RELIABILITY OF SMALL EARTH DAMS FOR DOMESTIC WATER SUPPLY: A CASE STUDY OF SMALL EARTH DAMS IN TRADITIONAL AUTHORITY KALOLO, LILONGWE, MALAWI.

MSC. (ENVIRONMENTAL SCIENCE)

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Declaration

I the undersigned hereby declare that this thesis is my own original work which has not been submitted to any other institution for similar purposes. Where other people's work has been used, acknowledgements have been duly made.

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Certificate of Approval

The undersigned certify that this thesis represents the student's own work and effort and has been submitted with our approval.

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Abstract

Access to adequate potable water is still one of the critical problems facing the rural population in Malawi. A number of instruments and strategies have been formulated to address the water accessibility problem. According to the National Strategy for Sustainable Development, 2004, construction of small earth dams is one of the strategies that has been adopted to improve access to potable water for domestic use by 2015. This study assessed the reliability of six small earth dams for domestic water supply in Traditional Authority Kalolo in Lilongwe District in Central Malawi. Flow Duration Curve (FDC) Analysis was employed and water quality assessments (colour, pH, iron, nitrates, sulphates, phosphates, potassium, faecal coliform, and total dissolved solids) were employed in order to determine adequacy of water and extent of water pollution in the dams, respectively. The ecological management classes of the dams were established using Rapid Assessment / Determination Method, which is done to set an ecosystem into a class as a function of the flow.

The study revealed that all the six dams under study were unable to meet the communities' water requirements for about 80% of the time. Considering that the small dams in the area were perched on *dambos* with minimal recharge from adjacent aquifers and that pattern of flows depict the dependency of the dams on surface flow with high flows in the rainy season and very low flows in the dry months, the dams were unable to store adequate amounts of water to meet the water requirements of the communities. Key informant interviews confirmed the inability of the dams to provide water for all year round. Dam location problems were alleged to be the major cause of 44% of the dams in the area not to be functioning.

The small earth dams in the study area were found to be moderately to largely modified from the pristine state, thereby negatively affecting the quality of water in the dams. Faecal coliform counts in the water were found to range between 600 and 3000 counts, greatly exceeding the recommended counts in the Malawi water quality standards, thereby rendering water from the dams unsuitable for drinking without prior treatment. Water quality assessments revealed significant seasonal dependency. Biological water quality deteriorates during the rainy season due to increased run off into the stream and dams. In view of this, prior treatment of the water is required before the water from the small earth dams can be used for domestic purposes.

The study proposes that dam designs should meet appropriate engineering and environmental standards encompassing hydrological, geological, ecological and socio-economic factors, if the small earth dams are to result into long term outputs.

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List of Acronyms and Abbreviations

AOAC	Association of Official Analytical Chemists
APHA	American Public Health Association
BBM	Building Block Methodology
BOD	Biochemical Oxygen Demand
CUMECS	Cubic Metres per Second
FAO	Food and Agriculture Organisation
FDC	Flow Duration Curve
FGD	Focus Group Discussions
GDP	Gross Domestic Product
GoM	Government of Malawi
GVH	Group Village Headman
ICOLD	International Commission on Large Dams
MBS	Malawi Bureau of Standards
MDGS	Millennium Development Goals
MOIWD	Ministry of Irrigation and Water Development
MPRSP	Malawi Poverty Reduction Strategy Paper
MS	Malawi Standards
NEPAD	New Partnership for Development
NSO	National Statistics Office
NSSD	National Strategy for Sustainable Development
PET	Potential Evapo-transpiration
SADC	Southern African Development Community

SD	Standard Deviation
SEP	Socio-Economic Profile
SPSS	Statistical Package for Social Scientists
T/A	Traditional Authority
TDS	Total Dissolved Solids
UNEP	United Nations Environment Programme
US EPA	United States Environmental Protection Agency
UV	Ultra Violet
WCD	World Commission on Dams
WHO	World Health Organisation
WRA	Water Resources Area
WRU	Water Resources Unit
WSSD	World Summit for Sustainable Development

Chapter 1: Introduction

1.1 State of Water Resources and Development in Malawi

In Malawi, surface water resources consist of a network of river systems and lakes that cover over 20% of the country's land area. Lake Malawi is the largest lake in the country with a surface area of about 28,760 km^2 and has the greatest influence on the water balance of the country (Government of Malawi, 2002). The National Water Resources Master Plan of 1986 categorises the drainage system of Malawi into three systems namely, the Lake Malawi System, Shire River System and the Lake Chilwa System. These water drainage systems has been subdivided into 17 Water Resource Areas (WRA). Each WRA comprises either one large river catchment or a number of smaller catchments. Each WRA has been subdivided into a number of Water Resource Units (WRU) of which there are 78 (MoWD, 2004).

Although Malawi is considered to be generally rich in water resources, the Malawi Demographic and Health Survey of 2000 indicates that about 35% of Malawian households have no access to safe water in form of piped water, protected wells or boreholes. In urban areas of the country, about 95% have access to safe drinking water while only about 58% of the rural population has access to safe drinking water (National Statistics Office, 2002). The Government of Malawi is committed to reduce the proportion of people without sustainable access to safe drinking water in specific time-bound targets. The adoption of the Millennium Development Goals (MDGs), participation to the World Summit on Sustainable Development (WSSD) of 2002 and the 3rd World Water Forum in Kyoto (2003), the African Ministerial Council on Water and the programs and actions articulated under the NEPAD framework are just but a few indications of Malawi's commitment to reduce the proportion of people without sustainable access to safe drinking water.

At national level, Malawi has formulated Vision 2020, Malawi Poverty Reduction Strategy Paper (MPRSP), National Strategy for Sustainable Development (NSSD) of 2004, and water related legislation including the Water Resources Act of 2000, Water Resources Management Policy and Strategies of 1999, National Irrigation Policy and Development Strategies of 2000 and the National Environmental Policy of 2002. The overall objective of these instruments is to manage and use water resources efficiently and sustainably so as to promote its conservation and availability in sufficient quantity and acceptable quality. The NSSD seeks to increase the number of households with access to safe drinking water from 62% to 84%, by 2015. Strategies to attain this goal were identified and adopted and include the construction of small community dams and rehabilitation of broken down water points.

The Government and its development partners have provided the rural masses with boreholes and rural gravity piped water supply schemes and have also established water boards to provide potable water to the urban population. By the year 2000, there were a total of 66 schemes operational for rural gravity piped water supply. Boreholes have also been constructed, as an effort to provide water to the rural population where the gravity piped water supply schemes have not been established. During the period 1990 to 2000, it is estimated that over 8,000 boreholes were constructed (Government of Malawi, 2002).

1.2 Small Dams Development

The need to conserve water resources through technologies that can easily be managed and manipulated by the rural community has compelled developing countries to promote the use of small earth dams, as sources of water supply for the development of irrigated agriculture, fish farming and some domestic uses such as brick making and livestock watering (Chavula, 2000). Globally, there has been massive investment in large dams which called for the establishment of the International Commission on Large Dams (ICOLD) in 1985 and the World Commission on Dams established in 1998, in response to the growing opposition to the management of large dams (WCD, 2000).

A dam is defined as any structure capable of diverting or retaining water (Ministry of Water and Irrigation, 1998). Dam size classification for Malawi is shown in Table 1 below.

Table 1: Dam Size Classification for Malawi

Size	Reservoir capacity (103 m3)	Height (m)
Very small	< 50	< 5
Small	50 - 1 000	5 – 8
Medium	1 000 - 5 000	8 – 15
Large	5 000 - 20 000	15 – 30
Major	> 20 000	> 30

Source: Guidelines for Design and Rehabilitation of Small Earth Dams (1999)

There are about 750 small to medium sized dams in the country, most of which lie in the basins of Ruo and South Rukuru Rivers in the southern and northern part of Malawi respectively. Total storage for these dams is estimated at approximately 100 million cubic metres (MoIWD, 2004). Most of these dams were constructed in the 1950s for the purpose of supplying drinking water for livestock. There are still potential dam sites in the country which remain undeveloped despite the concern on the inadequate development of water resources in the country, possibly due to inadequate financial resources in the water resources management sector.

A total of 89,900 ha of land are used for agricultural production which is only 56% of the potential area for irrigation, estimated at 161,900 ha. Currently, 28,800 ha are equipped for full or partial control irrigation. Most irrigation activities in Malawi are from surface water, from weirs, dams or by pumping from rivers. About 1,100 ha of surface irrigation structures are in need of rehabilitation (Wallingford, 2003).

