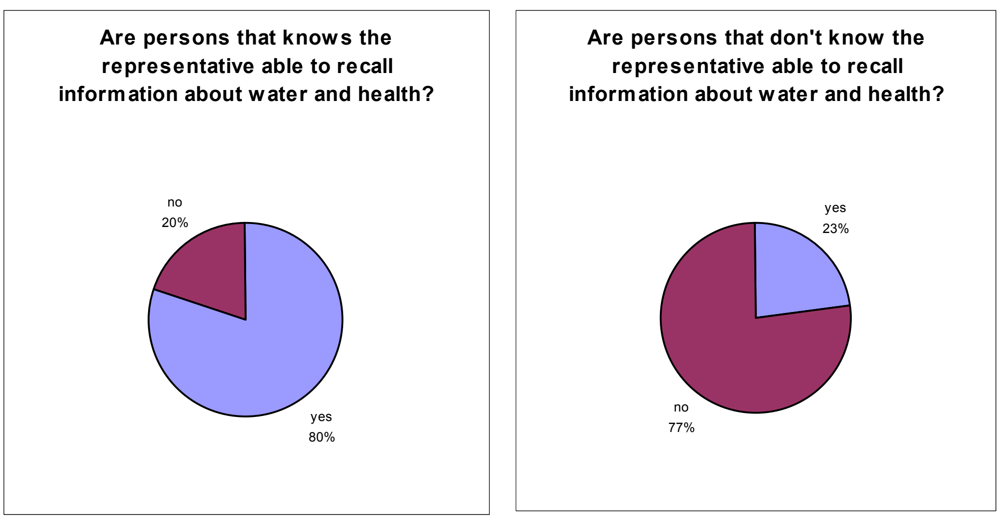


Figure 6: Percentages of poor informed and well informed people on the topics launched by the education programs. The left figure represents 65% of all inhabitants of Lege Dini, while the right figure represents 35%.

10.3.2 Quantity and quality of domestic and productive water
One of the major problems for the remotest villages of the area (and later also for the villages connected to the tap system, since it broke down) is the distance to the water source. Lack of donkeys and camels makes it very difficult and physically tough to collect enough water for the family, livestock and crops every day. In the figure below per distance (in minutes) the average water use is calculated.
Knowing that the average family size is almost six persons, the 40 liter average that Is taken by the families that have to walk a large distance, is very small, making less than 7 lpcd available, while according to the WHO the absolute minimum for a healthy life is 15 lpcd.

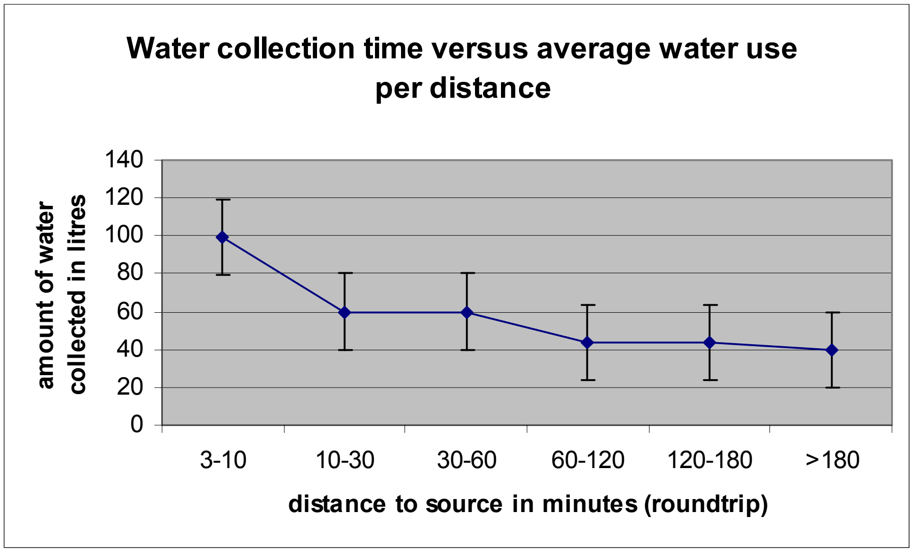


Figure 7: The time somebody is spending in walking to a water source to collect water (roundtrip) versus the water that is collected per family (I = range, ♦ = Average).

From the figure can be derived that most people that are living far away from the source are not willing or able to take enough water home. That means that activities using a lot of water will be carried out at the source, e.g. laundry and watering of livestock. As a result, the animals sometimes have to walk very for to get their water, resulting in lower water intakes and reduced productivity (van der Hoeve 2004). The problem of not being able to take home enough water can be caused by different reasons. For example, there is a physical constraint. People are physically not able to carry more water on their backs back home. But at the same time this is an economical reason; if these persons had the opportunity to buy a camel or a donkey to carry it for them, they would possibly collect more water.

The question about the constraints and causes of water shortage is answered differently. Many respondents come up with a financial, technical (pump capacity) or environmental (drought) reason as cause of the water shortage in the household; they explain that there just is not enough water for everybody or money to by it, otherwise they would have taken more. Only 21% of the respondents mentions the distance to the closest water source as the main problem of their water shortage problems.

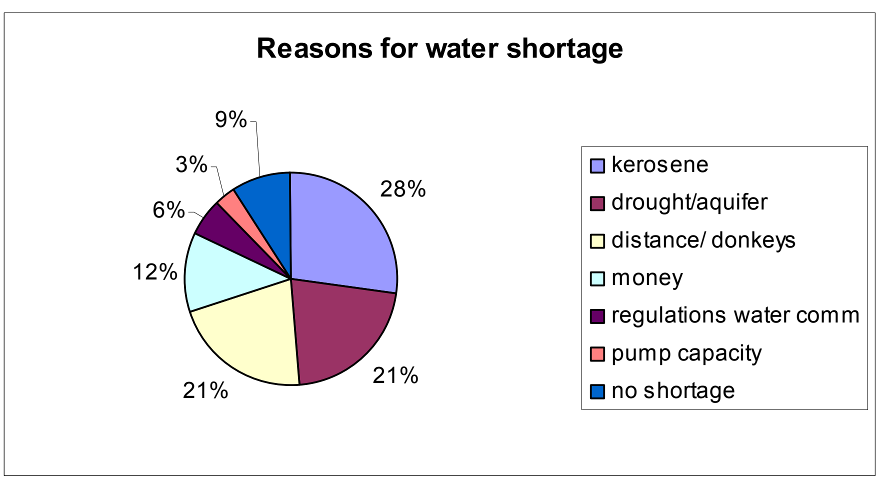


Figure 8: Reasons for water shortage mentioned by the inhabitants of the PA of Lege Dini. The questionnaire was hold between October 2004 and January 2005.

Taking a closer look at the reasons given in the questionnaire, most of these seem to be part of the financial problems in the area. If the answer "there is no kerosene" was given by the respondent, he/she was asked to specify in a follow-up question, whether the kerosene was not available or not affordable. Unfortunately people were often too ashamed to admit that they did not have enough money. The answer on the follow-up question was often just a smile or the same answer that was given on the first question. Distance has all to do with the livestock rate of a family (unless the walk is indeed taking a full day), thus with their financial situation. The pump capacity was mentioned by some villagers, while others thought it was the limited amount of water in the aquifer. The latter are probably right. When the pumping system broke down in Ajo the pump itself was still operating, while there was no water pumped up.

The quality is considered as good for all different uses. Even the sources that were tested and turned out to be contaminated (sometimes they looked already polluted from the outside) were qualified as good by the users. Probably this is the result of the fact that they have no other choice. Admitting that they are drinking poor quality water would underline the poverty of these people. Water is considered suitable for drinking by 85% of the respondents, water for livestock by 81% and for irrigation water by 93%.
Almost all farmers that own a small vegetable plot apply irrigation on their crops. However water for irrigation is just a small part of the total amount collected per family. The villages that have easy access to water spend (besides crucial needs for drinking/cooking) a lot of their daily amount on watering livestock. Since the villagers are all Muslims cleaning the hands, bodies and faces is very important and after drinking and cooking and livestock watering, these ablutions are the third main use of water.