Most earth dams in Malawi can be located but information on the extent of utilization of the catchment and their condition is in many cases unknown (MoIWD, 1999). An inventory of these dams in Malawi was made in 1986 during the National Water Resources Master Plan Study in order to provide establish a reliable database on which future development plans and interventions could be founded. To date, many small earth dams which had been constructed have failed within a few years of construction mainly due to catchment degradation and inadequate maintenance leading to heavy siltation of surface water systems (Wallingford, 2003).

The Malawi National Consultative Meeting on the WCD Report of 2004 states that degradation of catchment areas due to anthropogenic activities like intensive agricultural production, deforestation upstream of the feeder rivers or *dambos* have greatly contributed to the non functionality of most of the dams in Malawi, as most of them are heavily silted (Wallingford, 2003). Embankments and spillways have also been damaged by cattle and people who cultivate downstream of the dams. There has been lack of community management of these resources mainly due to the perception of the resources as being Government property. This is mostly because the beneficiary or surrounding communities were not adequately consulted or involved during selection of site, planning and construction of the dams.

Heavy siltation and sedimentation have resulted in declining water flows, making most rivers ephemeral or intermittent resulting into water reservoirs storing water that is not suitable for aquatic life, let alone for human consumption (Government of Malawi, 2005). Achieving the UN Millennium Development Goal of halving the number of people without safe drinking water by 2015 will therefore require heavy investments in the water sector.

1.3 History of Dams Construction in T/A Kalolo

Mandala dam is located in Mandala village and is accessed by a total of 9 villages for their domestic water needs. These villages are Mandala, Chinsindo, Matandaluzi, Kagona, Chasa, Mphoyo, Mndaula, Chibweza and Chamsanda. Gundamtengo dam is located in Gundamtengo village and is accessed by Gundamtengo, Chatimba, Chinthunzi, Jolofani, Gangire, Makanga, Funsamtima, Mneku, Kalata, Mwase, Eliya and Mphunda villages. Nabvumi dam, located in Chingondo village is only accessed by 6 villages, namely: Chingondo, Mkumba, Gezani, Chawantha, Mbuto and Chivuta villages. Kamanzi dam is located in Chawantha village and is accessible to Chawantha, Mbuto, Maliyana and Chino villages. Goliati dam is accessible to Goliati, Williamu, Mvuto, Masula, Chipanga, Katupa, Mchambo I, Zikalenga, Andiseni, Mzingeni I, Sagawa, Mchadza, Chimombo and Chipukwa villages and is located in Goliati village. Phazilamkango dam is located in Mchambo II village and is accessible to Chipanga, Izeki, Chinkhombo, M'bangombe, Katupi, Mnera and Mzingeni II villages.

Dams in T/A Kalolo were constructed between 2001 and 2002 by CARE International with community involvement in form of cash, bags of maize or maize flour. Kakoma Dam, belonging to Press Farming, which is not readily accessible to the surrounding communities, was constructed in 2005. Kanyambwe and Katsumwa dams, although acknowledged as existing dams by the Lilongwe District Socio-economic Profile, are just potential dam sites and there were no dams constructed on the sites.

Table 2: Status of Dams in T/A Kalolo and total population of beneficiaries

Dam	Location	Population of beneficiaries	Operational Status
Mandala	S 14^{o} 03.213' and E 033^{o} 27.768'	1935	Operational
Gundamtengo	S14^{o} 06.491' and E033^{o} 26.715'	1290	Operational
Phazilamkango	S14^{o} 09.955' and E033^{o} 22.580'	875	Operational
Nabvumi	S14^{o} 07.375' and E033^{o} 21.982'	1205	Operational
Kamanzi	S14^{o} 06.763' and E033^{o} 21.468'	540	Operational
Goliati	S14^{o} 06.763' and E033^{o} 21.468'	1445	Not Operational

1.4 Statement of the problem

Lilongwe District subtends several surface water resources mainly through a network of river systems, which are distributed throughout the district. Major rivers in the district include Lilongwe, Lingadzi, Diamphwe, Bua, Nanjiri and Mbabzi (Republic of Malawi, 2006). These rivers have a highly variable flow changing according to seasons and quickly react to rainstorms. Nearly all the rivers in the district maintain a dry season base flow in most years due to the large storage capacity of very deep soils in catchment areas. Many smaller streams in the Lilongwe plains however, dry up during the dry season.

The District has several sources of water supply namely, piped water, boreholes, wells, streams, rivers and *dambos*. The piped water supply caters for city dwellers and the rest of the water sources serve mainly the rural population (Government of Malawi, 2002). Boreholes are the largest source of drinking water for the rural communities, followed by protected wells (Government of Malawi, 2002).

Lilongwe district is facing a number of environmental challenges such as deforestation due to the massive tobacco industry and charcoal making, land degradation, water resources degradation and water resources depletion. Access to safe water in the district is generally low and the situation is made worse by frequent breakdowns and prolonged downtime of water points due to inadequate capacity to maintain the water points (Government of Malawi, 2006). About 42.4% of rural households are still using unsafe sources of water such as unprotected wells, springs, streams/rivers, dams and rainwater (Republic of Malawi, 2002). Out of the 3,363 water points available in the district, only 1992 (59%) of them are functional. Estimates indicate that only 37% of the households in the District with access to safe water sources travel less than the recommended 500 metres to reach the nearest source during the dry season (Government of Malawi, 2002).

Traditional Authority Kalolo is one of the areas in Lilongwe District which is water stressed. Geographical distribution of water points in the area is not uniform such that there is disparate access to water points. Only 25% of the population in the area have access to boreholes (Government of Malawi, 2002). There are some villages in the area with absolutely no borehole and still use water from unprotected wells. Overall, 44.6% of the population in T/A Kalolo use unsafe sources of drinking water. Nevertheless, T/A

Kalolo has the largest number of earth dams in the district. Out of the 62 small dams in the district, 9 dams (11%) are located in Traditional Authority Kalolo alone (Government of Malawi, 2002).

This study therefore made an assessment of the current status of water, in terms of quality, quantity and availability, in the existing small dams in T/A Kalolo and whether their use as a source of domestic water is a realistic strategy for the provision of potable water to the rural population of Lilongwe District. Recommendations of measures to improve reliability of water supply from the small dams will be drawn.

1.5 Rationale of the study

In spite of the increased number of boreholes and rural gravity piped water supply schemes in Malawi, access to potable water for the rural population is still a serious problem. This is attributed to non-functional water facilities and their geographical distribution such that majority of rural people continue to rely on unprotected wells and springs, rivers, lakes, ponds and dams for their domestic water supply (Government of Malawi, 1999).

The country's water resources have experienced degradation and depletion due to pressures caused by agricultural production, population growth, poverty, wood energy demands, urbanization, climatic changes and abstraction for water supply and irrigation schemes (Government of Malawi, 2004). Siltation and sedimentation of surface water bodies have led to declining water flows, making most rivers ephemeral or intermittent and drying out in the dry season. Anthropogenic activities that are carried out within the catchment of these rivers have resulted into pollution of the water bodies such that water being stored in reservoirs is not suitable for aquatic life or human consumption (Government of Malawi, 2005).

However, a number of policy instruments are promoting the construction of small dams as a source of water supply for the rural population in Malawi, including the NSSD 2004. It is therefore essential to study the relationship between small dams and the communities that host them. The reliability of small dams in Malawi needs to be examined because majority of the rural population are still using them as source of water for domestic use.

1.6 Objectives of the study

The main objective of this research was to assess the reliability of small dams in Traditional Authority Kalolo in Lilongwe District for domestic water use. Specifically the study aimed to:

1. Assess the availability of water in the small earth dams.
2. Estimate the current and future raw water use in the catchment areas of the dams.
3. Assess the ecological management class of the dams.
4. Determine the levels of physical, chemical and biological pollution in the dams i.e. faecal coliforms, pH, colour, turbidity, nitrates, phosphates, sodium, potassium, iron, sulphates, total dissolved solids, and compare them with national recommended standards on water quality.

1.7 Organisation of the thesis

Chapter 1 introduces the study area and water resources available in the area, background of the study, statement of the problem, its objectives and rationale of the study.

Chapter 2 is literature review.

Chapter 3 describes materials and methods that were used to collect data for the study and analysis of the data.

Chapter 4 discusses the results obtained from assessment of dam water for various water quality parameters and also discusses water availability levels per capita which were derived from historical stream flow discharge data (1970 to 2006), evaporation estimates and population figures. The estimated raw water demand for the host communities obtained from Focus Group Discussions and calculated from population figures will also be highlighted and projections for water demand made in order to establish how long the dams will be able to sustain water demands from host communities. Factors that were isolated from FGDs and observation of field activities as possible factors that affect water quality and quantity in the dams will also be discussed in this chapter.

Chapter 5 concludes the discussion and provides some recommendations.

Chapter 2: Literature Review

2.1 Water Use in Rural Areas

2.1.1 Domestic water use

The Water Act for Malawi defines "domestic uses of water" to include the provision of water for household and sanitary purposes and for watering and dipping of stock. Distribution of water by sectors in Malawi is estimated as follows: domestic use, 34%; industrial use, 17%; and 49% for agriculture and natural resource uses (Mulwafu, 2000). Agriculture and natural resources are the largest users of water and significant sectors for the economy of Malawi, contributing about one third of the country's Gross Domestic Product (Mulwafu *et al*, 2002).

Water use is defined as the sum of water that is utilized but not always collected (Wallingford 2003). In most parts of rural Africa, the source of water that is used depends on a number of factors including security and reliability of the water supply, accessibility of the supply and the quality of the supply (Wallingford, 2003). Common water uses that qualify as domestic in rural Africa include drinking, cooking, bathing, washing clothes, animal watering and brick making (Wallingford, 2003). Studies in this part of the world have placed figures of domestic water uses to vary from 20 to 40 litres per capita per day but World Bank indicates that the rural African population uses 50 litres per capita per day for domestic purposes (Wallingford, 2003). However, the World Health Organisation indicates that for adequate health and sanitation to be achieved, rural domestic water use has to average 150 litres of water per capita per day.

The Drawers of Water II study done in 34 sites in Kenya, Tanzania and Uganda between 1997 and 1999 found an average per capita water use of 38 litres per capita per day (Savenije and van der Zaag, 1998). The study found major differences in water use by piped and unpiped households with piped households using almost three times as much as the unpiped households. Similarly, urban households were found to be using significantly higher levels of water per capita than rural households.

Estimated average water use figures for Malawi for domestic use, livestock watering, and irrigation are shown in Table 2. Actual amounts of water used for various domestic purposes depend on availability of water and the proximity of the water supply. In situations where the source of water supply is distant, some uses like drinking and cooking are given priority over other uses like washing clothes and bathing which are then carried out at the collection point (Wallingford, 2003).

Table 3: Water Requirements for Malawi

Types of Use	Average Use (m^3/year)
Household use, all purposes, per person	70-140
Cattle, per 450 kg weight	28-42
Mule	16
Sheep, per 45 kg	3
Irrigation of seasonal crops per ha	5,000-6,000
Irrigation of pasture/sugarcane	12,000

Source: Guidelines for Design and Rehabilitation of Small Earth Dams (1999)

As a semi-arid country, Malawi has a unimodal rainfall season, which generally runs from mid November to early April averaging 1014 mm per annum (FAO Aquastat database, 2002). This seasonality of rainfall has a significant impact on the type of water source used, reliability of the supply, quality of water supply and also general access to water. The sources of water and seasonality of rainfall affect how much water is used in the rural areas.

Rural domestic use is mainly assessed using either (a) indirect methods, where population figures are used to calculate quantity of water consumed; and/or (b) direct methods which make use of socio-economic surveys and participatory techniques to estimate current and future water use. However, there are limitations associated with these methods because data concerning domestic rural water use is often expensive and time consuming to collect and also because majority of rural domestic water supply systems are not metred (Wallingford, 2003).

2.1.2 Environmental Water Flows

An environmental water flow is defined as the water regime provided within a river, wetland or coastal zone in order to maintain ecosystems and their functions, uses and benefits to man (Dyson *et al*, 2003). As such, the environment is considered as a legitimate water user. The quantity of water allocated to the environment is always less than what the environment ideally requires (UNEP, 2006). Depriving a water body or a groundwater system of these flows not only damages the entire aquatic ecosystem, it also threatens the people and communities who depend on it.

Most societies are often faced with the decision to weigh the potential costs and benefits to all water users, including the environment (Wallingford, 2003). In most instances, a certain modification of the natural environment is accepted but varies amongst ecosystems. Maintaining in stream flows is essential in order to assure adequate fish passage, temperature levels, dissolved oxygen, turbidity, and sediment concentrations, and to maintain existing aquatic habitats in the river under consideration (Vogel and Fennessey, 1985).

Environmental water requirement is also known as in-stream flow requirement. Various methods are used to assess environmental flows, some of which include: (a) hydrological index methods, (b) environmental flow assessment methods, (c) hydraulic methods, (d) holistic methods, and (e) habitat methods (Wallingford, 2003).

2.2 State of Water Resources

2.2.1 Availability of water

Availability of water is an essential prerequisite for any social and economic development. However, availability of water is vulnerable to global factors like climate variability and climate change. In the Southern African Development Community (SADC) region, water availability is vulnerable to national and local factors such as demands of growing urban populations, increasing sectoral demands and increased potential for conflict over water. These factors are responsible for worsening pollution of water, land and catchment degradation, destruction and encroachment on aquatic ecosystems and proliferation of invasive weeds (Ohlsson, 1995). Increasingly, environmental degradation from unsuitable land and water use patterns and other anthropogenic factors is undermining and threatening sustainability of the water resource availability and quality.

Surface water systems in Malawi are replenished by rainfall generated surface run-off from the catchment areas. They receive varying inflows of overland flow, through flow and base flow, which due to their very different flow paths and residence times, have different solute and sediment loads (Wallingford, 2003). Recent climatic changes and anthropogenic activities have affected water availability in most parts of the world. South Africa, for example is currently categorized as water stressed with an annual fresh water availability of 1.154 m3 per capita per year, less than 1,700 m3 per capita, the index for water stress (Otieno and Ochieng, 2004). In Malawi, around 3,000 cubic metres of water per capita are renewed annually in the country's rivers and lakes but in the dry season, only 300 cubic metres per capita are available implying a fairly small proportion of water available for the various uses (Mulwafu, 2000).

Lakes, rivers and reservoirs contain about 90 percent of the earth's surface storage of fresh water and are critical elements of the hydrological system. However, they have not received sufficient attention by the global water community resulting in their ecological integrity being threatened (Hirji, 2003). For rivers and reservoirs to be sustainable in provision of water for the various uses, the stream flow has to be stable with considerable contribution from base flow. The Mulunguzi Dam, for instance, is the only source of water for the Municipality of Zomba. A study done by Ngongondo (2003) revealed a negative persistence of the Mulunguzi River suggesting minimal carryover of river flow to subsequent hydrological years. This was in agreement with an earlier study by Sefe, (1988) which characterized the Mulunguzi River as flashy and that the Mulunguzi catchment does not sustain much water. Ngongondo (2003) therefore recommended the exploration of alternative sources of water for the Municipality and also the adoption of integrated water resources management.

River discharge greatly depends on climatic factors such as rainfall of the catchment or drainage area, inflow or outflow of groundwater, evapo-transpiration from the area, anthropogenic factors such as stream modifications and irrigation diversions and also catchment management practices (UNEP, 2006). The rate of evaporation varies with colour and reflective properties of the surface, called albedo. The most important meteorological factors that affect evaporation are solar radiation, wind, relative humidity and temperature (Wilson, 1983).

Hydrological index methods have been widely used in estimating water availability, using historical hydrological data. These data are usually in the form of long-term, historical monthly or daily discharge records. The most commonly used Hydrological index method uses the Flow Duration Curve (FDC) analysis. This is a simple method used in understanding catchment characteristics. An FDC uses present day historical flow records to produce curves displaying the relationship between the range of discharges and the percentage of time each of them is equaled or exceeded or in other words, the relationship between magnitude and frequency of streamflow discharges (Smakhtin, 2001).

FDCs are used in numerous hydrological assessments such as determining water supply potential; design of water resource projects (Mays, 2005; Vogel and Fennessey, 1995); abstraction licensing (Smakhtin, 2001); river and wetland inundation mapping; river, reservoir and lake sedimentation studies; in-stream flow assessments; hydropower feasibility analysis; water quality management; waste load allocation; flood frequency analysis; flood damage assessment (Vogel and Fennessey, 1995; Alaouze, 1991; Warnick, 1984; Male and Ogawa 1984; Searcy, 1959).

An FDC is constructed by reassembling the flow time series values in decreasing order of magnitude, assigning flow values to class intervals and counting the number of occurrences (time steps) within each class interval (Smakhtin, 2001). The flow time series can be at daily, monthly or annual intervals. FDC analysis is based on several critical indices such as the Q_{100} which is the river's firm yield; the Q_{95} which is the index of natural low flows or the environmental flow defining the upper threshold of abstraction (Dyson et al, 2003); the Q_{50}, the median flow, is an index of groundwater contribution to stream flow indicating hydro geologic conditions.