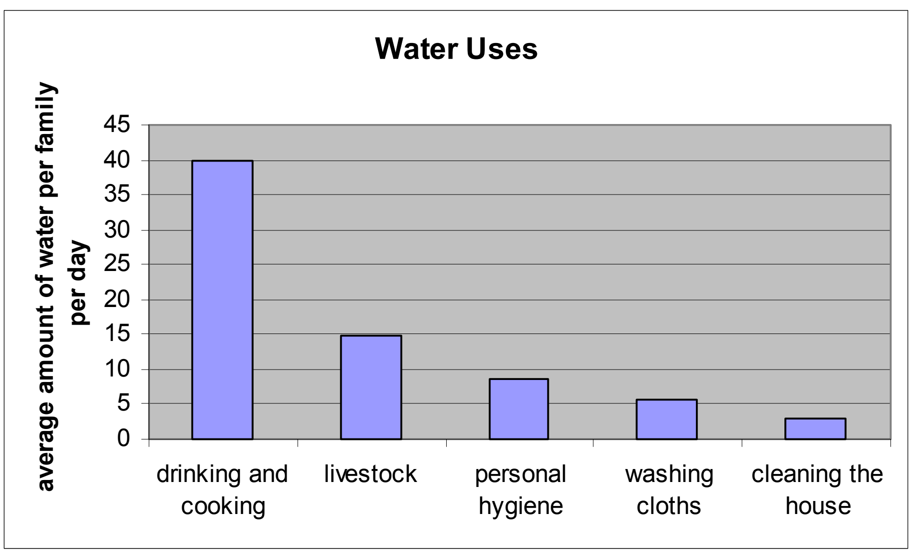


Figure 9: The average amount of water used per purpose, per household and per day, according to 40 families of the PA of Lege Dini

Irrigation is never mentioned, but if specifically asked, it turned out that water for irrigation is either wastewater or an extra amount of water is given/sold to people with vegetables.

Reuse of water and dung was also investigated in the interviews. Wastewater was mainly collected from bathing water and left-overs from cooking and cleaning utensils. Wastewater from the laundry basin was conducted via pipelines to the closest fields in most of the villages (those connected to a tap system). Laundry water is not preferred by the villagers since they believe that soapy water will burn the leaves of their crops. Strange in this story is that the water is not touching the leaves at all when applied by pipelines or a drip installation technique (tin can with holes in the bottom).A small majority of the respondents (54%) said to collect and reuse their water. Roof catchments and other types of water harvesting were hardly applied. Most of the time there is a lack knowledge and insufficient construction materials or financial possibilities to construct water harvesting installations. The small amount of water that could be reused was most of the time given to the livestock or poured over the crops in the (home) garden.

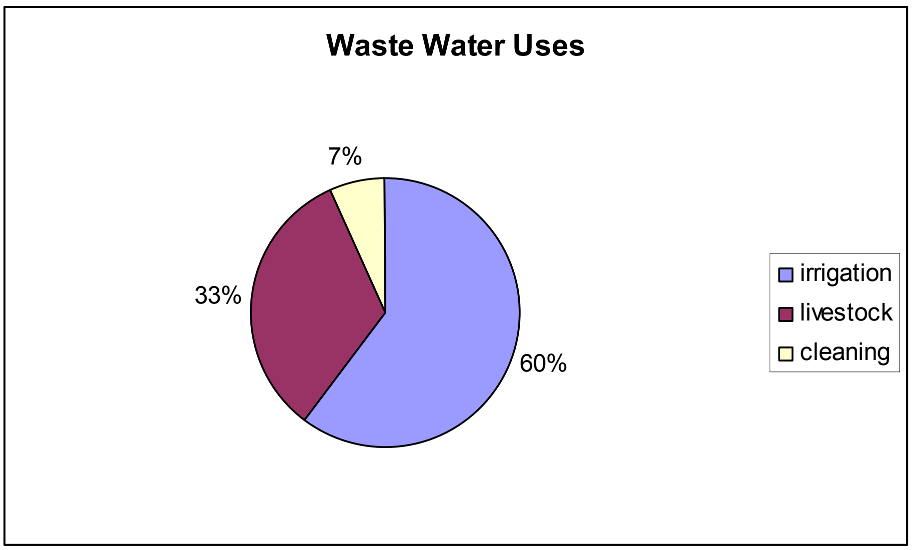


Figure 10: Mentioned uses of waste water during the survey in Lege Dini

Dung was collected in almost every village. Unfortunately most people did not know why and the dung stayed on a heap till the rain flushed it away. The dung was not even used as fuel. The fuel that was used for cooking etc. was wood collected every day in the mountains. Only one third of the interviewees said to apply the dung regularly as fertilizer. The main constraint for not applying the dung was that there wasn't enough irrigation water. Without irrigation water the farmers were afraid that the dung would make the plants burn by the sun. The dung was not used as fuel either. For cooking etc. fuel wood was collected daily in the mountains.

10.3.3 Sanitary issues

Only in the villages of Ajo and Kora there are communal latrines and plenty of latrines in the compounds. However these are barely used. Bad constructions without privacy and the uncomfortable feeling of defecating close to the house make the latrine an unpopular place.

10.3.4 Future

The answer on the question "what would you do in case of better water availability?" was creating a possibility for the respondents to stress all their problems relating to the water availability. Therefore the uses mentioned in case of more water were rather based upon emotion than upon rational thinking. A lot of people see the market in Dire Dawa as a great opportunity to increase their welfare. Selling cash crops is one of the possibilities and irrigation is therefore a frequently mentioned water use in case of better availability. Also maize and sorghum surpluses can be sold if irrigation is applied according to the farmers.

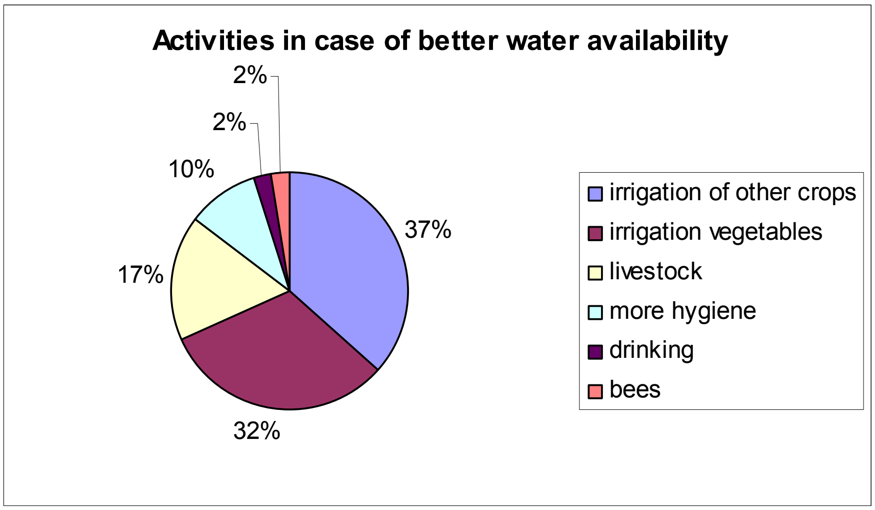


Figure 11: Uses on which they would spend more water mentioned by the inhabitants of the PA of Lege Dini in case there would be more water available to them.

11. Conclusions and Recommendations

11.1 Lege Dini Area

Use of Resources

In Lege Dini the water resources are not optimally used. In case of optimal use of the available water resources and the additional water sources that could be created, the area would take a huge step forwards on their way to become self-sufficient

Currently, some good quality water sources are used for purposes that require low quality and poor quality water sources are used for drinking, which could be reversed. Furthermore not all possibilities for water harvesting and wastewater reuse are known or applied by the inhabitants of Lege Dini.

There are many reasons to explain the fact that till now many opportunities for water use have not been explored or optimized. Generally this can be approached from three areas;

1. Lack of knowledge within the communities
2. Lack of financial resources
3. Lack of organizational structure inside and outside the villages.

1. Most people from the Lege Dini area are willing to get involved in education programs and are open to recommendations from outsiders. They have a strong will to learn and try to become self sufficient. Many organizations from the surrounding area try to help them in, amongst others, the area of water management. The people from Lege Dini know the advantages of the plans that have been executed with the help of outsiders (e.g. the construction of the water harvesting pond) and try to copy the techniques to benefit their family and fellow villagers. Unfortunately they often lack the skills and knowledge to do so, which results in poor or wrongly constructed interventions. Examples are the pond that was created downstream of the dung heap and the roof catchment system on the school that was not operating.

2. If there are enough people present with sufficient knowledge and skills, taking measures for improvement still requires a financial contribution from all villagers. Due to poverty they are often not able to make such investments.

3. To a certain extent the organizational structure can be blamed for the failure of optimal use of resources. Both governmental and non-governmental organizations implement projects in the area of Lege Dini, but often in an unstructured way without linking to existing structures. This often results in unfinished projects or a low participation rate of the local population, e.g. in education projects because of the fact that people do not know where and when to gather. Since the willingness to participate is high, this is a regrettable case. The low participation rate creates misunderstandings among the inhabitants of the villages and wrong impression of the people's interest to the intervening organizations. Below, a short overview and some examples of this organizational problem will be given. For more details on the institutional environment of Lege Dini see the thesis research of Jeths (2006).

First of all, the lack of organizational structure often results in different opinions about which water is for whom, as described in chapter seven. For actors and stakeholders it is important to know what the assumptions and regulations are for the use of the pump and reservoirs. If the surpluses of (drinking) water are not shared with neighbors but used for livestock and irrigation requirements for a couple of years, it would become more and more difficult to let people share in a later stage. It will become a custom for the inhabitants of Ajo that the water from the borehole is their own property. Therefore, if this water is to be shared, haste should be made by explaining the purpose of the borehole to all involved stakeholders and actors.

Another issue is the determination of the maximum amount of water that can be pumped up from the aquifer. According to the authorities that installed the pump, the amount that is being pumped up every day is a sustainable amount that will not exhaust this water layer. According to calculations of the NGOs that installed the system, it operates on a sustainable basis. However, all calculations are based upon estimations and assumptions and the accuracy seems questionable. Reason to doubt is the fact that, although the maximum amount of water that can be pumped up from the aquifer is calculated to be just enough for the whole population of Lege Dini including population growth, a second borehole in the same aquifer is considered. There is no complete and reliable dataset available from the groundwater levels and connected issues. This might result in an unnoticed exhaustion of the groundwater sources.
Although the reason was unknown by the time the study ended, the pump was not operating (or dry-pumping) from the second week of January onwards, which can indicate a technical failure or miscalculations.
The seepage wells that are dug by the villagers in the riverbed are also dependent on water use upstream and the groundwater level. Exhausting of this water layer can lead to disastrous water shortage for the inhabitants.
A last point of an unstructured institutional environment is the system of representatives. All NGOs and GOs work with different representatives at the community level. People in the communities lose track of who is representing what. Many different names are given when asked about representatives in the interviews. By organizing community meetings to discuss with the whole village about who is considered the representative and for what issues this could be sorted out very quickly.

Possibilities for Complementary Water Sources
Though almost all residents report water scarcity, the situation in Lege Dini could easily be much improved. With small investments the area can increase both quantity and quality of its water sources. From the interviews it became clear that in case of increased water availability people will indeed use this for irrigation of mainly cash crops. Hence, with more and better water the area can move into a positive spiral of better hygiene, less illnesses, more water for irrigation, higher productivity of man and animal labor, better harvest, more income, more possibilities for investment, more money for emergency situations, and better livelihoods in general. Water availability can be improved in a number of ways, some of which are discussed below.

First of all new *water harvesting structures* can be constructed in the area. The roofs of many houses are unsuitable for rainwater catchment, but larger houses, like the school, the clinic, and the house of the village leaders, are constructed with corrugated iron. Existing roof catchment installations are out of order and should be repaired. Storage tanks can collect this rainwater for a longer period of time. Especially when these are covered, contamination can be avoided. When other sources fail to provide enough water year-round, the stored water can be used. It would be worthwhile to make a calculation about the costs of the construction of improved roofs and the benefits it could provide. If more houses are able to contribute to the water harvesting, this will have a positive effect on the self-sufficiency of the area.
Another way of increasing the amount of water is by constructing more *harvesting ponds*. The pond near the village of Ajo is the main water source for livestock from the surrounding villages and serves this area from the rainy period till it falls dry in February/March. Inhabitants of other villages admit that such ponds could solve many of their problems related to water shortage. Some tried to create their own ponds. However, due to a lack of skills, these ponds were not correctly installed. Sometime the pond was not located on the lowest

part of the village and in one village, the pond was created just downstream of a dung heap. A second problem that can occur by creating ponds is the increased risk of malaria transmission.

Reuse of waste water is another, yet due to its quantity less important, option. People that reuse their wastewater (from cooking, washing, etc.) usually use it for watering their livestock. If ponds are constructed, livestock will be able to walk to these sources, which makes it possible for the families to use their waste water for irrigation. Irrigation will make it possible to cultivate a few cash crops like papayas and tomatoes. By selling these on the local market, the life standard of the families can be improved, while consumption of papaya that is rich in vitamin A can help prevent blindness.
The reason why the waste water is now especially determined for smaller livestock, is that the small goats and sheep cannot make the walk up to the nearest water source. By the creation of the ponds this problem will be tackled.

One of the major *advantages of increased access to water* near the homestead is the shorter distance from source to house, which saves a lot of time now used on collecting water. As showed in the results chapter, distance can become a severe problem in Lege Dini, especially for the poor, who have no transport facilities. As a result of low carrying capacity (camels/donkeys are not affordable) families are often not able to collect sufficient water for all family members. If the water source will be created near the homestead, households can walk up to the source twice or three times a day and will provide every member of the household with sufficient water. As a result, water consumption for cooking, hygiene and cleaning is likely to increase, which is highly beneficial for health[7]

Moreover, time will be saved to undertake other productive activities such as irrigation, and intensified cultivation, and spend more time on reproductive tasks such as child care. In case children are responsible for fetching water, the time savings may allow them to attend school.
A major *disadvantage of an* open *source near the homestead* is the potential increased malaria risk, but this could be prevented by appropriate design and management. Moreover, it is not clear whether the ponds will increase the risk of malaria transmission as they only hold water during the rainy season, when transmission is already high (Rämi, 2003).
Most Ethiopian people do not know how to swim and may drown in the pond. Keeping young children out of the pond area (see also fencing the water source) will largely prevent the problem of drowning, while a simple fixed rope can help adults to climb up the steep and often slippery side of the pond.
An important aspect to be taken into account is that if livestock drinks near the homestead, they graze near the homestead as well, which can easily lead to overgrazing. This forces the animals to again walk very far, if not for water, then for their daily food requirements. The number of animals has gone down since the implementation of the watershed development program (van Hoeve 2004). New assessments of the carrying capacity of the land would be useful to identify the needs for fodder and possibly intervention strategies. Some organizations such as HCS already started with fencing off some parts of the mountain to regain the vegetation cover and in the entire country tethering is now promoted for all

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[7] For further reading see: Howard G & Bartram J (2003) *Domestic water quantity, service level and health.* Informal paper WHO/SDE/WSH/03.02, Water Engineering and Development Centre (WEDC), Loughborough University, UK, and Water, Sanitation and Health Programme, World Health Organization (WHO), Geneva, Switzerland. 36p, 110 references. http://www.who.int/water_sanitation_health/diseases/wsh0302/en/index.html ***or*** Van der Hoek W, Feenstra SG, Konradsen F. (2002b) Availability of irrigation water for domestic use in Pakistan: Its impact on prevalence of diarrhoea and nutritional status of children. *Journal of Health, Population and Nutrition*, 20(1):77-84.

livestock. This means that free herding of animals will be replaced by 'cut and carry' of animal feed. However, the branches and twigs of the bushes in the area nearby a village are also collected as fuel wood. A very strange fact is that the manure, extensively present in the villages, is not used for fuel. In the period this research was executed, there were some experiments with "closed stoves". These stoves were working on manure. If the stoves are accepted by the local population, less pressure will be put on the mountain vegetation. If full recovery of the vegetation will be enough to meet the food requirements of livestock in a sustainable way, this would be a great step forward in the water facilities for animals.

Improving water quality

Many of the existent water sources are not suitable for all purposes. The well in Selela and the well in Hado Sere show increased values of contamination in the afternoon and also other open water sources show increasing values of contamination during the study period. *Protection of source* and water is therefore very important, also because people who can not afford clean drinking water from the borehole in Ajo or the spring in Kora will keep on using these contaminated sources for their drinking water. Methods can be developed to clean the existing wells and ponds. The main source of water contamination in Lege Dini is fecal contamination. The main reason behind this kind of contamination is lack of protection from surface runoff. Hence human excreta (with people bathing in the wells and using it as latrine), domestic animal dung (if animals are allowed to get near the water sources) and wild animal dung (from monkeys, etc.) get flushed into the water sources.
Before protecting the source from these contaminating factors the water source should be *cleaned by emptying* it (a pond can dry out). The bottom of the water source should be cleaned as well as possible. Depending on the materials available, after removing fecal residues chlorine can be used for disinfection. From then on there are many possibilities to avoid pathogen pathways to occur (the fecal-oral route, discussed extensively in Chapter 6). Below some possibilities to prevent new pollution of the source are mentioned:

1. Siphons or hand pumps can be installed to avoid people touching the water with contaminated hands.
2. A protective wall around shallow wells or ponds would prevent undesirable surface inflow.
3. A proper fence (if possible covered on top to avoid monkeys climbing over the fence) should keep out domestic animals and wild animals. The roof should be permeable to rain.
4. A management team should be trained to keep the situation optimally clean and repair the system if it breaks down.

The Lega Cat shallow well in Malkakaro turned out to be very contaminated; the values of chloride, nitrate and sulphate are 4 times higher than average. It is important to find out where the water comes from and how it can get polluted underway to the well. Possibly this contamination has a geological background.