The median flow (Q_{50}) is the discharge which is equaled or exceeded 50% of the time. The part of the curve with flows below the median flow represents low-flow conditions. The shape of a FDC in its upper and lower regions is particularly significant in evaluating the stream and basin characteristics. The shape of the curve in the high-flow region indicates the type of flood regime the basin is likely to have, whereas, the shape of the low-flow region characterizes the ability of the basin to sustain low flows during dry seasons. A very steep curve (high flows for short periods) would be expected for rain-caused floods on small watersheds. In the low-flow region, an intermittent stream would exhibit periods of no flow, whereas, a very flat curve indicates that moderate flows are sustained throughout the year due to natural or artificial stream flow regulation, or due to a large groundwater capacity which sustains the base flow to the stream.

Base flow is interpreted to be significant if the area below the median flow has a low slope, as this reflects continuous discharge to the stream. A steep slope for these low-flows suggests relatively small contributions from natural storages like groundwater. The associated streams may cease to flow for relatively long periods (Smakhtin, 2001).

Various indices are used to represent the characteristics of the low-flow regime for a stream. The ratio of the discharge which is equaled or exceeded 90% of the time, to that of 50% of the time (Q_{90}/Q_{50}) is commonly used to indicate the proportion of stream flow contributed from groundwater storage (Nathan and McMahon, 1990).

FDCs can be plotted using a number of plotting positions, including: (i) Weibull plotting position $\{r/(n + 1)\}$; (ii) Bloom plotting position $\{(r – 0.375)(n + 0.25)\}$; and (iii) Gringorten plotting position $\ln[-\ln\{(r – 0.44) / (n + 0.12)\}]$. The Weibull plotting position is recommended for use when the form of the underlying distribution is unknown and when unbiased exceedence probabilities are desired (Gringorten, 1963).

Reviews of Vogel and Fennessey (1995) and Smakhtin (2001) acknowledge the scarcity of relevant literature on the applications of FDS analysis, despite their wide use in hydrological practices. Smakhtin (2001) further observed that FDC applications have not been fully explored yet, in spite of increased interest of their use in hydrology, water resources management and river ecology.

2.2.2 Physical and chemical aspects of surface water quality

Only recently has there has been growing awareness of the importance of water quality in surface and ground water supplies (UNEP, 2006). Humans have polluted water resources through the introduction of agrochemicals and industrial chemicals into the water bodies and also due to alterations of catchments by different land use practices (UNEP, 2006). Current agricultural and industrial practices have heavily contaminated surface water sources and this has rendered most surface water unfit for human consumption in the country (Government of Malawi, 2002).

Studies done by Lakudzala *et al* (1999) and Sajidu *et al* indicate heavy pollution of water in rivers and streams in Malawi. The microbiological quality of most rivers is generally poor all the year round especially those that are draining through cities and towns. Typical counts of faecal bacterial colonies range from 50 to 100 per 100 millimetres of sampled water in Malawi (Government of Malawi, 2005). In addition, high levels of suspended solids are found in most surface water bodies. Streams that were once perennial have now become seasonal. The excessive soil erosion resulting from deforestation has led to loss of soil fertility, siltation and sedimentation of water bodies, degraded water quality and destruction of catchment areas (Government of Malawi, 2005).

A study done by Lakudzala *et al* (1999) revealed high levels of chemical pollution in the lower part of Shire River, most of which exceeded WHO guideline standards. Sajidu *et al* (2007) carried out studies in streams in Blantyre City before and after passing through industrial areas. Although they found values of pH and total dissolved solids (TDS) to be within the recommended standards, levels of phosphates and biochemical oxygen demand (BOD) were above the World Health Organisation safe limits suggesting that streams in the City get polluted by nutrients and heavy metals and due to agricultural activities and uncontrolled industrial waste disposal.

Studies have also revealed that pollution of water varies between seasons. Palamuleni (2001) found higher levels of pollution in the wet season than dry season because of increased run off in South Lunzu Township in Blantyre. She found surface water sources to have higher levels of physical and chemical pollutants with maximum levels at the onset of the rainy season.

In reservoirs, the storage of water induces physical, chemical and biological changes so that water discharged from reservoirs often has very different composition to that of inflowing rivers. Nutrients such as phosphorous are released biologically and leached from flooded vegetation and soil. Oxygen demand and nutrient levels generally decrease as the organic matter decays (WHO, 1996). Eutrophication of reservoirs may occur as a consequence of large influxes of organic material and nutrients, often arising as a consequence of anthropogenic activities in the catchment (Chapman 1996; WHO, 1996).

2.3 Ecological Management Classes

Modification of ecosystems results into loss of features or services such as water storage, flood attenuation, water purification, wildlife conservation, stock watering (Tharme and King, 1998). Setting ecological reserves is important in management of water resources because aquatic systems are maintained at different levels of condition, from almost natural to seriously modified ecosystems (Tharme and King, 1998).

Six classes of river condition or health are recognized from Class A to F, with A being the least degraded and F being the most degraded. The determination of habitat integrity in the context of the Building Block Methodology (BBM) is essential since this gives a general indication of the current ecological condition of the whole or part of a river, measured against a hypothetical natural situation (Tharme and King, 1998). Aerial surveys, photographs, river zonation, ground-truthing and rating of habitat integrity are some of the processes that constitute the Building Block Methodology. As can be assumed, this is a costly method in terms of time and financial resources.

2.4 Importance of Small Dams

Globally, substantial research has been carried out on large dams but small dams have been accorded less attention. Information on small dams is scanty, possibly because in terms of their impact on water supply and human health, they are thought to be less significant than large dams (Rusere, 2005).

Where small dams have been constructed, they are put to multiple uses, both consumptive and non consumptive. They divert water, attenuate floods, relieve drainage congestion and provide water for irrigation and domestic uses (Sugunan, 1997). In the control of floods, small dams help to moderate the flood water as it flows downstream so as to be compatible with the flood carrying capacity of the river channel (Rusere, 2005).

Small dams also perform an important ecological function of maintaining ecosystems and associated flora and fauna (Rosegrant *et al*, 2002). The extent to which small dams are used depends on a number of factors including quality of water, availability of water, their productivity, accessibility and available alternative sources of water (Sharma and

Sharma, 2002). It is important to note that there are also some functions that small dams perform that yield more technical than socio-economic benefits. Such functions include the ability of small dams to act as silt traps for large dams down streams and their ability to act as aquifer rechargers. In spite of the numerous beneficial roles that small dams play, their existence is associated with increased sedimentation, and loss of farmland. Another negative impact of small dams is their association with the prevalence of water borne diseases such as malaria, bilharzia (schistosomiasis), cholera, dysentery and diarrhoea (Chavula, 2000).

Sediment, salts, nutrients, organic loads, pesticides and pathogens are carried as part of the runoff into the receiving reservoirs. This leads to undesirable changes in water quality in the small dams. Because of this degradation resulting from unsustainable land use practices around them, such dams been abandoned (Sharma and Sharma, 2002; Dinar *et al*, 1995).

2.4.1 Establishment and Management of Small Dams

Dams represent one of the most significant human interventions in the hydrological cycle (MOIWD, 1999). Through provision of water for drinking, irrigation and electricity, dams have supported human socio-economic development (Chavula, 2000). The storage capacity of small dams should take into consideration a number of factors, including; environmental water demand, consumptive multiple uses of water such as irrigation, livestock watering, brick-making, storage allowance for sedimentation and "dead storage" (MOIWD, 1999). Water losses due to evaporation and seepage also have to be taken into consideration because not all the water stored in dams is withdrawn for use. In most instances, it is uncontrollable features like topographical conditions at the dam site and the catchment size that set the dam capacity (Manzungu, 2002). Groundwater recharge is another important aspect in storage capacity of dams in that the dam gradually releases water through seepage into the valley bottom bringing about a steady supply during the dry season. As a result, the capacity of most small dams varies within and between seasons.

About 750 earth dams have been constructed by different organisations since the 1950s for a variety of uses in the country (Government of Malawi, 2002). The main purpose was to provide water conservation for the benefit of the communities residing near the dams and *dambos*, predominantly for livestock watering and domestic purposes. However, many of them have failed within a few years of construction due to spillway failure and overtopping of the embankment. This could be attributed to the absence of guidelines for small dams design in the country during the time the dams were constructed. Only in 1998 has Government through the Ministry of Agriculture produced the Manual of Hydrological Design Guidelines for Small Earth Dams (Government of Malawi, 2002).