Since the quality of alternative sources will most probably be lower than the tap sources of Ajo and Kora, possibilities should be explored for small *water treatment options at home*. These treatment options should come together with an educational program how to apply these water treatment possibilities. If such education and recommendations in accordance with the social norms and values, and together with a practical plan for change, would be provided more frequently to them, the health situation could improve a lot.[8]

In this section a few recommendations for education topics and practical projects are listed.

- The water quality measurements showed that the water becomes more contaminated during transport and inside the household. Dirty containers, touching the water with dirty hands and insufficient closing of the lid are causing this. Proper health education could improve the water treatment inside the household. It can also prevent contamination at the source. The seepage wells in the riverbed of Lega Cat become probably more contaminated since women put their feet in the water source, while collecting the water. All this should be included in an education program.
- The collection of waste water is currently not widely applied. Explaining the possibilities of the reuse of water together with, for example, the introduction of small household containers to store the waste water, water use can be optimized both in quantity and collecting distance.
- An opportunity that has not been adopted in any of the development projects of the Lege Dini area is the SODIS method of solar disinfection. SODIS is an inexpensive, understandable and effective way to avoid people drinking highly contaminated water. On the internet there is a lot of material for education available (e.g. flip chart posters). Iron for construction of small roofs and other materials such as bottles and paint should be provided by operating organizations. However chemical pollution cannot be purified by the SODIS method. A disadvantage of SODIS is that it requires an investment made by the villagers or operating organization to buy sufficient bottles, black paint and, most expensive, corrugated iron to expose the bottles to the sun. In combination with the health projects that are currently executed in the area, these materials might be offered with a reduced price.
- Simple home treatment materials could be provided to the Lege Dini people, together with an explanation how to use it and on which occasions. Examples of home treatment methods are; clean containers, sand filter, pieces of cloth to cover the storage containers. The latter method can be used as a filter, but filters only larger particles, such as water fleas that can transport Guinea worms.
- A relatively inexpensive way of water disinfection is the use of CSP (Ceramic Silver Pot) filter. CSP filters remove turbidity and harmful bacteria from water.
- Another option is the closed stove, which is currently promoted in the area. Manure is used as fuel for those stoves. With the stove, water can be boiled for a couple of minutes, which minimizes the contamination for the consumer. Like the corrugated iron, the stoves require an investment from the local population.
- To eliminate micro-organisms, the rapid sand filters is a good option for Lege Dini, since it is inexpensive and does not require a lot of extra interventions.

Although one of the desires of the local population is growing vegetables, even with enough water supplies one problem will remain; the high levels of electrical conductivity. Since alternatives can hardly be found in the arid climate of Lege Dini, this water has to be used for irrigation. To avoid irreversible damage to the soil some precautions should be taken. If water with a very high EC-level is used the soil must be permeable, drainage must be adequate,

[8] For further reading see: Briscoe J, Feachem RG, Mujibur Rahaman M (1986) *Evaluating health impact: water supply, sanitation, and hygiene education*. Joint publication by United Nations' Children Fund/UNICEF, International Centre for Diarrhoeal Diseases Research/ICDDR, Bangladesh, and International Development Research Centre/IDRC, Canada.

water must be applied in excess to provide considerable leaching and salt-tolerance crops should be selected. In the Ethiopian case this can be for example tomatoes

Education

With education a lot of people can be reached and encouraged to change their behavior towards a more efficient, sustainable and effective way of acting and therewith contribute to the self-sufficiency (or self-reliability) of the area.

Many education programs are run in the area, but due to two main reasons they are not quite effective.

- Operating organizations work mainly with village-representatives who are not always recognized by their fellow villagers. Moreover, the representatives do not receive any training about how to transfer the learned information to the inhabitants of their village. Since these persons have a key-role in the whole system of education, a proper communication-skills training should not be neglected.
- The explained topics are sometimes not easy to remember for a lot of the inhabitants; leaving a copy of the material including clear pictures that explain the most important topics discussed, would serve as a reminder.

Skilled representatives and proper education materials alone will not help changing people's sanitary behavior. All programs should be adjusted to the *social norms and values* within a certain society. Within these boundaries the possibilities for improved sanitation and hygiene should be explored. In Ajo there is one latrine for the whole village, however men and women will never accept sharing the same sanitary facilities. If due to economic reasons, a second one cannot be constructed, but there are many more ways to dispose the excreta in an inexpensive way (e.g. covering the excreta with soil).
Furthermore, awareness creation on its own will not be very effective. Education programs should be combined with practical projects, such as SODIS. Besides from the employment that can be created among the villagers (e.g. in the form of food-for-work or cash-for-work programs) the 'actual change' that is recommended in the health education program will be created right at the moment of the program itself. With proper evaluations, users will directly experience the difference.

Emergency Plan

A very remarkable fact that was discovered during the study period was the absence of a proper emergency plan. When the borehole-pump construction failed to deliver water, there was no alternative plan for the inhabitants. Furthermore there was no response from the authorities in Dire Dawa and after some serious attempts from the people in Ajo, who sent one of their representatives to town, still nobody came to check out the possible causes. For weeks the people from Ajo and the villages around it had to walk to the spring source in Kora, which was now serving the whole PA of Lege Dini.
An emergency plan should contain the following elements:

- One or two technicians (from town) should be appointed as responsible technicians of the pump in Ajo. In case of break down they should be present at the pump within an established time span (e.g. 24 hours).
- The technician should be able to identify the problem and acquire the required materials for repairing the installation within an established time span.
- A financial plan should be made that officially identifies the organizations responsible for the financial costs in case of serious breakdowns of the system.

Perhaps this can be done by providing micro-credits to the people of Lege Dini (Eldis Microcredit Guide, 2005).

- As described earlier, by organizing better water harvesting facilities and by providing storage possibilities for the harvested water, a water buffer will be created. In case of breakdown, they people can use this water sources as emergency source and the pressure on surrounding sources will then be limited. Affordable (home) treatment options have to be available at the same time, as the harvested water may not always be of sufficient quality.

11.2 Towards a Multiple Use System Approach in Lege Dini

The amount of water that is now pumped up, taken from wells, collected by water harvesting and/or reused is too small to make the MUS-approach work for productive use of water and therewith make the area self-reliable. Unfortunately there is no data about the aquifer and the possibilities for a second borehole for drinking water or other uses. Furthermore according to the water analyses not all sources are suitable for all uses. Especially for drinking water there are limited sources. Another reason for the inadequacy of the multiple use approach is the distance between the villages and the possible water sources.
However the situation can be improved a lot if these constraints are addressed systematically. In this section these opportunities will be described.

For implementing the MUS-approach in the Lege Dini area a few considerations should be made. First of all, there should be enough water for all different domestic and productive uses. At this moment the people from Lege Dini are facing water shortage and try to survive with the water available. Mainly the water is used for domestic uses and livestock.

All the existing and created sources described above have different qualities. If there would be enough water in the area, implementing the MUS-approach would be a help in providing clean drinking water and proper water for livestock and irrigation.

Two sources in Lege Dini are suitable for drinking water: the borehole in Ajo, which is the main water source for seven villages and the spring in Kora, on which four villages depend. This means that about 250 families have to get their drinking water from the borehole and 120 families from the spring. The borehole pumps 1.6 l/s (efficient) during 10 hours, which means 46,800 liter per day, and 185 liter per day per family. With an average of 5.9 persons per household, this means more than 30 liters drinking water and water for personal hygiene per person per day. Even with the high population growth of 2.36% this is enough for the seven villages. The stream in Kora flows continually with a discharge of 0.3 l/s (25.920 l/day). This means 215 liters per family per day and provides even more water per family than the Ajo source.
The MUS-approach ‘multiple-sources-for-multiple-uses’ would stimulate the optimal use of sources in Lege Dini. The clean water sources will be used for drinking while more contaminated sources are used for contaminated sources are used for other purposes. Depending on the purpose, the most suitable sources can be indicated.
The ponds and wells can be used for livestock. If they are built in the vicinity of the villages, even smaller animals can make the walk to the water source. Ajo has enough water in the pond for watering all animals till February/March. The last month till the rains start could be bridged with water from roof catchments and other sources like the wells in Selela, Hado Sere, Malkakaro and Ayalegungun. The disadvantage of having water resources near the

homestead have been discussed above and should be investigated. If overgrazing turns out to be a continuous problem, water harvesting ponds should be constructed further away, in areas with sufficient vegetation for grazing.
Irrigation can be applied by reusing the wastewater of the household. Most people of Lege Dini do not at the moment apply it on their crops, since they think that slightly contaminated water will burn the leaves of the plants. Furthermore, if contaminated water is poured over the crops that are eaten raw in Lege Dini, like the stems of sugarcane, the chance of infection is rather high. To avoid this, drip irrigation can be widely promoted. In many villages people already apply drip irrigation by pouring water into a tin can with small holes in the bottom, which is connected just a few centimeters above the ground. Not all waste water is suitable for irrigation, especially if it is collected at the source of Lega Cat.

In short the following water source division can be made in the Lege Dini watershed.

- Both the spring source of Kora and the borehole in Ajo contain water that is suitable for drinking. The fecal contamination in these sources can be minimized by systematic checking and rehabilitation of the infrastructure to avoid leakages. The system in Kora is also exposed to sunlight, which increases the temperature of the water on its way down to the village. These high temperatures can increase the reproduction speed of some bacteria. Subterranean construction of pipelines will minimize this increase in temperature. The main contamination of drinking water takes place after collection, so provision of drinking water should come along with an education project for health and hygiene.
- For livestock, the water harvesting pond in Ajo seems to be the most suitable source. For all types of animals, high values of electrical conductivity forms the highest health risk. The pond in Ajo shows values around 270 µS/m, which is the lowest value in Lege Dini. However this electrical conductivity rate may still cause temporary diarrhea in livestock not accustomed to such water. Other sources in Lege Dini all exceed 500 µS/m. These water sources are less suitable and the water can even be refused by some animals. The creation of water harvesting ponds near other villages will increase the possibilities for safe livestock watering.
- Selection of the most suitable irrigation source depends on the crop type that has to be irrigated. Vegetables that are eaten unprocessed should not be irrigated by fecally contaminated (waste) water. This excludes the sources of Selela and Hado Sere for irrigation of vegetables. For non-food crops or crops that are usually cooked or heated, fecally contaminated water can be applied. Since feces often contain a lot of nutrients fecally contaminated water can even stimulate crop growth.[9]

  For optimizing crop growth the electrical conductivity is important. If waste water is applied as irrigation source, the origin of this waste water is important. As mention before, the electrical conductivity is very high in most sources. Values exceeding 500 µS/m can reduce the harvest of moderate sensitive crops by 20% while sensitive crops might be reduced by 40%. Waste water from the household can be used for irrigation. Unfortunately, most sources that would be used in the household for cleaning purposes etc. (coming from the most contaminated sources of Hado Sere, Lega Cat and Selela) are showing high electrical conductivity levels. Moreover the high chloride and nitrate content of Lega Cat would damage the crops as well.

[9] Not only feces, but especially urine contains a lot of nutrients. Urine can be separated from feces by special toilets such as the ECOSAN toilet. A lot of research is done on the safe applicability of urine in agriculture. These techniques are not (yet) applied in the Lege Dini area, but studies are conducted in other parts of Ethiopia. For further reading see http://www.waste.nl or http://www.ecosan.nl

The water harvesting ponds, however, would be suitable for irrigation. Since this was already allocated to livestock, a choice should be made upon which source will be used for livestock and which source for irrigation depending on the importance of crops and livestock for the farmer's strategy of making a living. The choice of crop cultivation can also be changed. If farmers are mainly cultivating sensitive crops, the pond size can also be reconsidered.

- The sources of Hado Sere, Lega Cat and Selela are suitable for cleaning purposes. For doing the laundry, the water should be not too hard. The sources of Selela and the pond of Ajo are showing the lowest dH values which make them most suitable for laundry.
- For indicating suitable sources for bathing, further research on Schistosomiasis and *Legionella* bacteria should be conducted

The execution of the above outlined plan is hampered by the extreme poverty in the area of Lege Dini. Especially in the smaller villages people are not involved in making money, but are not even self sufficient or exchange their products for other necessities. They will not be able to get their drinking water from the Ajo borehole or the Kora spring, since this water presently costs 0.10 - 0.15 Ethiopian Birr per container. Since installing pipelines and a pump would even more expensive for these villages, perhaps they could exchange water. If the inhabitants of poorer and remoter villages travel to Ajo to collect drinking water, they could bring some of the more contaminated water (suitable for e.g. cleaning purposes and irrigation) with them and exchange that for clean water with a reduced price.

11.3 Limitations to the implementation of MUS world-wide

In general, problems will occur if the water sources are not maintained in the right way. The water quality will decrease and for example a source that was used for drinking water can no longer serve as such. A new division should be made or (home) water treatment practices should be promoted. This will be avoided if the introduction of multiple use systems is carried out as part of an integrated water (source) management plan, which is the core of the MUS approach.

While the MUS-approach can have a positive effect on water management in developing countries, there are some limitations that will make the approach more difficult or impossible to implement in general.

First of all, full implementation of the MUS-approach requires cooperation between different water delivery sectors and ministries. Water for irrigation, for example, can be the responsibility of the ministry of agriculture, while drinking water is listed frequently under the umbrella of the ministry of public health. For rural areas data sets about water resources are not always complete and information about water needs and uses for different purposes is hardly ever available. Yet sharing these data with another sector or ministry requires a correct and detailed data set of a certain region. It would be an expensive operation to collect all the required data from every location where the MUS-approach could be introduced. Furthermore a lot of energy and man hours have to be used for comparing the data and set up an integrated plan for multiple uses of water. If organizations are not fully convinced of the benefits of the MUS-approach they probably will not be likely to invest their time in such an operation. All these topics should be discussed about with the actors involved before starting a project implementation. However one of the sub-goals of the MUS-project is the development of a 'shortcut' document for data collection. In this document the minimum required information is defined as well as guidelines about the extent that is required. This will make it easier to collect the basic data, without spending money on the collection of less important parameters.

Secondly logistical problems can occur. In watersheds where the villages are located on relatively large distance from each other, the multiple sources for multiple uses approach is difficult to implement. Often the clean sources are not found in all villages, but are concentrated in one or two villages. Sources in the vicinity of those other villages are suitable for uses such as washing, cleaning etc. Man can decide upon two options; a. Pipelines have to be connected to the clean source to reach the people in the remoter villages, or b. People from remoter villages have to walk all the way to the source or appropriate systematic transport is arranged. In a small watershed like Lege Dini, this is realizable, while in larger areas the distances will become too large. Both options are not preferable in larger watersheds; water that has to be piped for a large distance will be heated by the sun. Since higher temperature often cause a rapid development of bacteria, it is advisable to adjust the piping length to the local climate. Walking to the source, takes along another problem; in this research as well as in other literature[10]. It turned out that the larger the distance to the source was the less personal hygiene will be applied. Using clean water does not make sense in case it is contaminated again due to poor hygiene.
A solution for this problem is small home water treatments as described in chapter 6. Unless the sources are not chemically polluted, treatment methods such as sand filters and SODIS can be used, together with adequate education about water handling and in-house storage.

Finally low quality water should not be classified as suitable for irrigation and livestock. As described in the chapters above, some contamination can damage animals and plants enormously and sometimes this has a direct effect on human health as well. Undeveloped sources should therefore be tested carefully and if necessary cleaned and managed in a sustainable way to make it suitable for irrigation and livestock.

[10] For further reading see: JMP (2005) WHO and UNICEF Joint Monitoring Programme (JMP) for water supply and sanitation. http://www.wssinfo.org/ ***or*** JMP (2005) Water for life: making it happen. WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation. ISBN 92 4 156293 5. Geneva, World Health Organization and UNICEF, 2005.)

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Annexes

1. **Questionnaire**
2. **Protocol Laboratory**
3. **Graphs and Tables**
4. **Background Millennium Goals**
5. **Roof catchment calculation (Source: Jeths, 2006)**
6. **Water requirement data**
7. **Rainfall and precipitation data**
8. **Maps and pictures**

Annex 1: Questionnaire

Sanitary Survey, Water Supply and Hygiene Behaviour Lege Dini

Questions marked with (*) are cross-checked during the interview

<u>Theme 1: General Data</u>

Name of the farmer:
Age:
Number of children:
Children that (did) go to school:

<u>Theme 2: Involvement in health programmes and Awareness</u>

Do you know the health educator in Lege Dini?
What do you think about the health education provided?
Do you participate in meetings about health?
Did you change your behaviour concerning health and sanitation after these meetings?
What did you change?
Have you or members of your family been ill the last couple of months?
What do you think was the reason of this illness?
What do you think about the water quality of the different sources? (*)
What kind of factors can contaminate the water? (*)
How do you protect your water to avoid this contamination? (*)
Who placed the fences around the drinking water places and why?
What would you do with the water if there will be more available?