In the 1990's, Government of Malawi and its development partners, embarked on a rehabilitation programme of small earth dams as part of its national water resources conservation strategy to improve water supply in the rural areas. To date, a large proportion of small dams in the country are still not operational. The Report on the

Malawi National Consultative Meeting on the WCD 2004 proposes the establishment of an institutional structure responsible for the development and monitoring of dams in Malawi. The Report further indicates the need for the development of a policy for dams' development as imperative in order to provide guidance in the development of small dams and also to assist in attracting interested investors.

Catchment management is very crucial in the sustainability and productiveness of dams, both large and small. Studies reveal that environmental degradation of catchments results into the life span of most small dams being shortened leading to abandonment of the dams (McCartney and Sally, 2002). Post project monitoring and evaluation is also critical as far as management of small dams is concerned in Malawi.

2.4.2 Health Risks Associated with Dams

In Africa, warnings have accompanied many irrigation and dam projects regarding the likely impact of the prevalence of water borne diseases. Recently, scientific findings have confirmed that dams constructing mostly leads to a surge in schistosomiasis transmission (World Commission on Dams, 2000). In part of Upper Egypt, schistosomiasis prevalence is said to have increased from 6% to 60% three years after the Aswan low dam was completed in the early 1930s. Following the construction of the Sennar dam in Sudan in 1926 and the Gezira scheme which followed, schistosomiasis spread. At the Arusha Chini irrigation project in Tanzania, research reported the prevalence of schistosomiasis to be 85 % in 1962 (Nathan & McMahan, 1990). In

Zambia, prevalence of schistosomiasis around Lake Kariba in 1968, 10 years after the Zambezi River was dammed, was 15% in adults and 70% in children.

It is imperative to protect water sources from contamination by human and animal excreta which contain a variety of bacterial, viral, protozoan pathogens in order to protect communities that use the water for domestic purposes from outbreaks of intestinal and other infectious diseases associated with microbial contamination (WHO, 1996). Health risks due to chemical contamination in water differ from those caused by microbiological contamination in that there are few chemical constituents of water that can lead to acute health problems. In circumstances where there is massive chemical contamination, the water becomes unusable owing to unacceptable taste, odour and appearance (WHO, 1996; National Academy of Sciences, 1989).

It is recommended that if small earth dams risk structural failure or have been abandoned, they should be removed, though costly an operation, in order to curb the negative impacts associated with abandoned dams such as prevalence of water borne and vector borne diseases (World Commission on Dams, 2000).

Chapter 3: Methods and Materials

3.1 Description of the Study Area

Lilongwe district has a population of about 1,346,360 people, with a population density of about 219 people per square km. The district covers a land area of 6,159 km^2 and lies in the country's central region, located at 13°59′S 33°47′E (Government of Malawi, 2002). Lilongwe district has 17 Traditional Authorities namely: Kalolo, the study site, Chadza, Chiseka, Mazengera, Chitekwere, Khongoni, Chimutu, Chitukula, Mtema, Kalumbu, Tsabango, Kalumba, Njewa, Malili, Kabudula, Masula and Masumbankhunda (GoM, 2006). Traditional Authority Kalolo lies on the western side of the district, bordering Mchinji district and is surrounded by Traditional Authorities Masumbankhunda, Malili, Kabudula and Khongoni (Figure 1). According to the 1998 population census, T/A Kalolo had a total population of 104, 939 and the projected population for 2006 was 134, 088 (Government of Malawi, 2002).

Lilongwe has a warm tropical climate characterised by one rainy period of approximately 5 months, lasting from end November to end April, and dry weather in most areas during the remainder of the year. The district has Mean Annual Temperatures of about 20 degrees to 22.5 degrees Celsius. The passage of the inter-tropical convergence zone, experienced between December and June, is the major rain-bearing system in the district (Government of Malawi, Unpublished). Mean Annual rainfall is from 800 mm to 1, 200 mm. Rainfall distribution is also highly influenced by orographic effects, with windward slopes receiving more than the leeward sides of hills or mountains, and areas with higher elevation receive more rainfall than lower lying areas (Pike and Rimmington, 1965).

Lilongwe District is underlain by Basement Complex rocks of Precambrian and Cambrian age, consisting mainly of gneiss schists and metamorphosed igneous intrusions. The geology of the district has largely been influenced by extensive faulting which took place during the Mesozoic and Tertiary Eras which has led to the formation of the Great African Rift Valley (Government of Malawi, Unpublished).

The soils in Lilongwe are generally very deep, well drained, red to reddish brown and have a coarse to medium top soil overlying a medium to fine textured subsoil. Most soils are acidic to slightly acidic (pH 5.0 to 6.5) and the nutrient status is generally low with widespread deficiencies of nitrogen and phosphorus (Lorkeers & Venema, 1991). The structure of most cultivated topsoil is weak and therefore highly erodible. The soils are most commonly classified as Chromic Luvisols, Eutric Cambisols and Haplic Lixisols with Phaeozems, Gleysols and Fluvisols also being common.

The most important soil families in Ming'ongo EPA, in which T/A Kalolo is located, are *Mpili* and *Euthini* for the upland soils and *Tenthema* family in the *dambos*. In the *Tenthema* family, soils are classified as Eutric Gleysols, inundic phase and the soils are derived from colluvial deposits and belong to the gleyic group (Lorkeers & Venema, 1991). The soils are very deep, poorly drained and frequently flooded, with variable textures. Organic matter content of the upper 30 cm is low to medium. Total nitrogen in these soils is low, available phosphorous is low and exchangeable potassium is very low to medium. Nutrient retention capacity is very low for soils in the *Tenthema* family. Soils within the catchment of the dams in T/A Kalolo can be categorised as belonging to the *Tenthema* family because the dams are situated in *dambo* areas.

There are a total of 62 man-made dams in Lilongwe, with T/A Kalolo having the largest number of dams (9 dams) compared with the rest of the T/As in the district (Government of Malawi, Unpublished). Figure 1 shows location of dams in T/A Kalolo. The dams in the area were constructed by CARE International between 2001 and 2003 and they have an average size of 150m x 100m. The dams were constructed with full involvement of surrounding communities through provision of labour and some of the materials like sand. Table 3 below gives a brief description of the dams in T/A Kalolo, their location, operational status and the streams that feed the dams.

Figure 1: Location of Traditional Authority Kalolo in Lilongwe District.