<u>Theme 3: Water sources</u>

Where do you get your water and for which purpose?
When during the day do you collect water?
How do you collect water and for which purpose?
How much water do you need per day and per purpose? (*)
How much water are you allowed to take and for which purpose?
What do you think would be a convenient amount of money to take for you / your family? (*)
What do you think about the quality of the water and for the different purposes?(*)
How do you transport the water?
Where do you throw away your bathing, cooking or cleaning water? (reuse)
If reuse is mentioned:
For what purposes is it reused?
How is the water transferred to the second use?
How do you drink the water from the jerry can?
How do you prepare food? (Can you give a detailed description of the cooking procedure?)(*)
Do you use water for other purposes (other than the purposes already mentioned by respondent)? (*)
How much for each purpose/day?
What do you think about the condition of the jerry can? (do they mention cleaning?)
Do you protect the water on another way? (*)

What do you think about the maintenance of the water sources?
What do you think about the procedure that is executed in case of a break down of the system?

Theme 4: Disposal of human faeces

Where do you defecate?
Why do you do that on the mention place?
Does it change if you are out of the village? (E.g. working on the land)
Can you describe the steps you accomplish during and after defecating? (Ask only if not shy after first questions, important to know where they leave their stool)
Where do your children defecate? Why on that place?
Can you describe the steps accomplished by you during and after your child has to defecate?
In case of latrine: How often is the latrine cleaned in the area?
Is the latrine maintained?
What do you think about the state of the latrine?

Theme 5: Personal Hygiene

Who divides the water inside the house?
Who has access to water inside the house? (*)
How is water stored inside the house?
What do you do with the wastewater from the household? (*)
How much water do you use for personal hygiene and for which parts of the body? (*)
Does this change in times of water shortage?
How much water do you use for personal hygiene of your family (husband/children)? (*)
What is the procedure in case of illness, birth or death? (are preventive or extra hygiene measures taken).
Do you wear footwear?
Do your family members wear footwear?

Theme 6: Food Hygiene

Do you use the water for any other purpose than mentioned before?
If mentioned kitchen/food:
Which parts/equipment of the kitchen/cooking place do you clean?(*)
Which preparation measures do you take before you start cooking? (Like washing the food, boiling water etc. don't use examples however) (*)
Which water do you use for food preparation?
How do you treat the water that is used for food preparation? (*)
What do you do with leftovers?
How do you feed your baby/small child?

Theme 7: Hygiene in and around the household

Do you use the water for any other purpose than mentioned before?
If mentioned house/compound:
Which parts/furniture do you clean? (*)
Do you take preventive measures against mosquitoes?
What do you think about the hygiene on public places, like the mosque etc?

Theme 8: Livestock

Where do you herd your livestock?
Where does they livestock drink?
Where does the livestock sleep/spend the night?
What do you do with the dung? (*)
Do you take extra hygienic measures concerning livestock?
If the livestock is herded to a pond or well, how does it drink the water (is it carried up, or does the livestock go down)?

Cross-check

Is there any water use still not discussed?
What is your main concern related to water?
What would you like to learn more about? (*)
What did you change in the last years (if still not clear) (*)

Annex 2: Protocol Laboratory

The laboratory facilities in the Dire Dawa were limited, including the sterilization possibilities. Due to the simple technological equipment, most values could not be measured exactly. Therefore most measurements are repeated various times and the average value is listed in the results chapter. For parasite analysis and electrical conductivity measurements, the Central Laboratory from the Alemaya University was used.

Thermotolerant coliforms
All water samples were analyzed on the presence of thermotolerant coliform bacteria. Every month samples were taken in the morning, before the villagers started to collect their water and before the livestock arrived to drink. In December, from three open sources, the samples were taken in the late afternoon as well to compare the results with the morning samples. Most people get their drinking water in the morning. The problem with the sources in Selela and Hado Sere is that there is only space for one person to collect water. If somebody is late, he/she will have to wait till the afternoon to get water. Therefore it was interesting to see the course of contamination during the day.
All samples were placed in an icebox immediately after the sampling and filtered within 12 hours.
Since the analysis was done for all thermotolerant coliforms it was not possible to confirm whether the coliforms were from human feces or from livestock dung. Observations were done in order to find the main contamination factor.

For the analysis of thermotolerant coliforms the membrane filter technique was used.
Before the analysis all materials were sterilized in a steamer (Prestige Medical Portable Steam Steriliser 7500 Series). Than, the samples were shaken and the lids were removed from the bottle. From each sample, 100 ml was filtered through a membrane filter (Gelman Sciences Sterilised Membrane). The membranes were placed in a sterilized dish and colored with a lauryl red solution. (Membrane Lauryl Sulphate Broth).
Than, the dishes were allowed to stay for 24 hours in a heated area inside a mobile water analysis kit (Oxfam DELAGUA-kit). After the 24 hours the dishes were removed and the colonies were counted. If the number of colonies exceeded 75 the next measurement was done with a two or four times diluted sample.

Electrical conductivity, pH and temperature
The electrical conductivity (EC) was measured by an Electrical Conductivity Meter. All samples were measured three times in order to get a reasonable average value. Since there was no portable EC meter available, samples were taken in small bottles and directly placed in an icebox. All samples were analyzed within 5 hours after sample taking.
The pH was measured with a pH meter (HACH Company). Before every measuring day, the meter was calibrated in a buffer solution (Color Coded Yellow) with a pH of 7.00 (±0.02, cat. 288 35-49). After each measurement the pH meter was rinsed by the buffer solution. All samples were measured three times.
The temperature was taken on spot using a thermometer (Cocmapen 21982).
The EC, pH and temperature were measured monthly.

Hardness (in mg $CaCO_3$ per liter)
For measuring hardness EDTA Tetra sodium Salt with a normality of 0.800 ± 0.004 from HACH Europe was used as titration liquid. From each sample 50 ml was poured in a clean 100 ml Erlenmeyer. By using 50 ml of the sample the digital multiplier was 2.0. Firstly 1.0 Buffer Solution Hardness 1 (pH 10.1 ± 0.1, cat. 424-32 HACH Europe) was added to the

sample. Than one powder pillow with Permachem Reagents Man Ver 2 (Hardness Indicator, cat. 851-99, HACH Europe) was added. With a digital titrator (HACH Europe) the amount of titration solution merged with the sample was measured till the color changed from red to blue. All measurements were repeated three times and samples were taken from each source monthly.

Chloride (mg/l)
Chloride was also analyzed by titration. Silver-Nitrate ($AgNO_3$) 0.2256 ±0.0010 was used as titration liquid. To 50 ml of the samples one powder pillow HACH Chloride 2 indicator was added. When the color changed from yellow to red the amount of used titration liquid could be defined. The digital multiplier by 50 ml was 0.25. All measurements were repeated twice and samples from all sources were taken monthly.

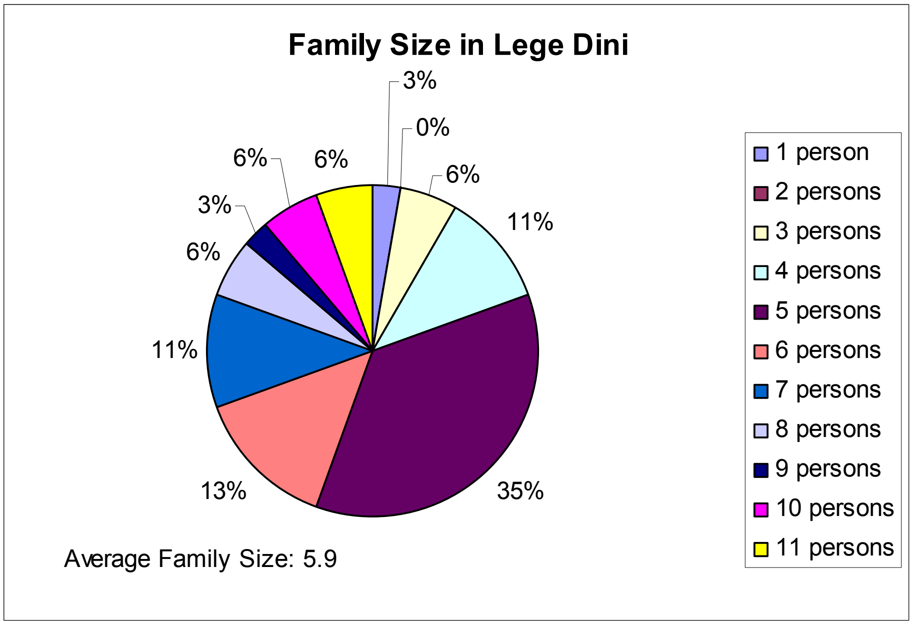
Nitrate (NO_3^-) and sulphate (SO_4^{2-})
Nitrate and sulphate were analyzed once during the research, since the spectrophotometer was only available from late December till mid-January. Both nitrate and sulphate were analyzed on the spectrophotometer (HACH, DR/2000) using reagents (HACH Nitra Ver 5, cat. 14034 – 99 and HACH Sulfa Ver 4, cat. 12065-99 respectively).
Samples for nitrate and sulphate analysis were directly after taking placed in an ice box. To avoid leaking the lid was tightened firmly and secured with tape.