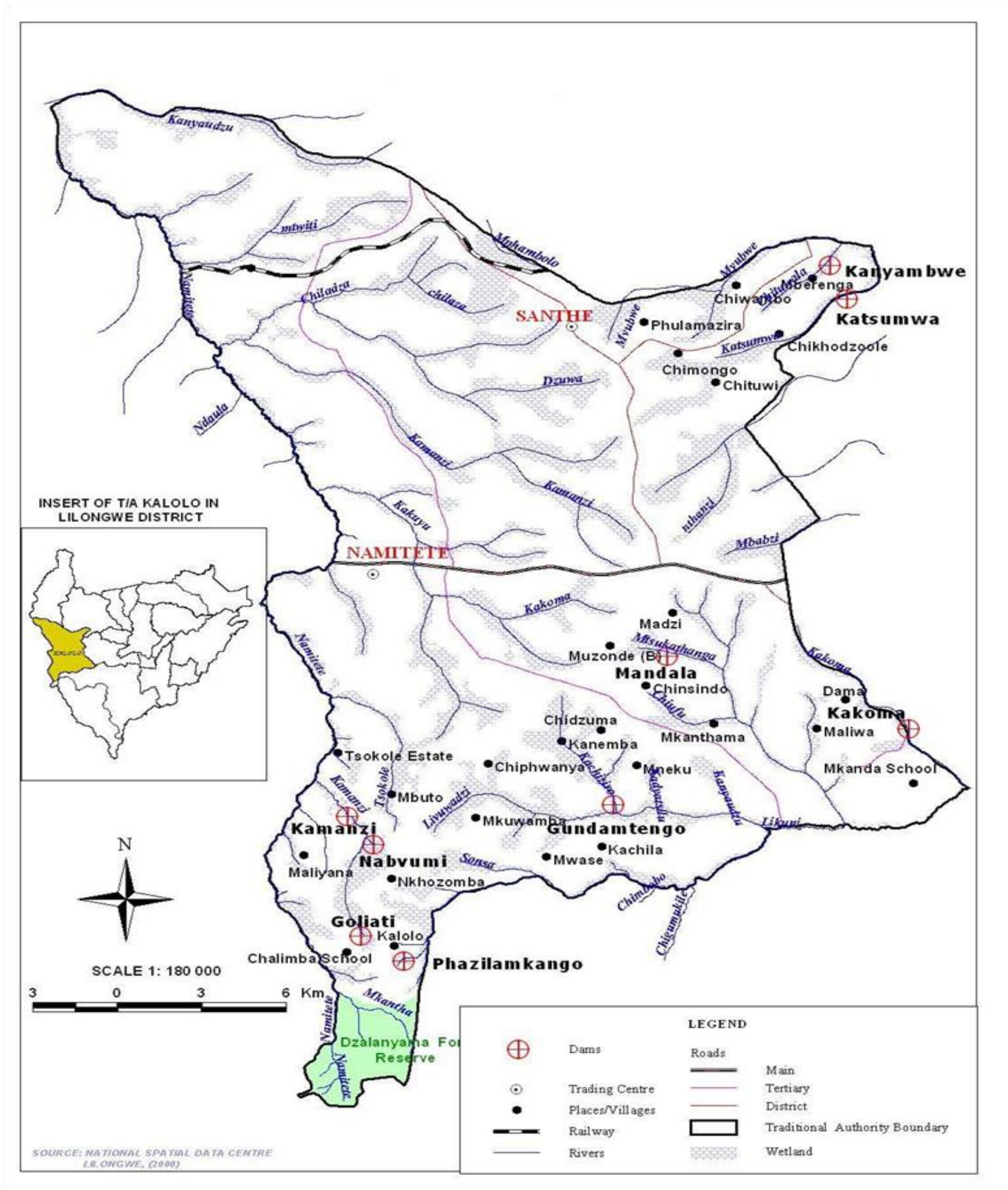


Figure 2: Location of Dams in Traditional Authority Kalolo, Lilongwe

Table 4: Status of Small Dams in Traditional Authority Kalolo

Dam	Dam Capacity (m^3)	Catchment area (km^2)	Feeder stream
Mandala	5250	10.629	*Mtsukanthanga* stream into *Likuni* River
Gundamtengo	5250	10.144	*Chipoka / Mphafayanjiru* stream into *Likuni* River
Phazilamkango	5250	4.852	*Phazilamkango* stream into *Likuni* River
Nabvumi	5250	8.099	*Kamanzi* stream into *Namitete* River
Kamanzi	4200	9.844	*Kamanzi* stream into *Namitete* River
Goliati	7500	1.039	*Kamanzi* stream into *Namitete* River
Kakoma	19,125	-	*Likuni* River
Kanyambwe	8000	-	*Nsaru* River
Katsumwa	-	-	*Nsaru* River

3.2 Data Collection

Available data on stream flow discharges for the feeder rivers/streams and average temperatures for 10 day periods (dekad) in degrees Celsius were collected in order to make estimates of the amount of water available for use in the dams and estimate the potential evapo-transpiration levels for the area, respectively.

Key Informant interviews were conducted to establish water-using activities and the water demand for the area. Habitat Integrity or ecological management classes of the dams were also established using information derived from the interviews and from field observations.

Water quality information was derived from data resulting from analysis of water samples collected from six community dams in Traditional Authority Kalolo that were operational at the time of the study. These dams were Mandala, Gundamtengo, Nabvumi, Phazilamkango, Kamanzi and Goliati dams. The other dams, Katsumwa and Kanyambwe dams were not operational during the study period. For purposes of this study, Kakoma dam was excluded from the assessments carried out because it is a privately owned dam with no access for the communities.

3.2.1 Estimation of Water Use

3.2.1.1 Domestic Water Use

Both direct and indirect methods of estimating rural domestic water use were used in this study. Key Informant and individual interviews were carried to obtain information on categories of domestic water use and amounts of water used for each category including water use for livestock watering. Estimates on per capita water use were based on an average household occupancy of 5 members for Malawi (Republic of Malawi, 2006).

For the indirect method of estimating domestic water use, population figures for the area were used to estimate the expected quantity of water use per capita against the mean flow using the equation below (Wallingford, 2003).

$$Volume = (Q \times C) \div P \qquad (1)$$

Where Q is the mean discharge in m^3/ year;

C is a time conversion constant;

P is the total population

The indirect method of estimating water use gives an estimate of the amount of water that needs to be used in order to maintain the habitat integrity of the river ecosystem.

3.2.1.2 Future Domestic Water Use

Future water use in the area water was projected using the linear equation in the low range and exponential projector in the high range (Savenije and van der Zaag, 1998).

$$W_t = W_0(1+r)^t \qquad \textbf{(linear)} \qquad (2)$$

$$W_t = W_0 e^{rt} \qquad \textbf{(exponential)} \qquad (3)$$

Where W_t - water consumption at future time t

W_0 - annual water demand at base time t=0

r – Annual growth rate of the consumption

t - Time in years

The 1998 Censual population growth rate for Lilongwe District was 2.9% (Government of Malawi, 2002). The annual growth rate of consumption normally follows population growth rate of the area, hence *r* was set to 2.9%.

3.2.1.3 Potential Evapo-transpiration for the area

Evapo-transpiration figures for the area were estimated using temperature data that was collected from the Department of Meteorological Services in Blantyre through Chitedze Research Station for a 35-year period (1971 to 2006). The temperature data was used to calculate potential evapo-transpiration (PET) using Thornthwaite's model (Ward and Robinson, 1990; Chow, 1964), first, as monthly heat index as follows:

$$I = (\frac{T}{5})^{1.514} \quad (4)$$

where *I* is the Heat Index and *T* is mean temperature of the month in ^{O}C

Then monthly heat indices were added to obtain an annual heat index, which was then used in the calculation of the constant "*a*" below and further, the PET:

$$E_p = 1.6b\left(\frac{10t}{I}\right)^a \quad (5)$$

$$a = 6.75 \text{ x } 10^{-7} I^3 - 7.71 \text{ x } 10^{-5} I^2 + 1.792 \; x \; 10^{-2} I + 4.9239 \text{ x } 10^{-1} \quad (6)$$

Where E_p is monthly potential evaporation in cm; t is the mean monthly temperature in degrees celcius and b is a factor to correct for unequal day lengths

Thornthwaite's model has been widely applied in data scarce sites, mostly used in situations where temperature data is the only climate record available in the area (Ward and Robinson, 1990; Chow, 1964).

In order to determine reliability of flows in supplying water, total water use for the area (human, livestock and PET) was plotted on the FDCs to find out the probabilities of supply. Considering that the dams in T/A Kalolo are perched on *dambos,* with poorly drained soils, seepage dynamics were not considered. According to the Richter method of assessing environmental flows, flows which are **NOT** equaled or exceeded 90% of the times are not reliable, so assessment of reliability of the dams in this study was set at Q90 (Dyson *et al*, 2003).

3.2.1.4 Environmental Water Requirements

The study used the Tenant-Montana method to estimate environmental water demand. This is a hydrological look up method which uses existing river flow data from gauging stations (Dyson *et al,* 2003). Hydrological indices such as percentages of the mean flow or certain percentiles from a flow duration curve are set. This method is commonly used for environmental flow setting to determine simple operating rules for dams or off-take structures where few or no local ecological data are available (Dyson *et al*, 2003). The Q90 set for environmental flows in this study is also recommended by the

Ministry of Irrigation and Water Development in allocating water abstraction permits (Mhango and Joy, 1998).

3.2.2 Assessment of Ecological Management Classes

The habitat integrity of the dams' ecosystem was established using a Rapid Assessment / Determination Method which uses parameters such as bank erosion, indigenous vegetation removal, water abstraction, water quality, exotic vegetation encroachment, channel modification, flow modification and inundation (Dyson et al, 2003; Kleynhans, 1996; Tharme and King, 1998). This assessment is done to set an ecosystem into a class as a function of the flow. In an ideal situation with adequate resources, the BBM is used and in this methodology, assessments are based on video graphic, low altitude aerial surveys of the river or stream ecosystem which provide information about the characteristics and present condition of the ecosystem. The Department of Water Affairs and Forestry in South Africa uses a similar classification where objectives are set according to different ecological management targets, from A to F as indicated in Table 5 (Dyson *et al*, 2003). The rapid assessment used in this study is based on individual interviews and field observations of the status of the dams' ecosystem.

Table 5: Classification of Ecological Management Classes

Class	Description	Score
A	Unmodified, natural	100
B	Largely natural with few modifications. A small change from the natural in habitats and biotas may have taken place, but the ecosystem functions are essentially unchanged.	80-99
C	Moderately modified. A loss of and change from natural habitats and biotas has occurred, but the basic ecosystem functions are still predominantly unchanged.	60-79
D	Largely modified. A large loss of natural habitats, biotas and basic ecosystem functions has occurred.	40-59
E	The losses of natural habitats, biotas and basic ecosystem functions are extensive.	20-39
F	Modifications have reached a critical level and the lotic system has been completely modified, with an almost complete loss of natural habitats and biotas. In the worst instances, basic ecosystem functions have been destroyed and the changes are irreversible.	0-19

Selected modifiers are assessed based on the observed and are scored between 0 and 25. Scores are then totaled and compared with the classification table above.

3.2.3 Estimation of Water Availability in the Dams

The study used Flow Duration Curve (FDC) analysis method in estimating water availability in the dams. Each flow record was sorted in descending order and the FDC was plotted using the Weibull plotting position formula (Gringorten, 1963):

$$P = \left(\frac{i}{n+1}\right)100 \qquad (7)$$

Where: P is the probability of exceedence of a certain flow magnitude,

i is the rank of that flow

n is the total length of the flow record.

Historical stream flow discharge data for feeder rivers for the dams were collected from Ministry of Irrigation and Water Development, Surface Water Resources Section for a 30-year period, 1962 to 1991 for some rivers and for a 25-year period, 1978 to 2002 for others. The river flow data were converted to annual series and hydrologic year time series which starts from 1st November and ends on 31st October to estimate the volume of water available in the dam in m^3/month or year through calculation of means. These were processed in Microsoft Excel Spreadsheets to show trends and pattern of stream flows for the feeder rivers. Flow duration curves were produced to display the relationship between the range of discharges and the percentage of time each of them is equaled or exceeded. Since the flow record was available for a period of 25 to 30 years, which is considered adequate in hydrological assessments, the study did not carry out further analysis to build confidence in the flow estimates (Dyson *et al*, 2003).

3.2.4 Water Quality Assessments

For collection, preservation and analysis of the samples, the standard methods as given in APHA (1985), Brown *et al* (1970) and Hem (1985) were followed.

3.2.4.1 Collection of Water Samples

Water samples were collected in triplicates from two sampling points, at the inlet and outlet of the dams during rainy season (22nd to 24th February 2007) and dry season (10th to 12th July 2007) in order to capture seasonal variations in water quality.

Six water samples were collected in one-litre new polyethylene bottles that had been labeled accordingly and rinsed three to four times with the water sample before filling it to capacity. Three samples were collected for cation analyses and three samples for other analyses. Samples for cation analyses were acidified at the sampling points by adding 1 mL of concentrated nitric acid and all samples were kept in a well-ventilated place. Acidification prevents precipitation of unstable metal elements, such as iron, and also prevents adsorption of some metal elements onto the surface of the container. The samples for the other analyses were kept at a temperature below 4^{o}C in cooler boxes in the field and in a refrigerator in the laboratory prior to analysis (APHA, 1985). pH was measured at the collection point, whilst the rest were analysed at the Central Water Laboratory, Ministry of Irrigation and Water Development.

3.2.4.2 Analysis of Water Samples

A total of 11 water quality parameters were analysed, and these were: pH, colour, Total Dissolved Solids (TDS), nitrates, sulphates, phosphates, iron, potassium, sodium and faecal coliforms.

(i) pH

A pH electronic metre, Metrohm Model 744 with an accuracy of ±0.01, in the range 0 to 14 was used to measure pH of water samples as per the method outlined in APHA (1985). The calibration was done by dipping the electrodes in pH buffer 4.00 followed by pH buffer 7.00 before analysis of the water samples commenced.

(ii) Colour

Colour was determined using UV/Visible Spectrophotometer (HACH, Model DR/3000) at the wavelength of 455nm (AOAC, 1990). Two standards were used to calibrate the Spectrophotometer; Zero (0) mg/l and 250 mg/l. The zero standard was prepared using de-ionised water and 250 mg/l colour standard was prepared by pipetting 50 ml of the 500 platinum-cobalt solution (factor prepared) into a 100 ml volumetric flask and diluted to the mark with de-ionised water.

(iii) Total Dissolved Solids (TDS)

TDS was measured using the Evaporation Method outlined in APHA (1985) whereby a well mixed sample was filtered through a standard glass fibre filter and filtrate evaporated to dryness in a weighed dish and dried to constant weight at 180ºC. Increase in the dish weight represented Total Dissolved Solids.

3.2.4.3 Chemical Analyses

(i) Nitrates

Standard stock solution for nitrates was prepared as follows: Potassium nitrate, KNO_3, was dried in an oven at 105^0C for 24 hours before dissolving 0.7218g in deionised water and diluting to 1000 ml. Then 100 ml of the stock nitrate solution was diluted to 1000 ml to give an intermediate nitrate solution from which the working standard solutions were prepared. The following standard solutions were used in the final determination: 0.0, 1.0, 2.0, 4.0, 5.0 and 10 mg/l to come up with a standard curve. The determinations were done using Ultraviolet Spectrophotometric Screening Method.

Five ml of water samples and a blank was pipetted into a 100ml Pyrex beaker and mixed with 2.0 ml sodium salicylate solution (0.5% w/v). The mixture was evaporated to dryness on a water bath. After removing from water bath, 1 ml sulphuric acid (conc.) was added and mixed well before being allowed to stand for 10 minutes. This was diluted to 50 ml with de-ionised water before adding 10 ml NaOH solution and mixed thoroughly. The solution was quantitatively transferred to a 100 ml volumetric flask and diluted to the mark with de-ionised water. Absorbance was measured on a UV-Visible spectrophotometer model JENWAY 6405 against the blank at 410 nm wavelength (APHA 1985; AOAC, 1990).

(ii) Phosphates

The Ultraviolet Spectrophotometric Screening Method was used to screen phosphates in water samples as outlined in APHA (1985). Standard stock solution was prepared by dissolving 219.5 mg anhydrous KH_2PO_4 in de-ionised water and diluted to 1000 ml. 50 ml of the phosphate stock solution was diluted to 100 ml with de-ionised water to make an intermediate phosphate solution from which the working standard solutions were prepared. The following standard solutions were used in the final determination 0.0, 0.2, 0.4, 0.5, 1.0, 2.0 and 4.0 mg/l from which a standard curve was developed.

A water sample volume of 50 ml and distilled water of 50 ml as a blank was pipetted into a clean 125 ml Erlenmeyer flask. One drop (0.05 ml) of phenolphthalein indicator was added. A red colour developed and 2.5 M H_2SO_4 was added drop by drop to discharge the colour. Then 8.00 ml combined reagent was added and mixed thoroughly. After 15 minutes, absorbance was measured at 880 nm using a UV-Visible spectrophotometer (JENWAY 6405 UV/Visible spectrophotometer). Combined reagent involved mixing 50ml of 2.5 M H_2SO_4, 5ml Potassium antimonyl tartarate solution, 15ml Ammonium molybdate solution and 30ml Ascorbic acid solution (APHA 1985; AOAC, 1990).

(iii) Sulphates

The Ultraviolet Spectrophotometric Screening Method was used as outlined in APHA (1985). Standard stock solution for sulphates was prepared by dissolving 0.1479 g anhydrous Na_2SO_4 in de-ionised water and diluted to 1000ml. The following standard solutions were prepared from which final determinations were made using 0.0, 5.0, 10, 20 and 30 mg/l. The calibration curve was then drawn after reading absorbances using UV-Visible spectrophotometer (JENWAY 6405 UV/Vis spectrophotometer) at 420 nm. A sample of 100 ml was transferred into a 250 ml Erlenmeyer flask and mixed with 20 ml buffer solution using a stirring apparatus. Buffer solution was prepared by dissolving 30 mg of $MgCl_2.6H_2O$, 5g sodium acetate and 20 ml acetic acid in de-ionised water and made up to 1000ml (APHA, 1989).While stirring, 0.5 g of $BaCl_2$ crystals was added. After stirring for 60 seconds at constant speed, absorbance was measured by an UV-Visible spectrophotometer (JENWAY 6405 UV/Vis spectrophotometer) at a wavelength of 420 nm within 5 minutes.

(iv) Iron

The standard stock solution was prepared by dissolving 1.000 g iron wire (GPR) in 50 ml of 1:1 HNO_3 / H_2O (AR grade) and diluting to 1000 ml in a volumetric flask to obtain a 1000 mg/L iron stock solution. The stock solution was used to prepare a 100 mg/L intermediate stock solution from which the working standard solutions were prepared. The standard solutions used in the final determination were 0.00, 0.5, 1.0, 2.0, 5.0 and 10.0 mg/L.

The Colometric Phenanthroline Method was used in the analysis of iron, as outlined in APHA 1985. This method involved the use of acidified sample which was then added with Hydroxylamine hydrochloride. The pH of the sample was further adjusted to 3.2-3.3

by addition of ammonium acetate buffer and the iron complexed with 1.10 phenanthroline to produce an orange-red solution. The reaction in this process is directly proportional to the amount of dissolved iron in the sample. The measurement of the colour intensity was then done by using a UV/Visible Spectrophotometer set at the wavelength of 508nm. The Iron concentration in the sample was finally determined from a calibration graph. (APHA 1985; AOAC, 1990).