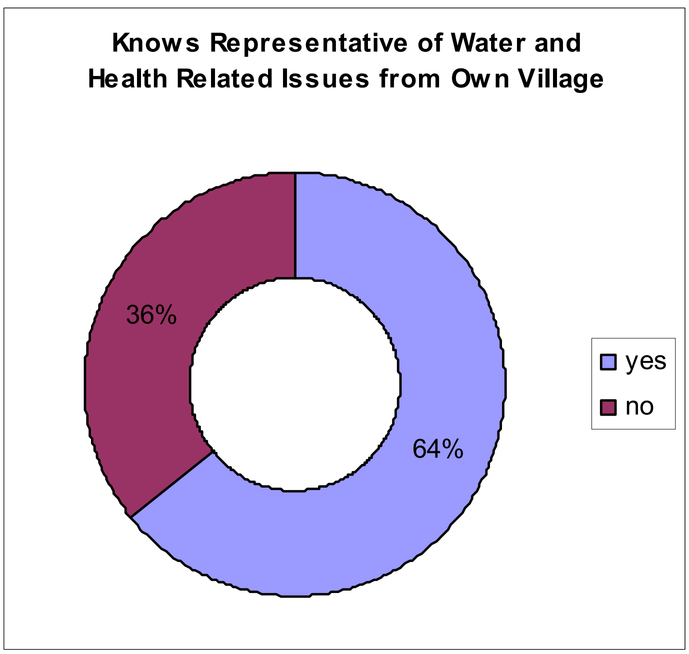
Parasite analysis
For analyzing the water on *Cryptosporidium* oocysts and *Giardia* cysts, water samples were collected from the five main water sources; a water harvesting pond, a bore hole, a river stream and two shallow wells.
The samples were collected in large 30-liter containers and after transportation the samples were directly placed in the refrigerator of the laboratory. The samples were taken in the morning in December 2004.
The samples were pumped with a small electric pump through a cylindrical filter (4µm). The residues in the filter were removed by scraping the surface of the filter. Then the filter was rinsed with distilled de-ionized water and scraped again.
The collected material was stored in small tubes (20 ml) and conserved in 4 ml of 10% formaldehyde.
After 1 month the 10 ml of the supernatant was removed from the tubes and centrifuged for 15 minutes at 200g

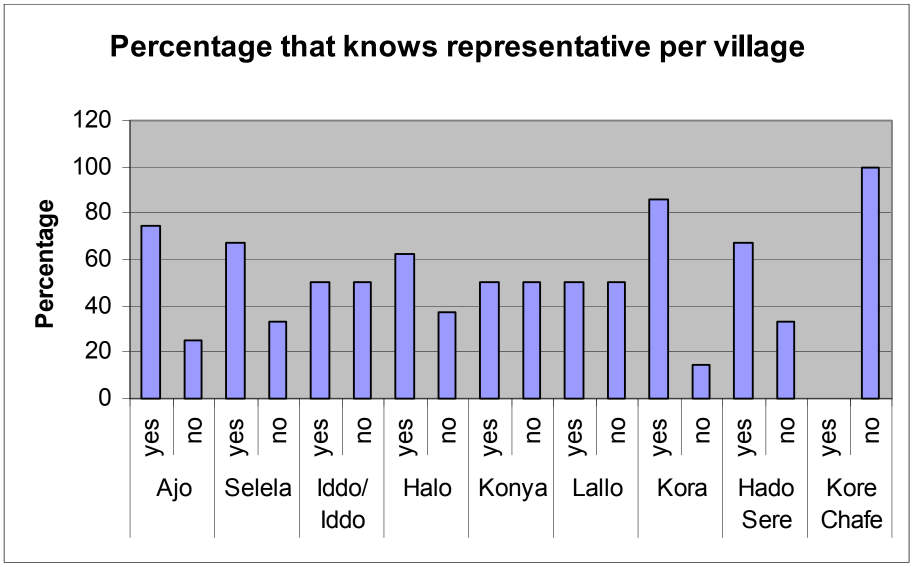
Giardia cysts
Giardia cysts were analyzed using a light microscope with a 40X objective. From all sources two slides were prepared with a drop of the concentrated specimen. From each slide 25 fields were randomly selected. The number of positive fields and the amount of cysts per field were reported.

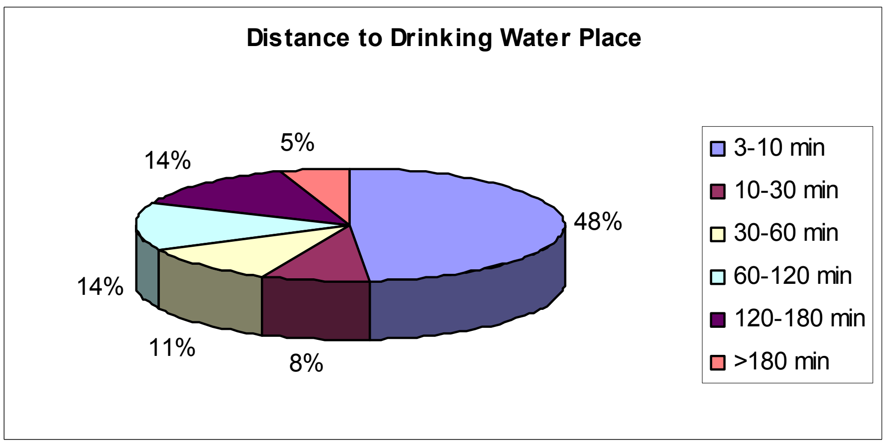
Cryptosporidium oocysts
For analyzing the *Cryptosporidium* oocysts the Ziehl-Neeilsen staining was used. First the solution from the 20 ml tubes was centrifuged with a solution with a higher gravity. The solution used for this purpose was sucrose with a specific gravity of 1.105 and this was pipetted in a centrifuge tube. On top of the sucrose 5 ml of the water sample was layered. After centrifuging for 15 minutes at 200g, a cloudy layer became visible at the interface of the tube. This layer was removed by a pipette and used to prepare 2 slides for each source. When the smears were dry the Ziehl-Neeilsen method was applied. With a 100X objective the slides were examined in an oil-immersion. From each slide 25 fields were randomly examined. The number of positive fields and the amount of cysts per field were reported.

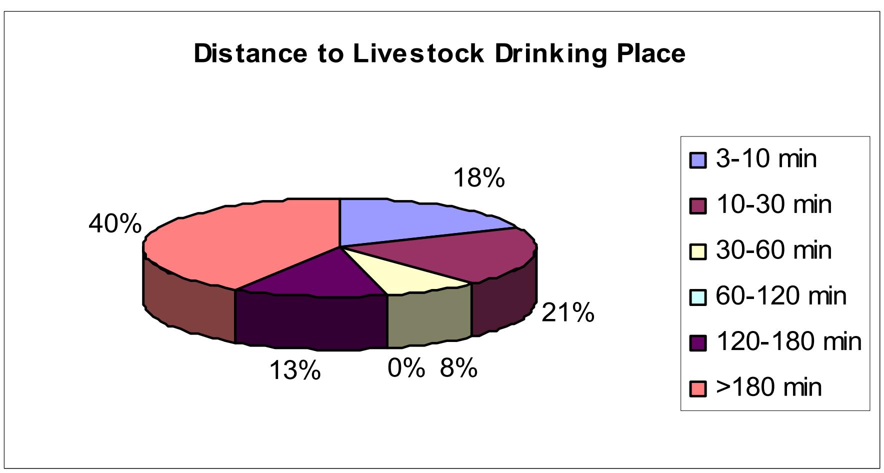
Annex 3: Background Graphs and Tables





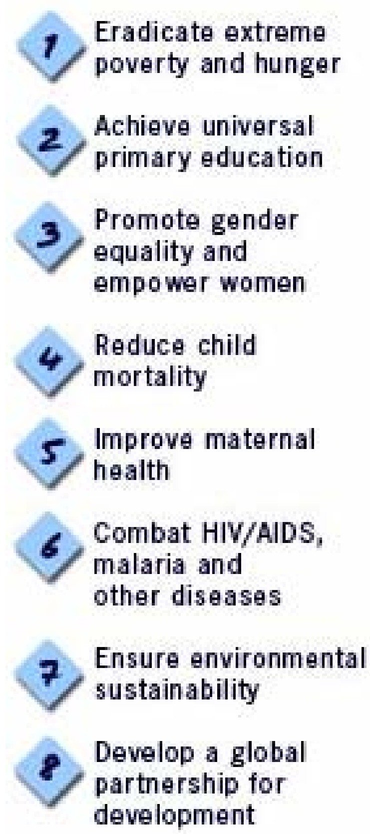

Percentage that knows representative per village
Percentage
120
100
80
60
40
20
0
yes
no
Ajo
Selela
Iddo/ Iddo
Halo
Konya
Lallo
Kora
Hado Sere
Kore Chafe


Distance to Drinking Water Place
5%
14%
48%
14%
11%
8%
3-10 min
10-30 min
30-60 min
60-120 min
120-180 min
>180 min


Distance to Livestock Drinking Place
18%
40%
21%
13%
0%
8%
3-10 min
10-30 min
30-60 min
60-120 min
120-180 min
>180 min

Annex 4: Background UN Millennium Development Goals (source: http://www.un.org/millenniumgoals/)

The eight Millennium Development Goals (MDGs) – which range from halving extreme poverty to halting the spread of HIV/AIDS and providing universal primary education, all by the target date of 2015 – form a blueprint agreed to by all the world's countries and all the world's leading development institutions. They have galvanized unprecedented efforts to meet the needs of the world's poorest.



"We will have time to reach the Millennium Development Goals – worldwide and in most, or even all, individual countries – but only if we break with business as usual.
We cannot win overnight. Success will require sustained action across the entire decade between now and the deadline. It takes time to train the teachers, nurses and engineers; to build the roads, schools and hospitals; to grow the small and large businesses able to create the jobs and income needed. So we must start now. And we must more than double global development assistance over the next few years. Nothing less will help to achieve the Goals."

United Nations Secretary-General
Kofi A. Annan

Annex 5: Roof Catchment Calculation (Source: Jeths, 2006)

Calculation on number of papaya trees that can be irrigated by supplemental rooftop water harvesting in Ajo village.

Building	length (m)	width (m)	area (m^2)	volume (rainfall of 420 mm) m^3	effective volume m^3	no of papaya trees	storage capacity
Clinic	14.40	7.70	111	47	26	16	13
Latrine Clinic	4.2	4.2	18	7	4	3	2
Shop next to clinic	6	5	30	13	7	4	4
Shop next to agr office	4.3	3.7	16	7	4	2	2
house	3.9	2.2	9	4	2	1	1
HCS building 1	9.7	5.3	51	22	12	8	6
HCS building 2	11.8	5.3	63	26	15	9	8
shower	2.7	1.9	5	2	1	1	1
Generator house 1	6.6	5.3	35	15	8	5	4
Generator house 2	6.4	4.3	28	12	6	4	3
School	38.9	9.3	362	152	85	53	43
Latrine school	6.9	4.4	30	13	7	4	4
Small school	12.6	5.4	68	29	16	10	8
			Total school	**193**	**108**	**68**	**55**
Agricultural office	9.8	3.3	32	14	8	5	4
	8.9	3.8	34	14	8	5	4
Latrine agr office	2.4	1.9	5	2	1	1	1
			Total agricultural office	**30**	**17**	**11**	**9**

Total irrigation requirement for papaya in DDAC: 1588 mm (=1.6 m); area 1 papaya tree: 1 m^2

Yearly rainfall ranges between 420 to 650 mm for the Legedini PA. To be on the 'safe' side calculations are done with the lowest level of 420 mm

Not all water rainfall is effective. Therefore it is assumed that about 80% will be collected in the reservoir (some water is needed for flushing sand and other pollution can be catched on the roof and will be available for collection). Irrigation efficiency is estimated to be 70% in case drip irrigation with the tins is practised.

The rain will fall, spread over some months. In case the collected water is used for supplemental irrigation, it is only needed to bridge the dry spells. So a smaller storage capacity is needed to irrigate the calculated number of papaya trees (assumed that in the rainy season no additional irrigation is needed). The reservoirs will be needed several times a year between the rains, but should at least have to capacity to bridge the Bega which lasts for 5 months. To be on the safe side 6 months are taken in the calculation. Assumption is made that the collected water is only used for supplemental irrigation (and not domestic use or other productive uses)

Calculations:	
Effective volume	0.8*0.7*roof area*420 mm of rain
No of papaya trees	effective volume/1.6
Storage capacity	effective volume/2

The estimation of 4 litres per day in the USAID tins for the papaya trees, by the peasants amounts a total volume of 1.46 m^3 per year, which appears to be a good estimation; only the different water requirements during the months is not taken into account. However the field period was after the large rains, therefore it can be assumed that 4 litres a day is a good assumption for the water requirement in the dry season

Annex 6: Water requirement data

Projected per capita domestic water demand (lpcd) and population percentage by mode of services.

Mode of services	2005	2010	2015	2020	2025
House connections	19%	20%	21%	23%	26%
	126	139	154	170	187
Yard connections	36%	45%	54%	62%	68%
	55	61	67	74	82
Neighbourhood users	23%	18%	13%	8%	4%
	24	26	29	32	36
Public tap	22%	17%	12%	7%	2%
	24	26	29	32	36
Average demand (lpcd)	55	64	76	90	106
Adjusted domestic demand	66	78	92		
Rural demand (public tap)	47%	62%	85%	90%	100%
	25	25	30	35	35

source: WWD&SE (2003e)

Projected Rural Domestic Water Demand for Dire Dawa Administrative Council

Description	2005	2010	2015	2020	2025
population Growth Rate (%)	2.40	2.40	2.40	2.40	2.40
Population (nr)	122535	149872	183309	223023	271342
Coverage(% by level of services)					
Public Taps	47	63	85	90	95
Service Level (lpcd)					
Public Taps	24	26	29	32	36
Water Demand (m3/d)					
Public Taps	1382	2455	4519	6423	9280
Total domestic demand,m3/day	1382	2455	4519	6423	9280
Climatic adjustment factor m3/day	1.1	1.1	1.1	1.1	1.1
Adjusted domestic day demand,m3/day	1520	2700	4970	7065	10208
Public Demand/Non-domestic demand	76	135	249	353	510
Livestock water demand,m3/day	1838	2248	2750	3345	4070
Average day water demand,m3/day	3434	5084	7969	10764	14788
Loss in distribution system,m3/day	172	254	398	538	739
Total average day water demand,m3/day	**3606**	**5338**	**8367**	**11302**	**15528**
Maximum day factor	1.45	1.45	1.45	1.45	1.45
Maximum day demand	5229	7740	12132	16388	22515
Peak hour factor	2	2	2	2	2
Peak hour demand	7212	10675	16734	22604	31056

source: WWD&SE (2003e)

Annex 7: Evaporation and rainfall data in DDAC

Monthly climatologic data meteo station Dire Dawa

MONTHLY REFERENCE EVAPOTRANSPIRATION PENMAN MONTEITH						
Meteo station:	Dire Dawa			Country:	Ethiopia	
Altitude:	1150 m			Co-ordinates:	9.46 North	41.31 East
Month	**Avg. Temp. °C**	**Humid. %**	**Wind km/day**	**Sunshine Hours**	**Radiation $MJ/m^2/day$**	**ETo-PenMon mm/day**
January	21.7	39	363	8.8	20.3	6.1
February	23.3	43	328	8.0	20.5	6.1
March	24.7	44	380	7.8	21.3	6.8
April	26.1	48	397	7.4	20.9	6.9
May	27.6	35	354	8.4	21.9	7.8
June	28.7	30	475	8.1	21.0	9.3
July	27.2	41	484	7.5	20.3	8.1
August	26.6	41	441	8.0	21.5	7.8
September	26.2	35	363	7.7	21.1	7.5
October	25.5	28	363	8.3	21.1	7.7
November	23.1	30	363	9.4	21.4	6.9
December	21.8	30	311	9.3	20.5	6.1
Year Av.	**25.2**	**37**	**385**	**8.2**	**21.0**	**7.2**

Source: WWD&SE, 2003f; Year of data collection unknown.

Monthly rainfall data meteo station Dire Dawa

MONTHLY RAINFALL DATA		
Meteo station: Dire Dawa		Country: Ethiopia
	Eff. Rain method: USDA S.C. Method	
Month	**Rainfall (mm/month)**	**Effective Rainfall (mm/month)**
January	15.9	15.5
February	16.6	16.2
March	65.1	58.3
April	52.6	48.2
May	34.9	33.0
June	15.7	15.3
July	70.7	62.7
August	112.4	92.2
September	65.7	58.8
October	24.8	23.8
November	9.9	9.7
December	8.5	8.4
Year Total	**492.8**	**442.0**
Eff rain form:	Peff=(Pmon*(125-0.2*Pmon)/125	for Pmon ≤ 250 mm
	Peff=125=0.1*Pmon	for Pmon > 250 mm

Source: WWD&SE, 2003f; Year of data collection unknown.

Annex 8: Maps and pictures