(v) Potassium and Sodium

The Flame Photometry method was also used in the analysis of potassium and sodium, as outlined in APHA 1985. A Flame Photometer, Corning Model 400 was used. The reagents were dried in an oven set at 180^{o}C for two hours. Calibration curves were plotted to calculate concentrations. The calibration graph for the standards of the two parameters ranged from 0-5.0 mg/l.

Standard Sodium (stock) solution was prepared as follows: 2.542 g + 0.005 g of Sodium Chloride previously dried at 140 ^{0}C for an hour was weighed and quantitatively transferred to a clean 1000 ml volumetric flask and diluted to the mark with distilled water. Similarly, the standard Potassium (stock) solution was prepared by weighing 1.907 g + 0.005 g of Potassium Chloride which was previously dried at 110^{0}C for an hour. The solid was quantitatively transferred to a clean 1000 ml volumetric flask and diluted to the mark with distilled water. Standard Sodium/Potassium (Working) solution was prepared by pipetting 10 ml of the Sodium stock solution and 10 ml of the Potassium stock solution into a clean 100 ml volumetric flask and diluted to the mark with distilled water.

3.2.4.4 Bacteriological analysis

Faecal coliform counts in the water samples were determined using the Membrane Filtration Method as illustrated in APHA (1985). Culturing of bacteria was done in the laboratory. A sample aliquot ranging from 5 to 10 ml of water was filtered through a filter membrane of 0.45 mm pore size and 47 mm in diameter. The membranes were then incubated on membrane Lanyl sulphates broth at 44 – 44.5°C for 24 hours. Faecal coliform colonies were then counted.

3.3 Data Analysis

FDC analysis was carried out for the hydrological data using the historical flow records, in Microsoft Excel, to display the relationship between the ranges of discharges. Descriptive statistics (mean, standard deviation, autocorrelation) of the flows was also done using AQUAPAK (Sinclair Knight Merz Pty Ltd).

For the water samples, descriptive statistics (mean and standard deviation) were used to analyze the water quality parameters. In order to examine seasonal differences in the water quality, paired *t*-tests were run in Statistical Package for Social Scientists (SPSS). The results were compared with national recommended standards dealing with water quality (MBS, 2005).

The Malawi standards dealing with water quality include MS 214: Drinking water specification; MS 675: Water Quality – Physical methods of test; MS 676: Water quality – chemical methods of test; MS 677: Water quality – Microbiological methods; MS 678:

Drinking water quality – Control and surveillance of water in public supply networks; MS 733: Borehole and Shallow well water quality specification and MS 539: Industrial effluents – Tolerance limits for discharge into inland surface waters.

The MS 214 specifies the physical, biological, organoleptic and chemical requirements for water quality from public water supply for human consumption. Since the water from public water supply is treated, this standard is more stringent and would not apply to untreated water from rural earth dams. The MS 733 outlines requirements for untreated or raw ground water in boreholes and shallow wells suitable for human consumption and all usual domestic purposes. Therefore the MS 214: Drinking water specification and MS 733 have been used for further reference.

Chapter 4: Results and Discussion

4.1 Management of Small Dams in T/A Kalolo

In T/A Kalolo, sources of water for domestic use include boreholes, protected wells, dams, unprotected wells in *dambos*. There are a total of four functional boreholes; one protected well; 16 unprotected wells in *dambos* that are used as sources of domestic water by the communities. This implies that there is general inadequacy in access to potable water in the area considering that 16 unprotected wells are still being used as a source of water for domestic use.

Because of the wide use of unprotected wells, dams and *dambos* in the area, communities are provided with chlorine (water guard) by Health Surveillance Assistants (HSA) responsible for the area for treatment of water at home. The wells are also disinfected periodically to prevent water borne diseases. In terms of sanitary conditions, it was observed during the field visit and confirmed through interviews that some people in the area had no toilets. According to GVH Mandala, Ellen Mainala, Aliness Mastala and Hazwell Austin, most households in Mandala village which did not have toilets were female headed with inadequate resources to hire men to construct pit latrines for them. These households use bushes as toilets which is a health hazard if collected as runoff into surface water bodies.

Key informant interviews that were done in the area revealed that local institutions were put in place to oversee the general management of water resources in the area. These include: Dam Committees, Health Committees, Forestry Committees and Water Point Committees. These committees, together with the user community, are responsible for the management of boreholes, protected wells, unprotected wells, the dams and *dambos*. By-laws were set up for individual dams to govern management of dams and they restrict on site use of dams for bathing, washing clothes and livestock watering. Regulated fishing is also practiced with communities allowed to fish on specified days and fishing season is closed during fish breeding season. Community policing is also practiced as a way of ensuring that there is no abuse of the resource.

4.2 Water Use in Kalolo

4.2.1 Current Domestic Water Use

Key Informant and individual interviews were conducted in villages surrounding the dams as a direct method of estimating the amount of water used for the various categories of domestic water use. Figure 3 below shows categories of domestic water use and average amounts used for each category in the area. It was found that on average, the largest amount of water drawn in the area was used for bathing (47%) and the activity that required the least amount of water was drinking (4%).

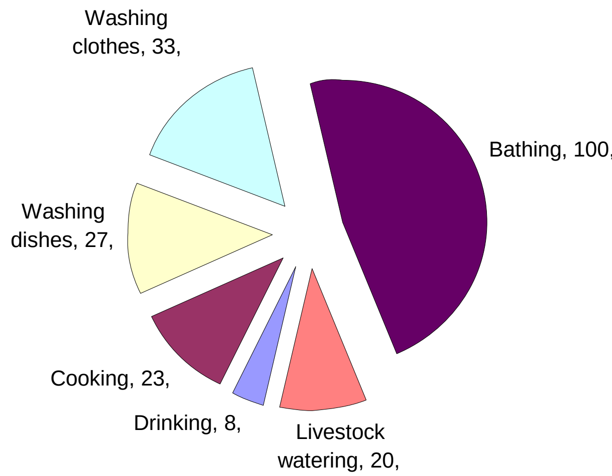


Figure 3: Average amount of water used in litres per household per day in T/A Kalolo

From the average amount of daily water used for each category of domestic uses at household level obtained from the interviews, the total annual domestic water use for each dam were calculated and are summarized in Table 6.

Table 6: Annual Domestic Water Use in T/A Kalolo (Direct Method).

DAM	WATER USE				
	Human Use (L/day)	livestock Use (L/day)	Total Daily Use (L/day)	Total Annual Use (L/yr)	Water Use in m3/s
Mandala	89010	4905	93915	33809400	0.391
Kamanzi	22680	1735	24415	8789400	0.102
Gundamtengo	43860	5313	49173	17702280	0.205
Nabvumi	57840	2540	60380	21736800	0.252
Phazilamkango	35875	2008	37883	13637880	0.158
Goliati	54910	7510	62420	22471200	0.260

The per capita water use in the area ranged from 34 litres/capita/day in villages surrounding Gundamtengo Dam to 48 litres/capita/day in villages surrounding Nabvumi Dam. These domestic water use figures estimated from this study are in line with the figures obtained by Wallingford (2003) of 20 to 40 litres/capita/day for domestic water use in rural Africa. Variations in the per capita domestic water use in rural areas are dependent on water points: population ratios, household occupancy rates and the distance travelled to a water source (Wallingford 2003).

Water consumption was lowest for Kamanzi area (0.102 cumecs) and highest for Mandala area (0.391 cumecs). Since there were variations in the population of beneficiaries for individual dams, the variations in water use values calculated using the direct method of estimating water use can be attributed to the differences in population levels.

In estimating water use through the indirect method, population figures for the beneficiary communities were used against the mean flow. Results of the estimated water use are tabulated in Table 7.

Table 7: Annual Domestic Water Use in T/A Kalolo (Indirect Method).

DAM	Mean Discharge (m3/sec)	Water use (L/day)	Livestock Use (L/day)	Total Water Use (L/yr)	Water Use in m3/s
Mandala	0.021	932.94	4905.0	2130848.61	0.025
Kamanzi	0.062	9918.74	1735.0	4253615.22	0.049
Gundamtengo	0.072	4823.93	5313.0	3699980.55	0.043
Nabvumi	0.051	3657.24	2540.0	2261991.27	0.026
Phazilamkango	0.004	407.61	2008.0	881697.84	0.010
Goliati	0.007	389.95	7510.0	2883482.07	0.033

Comparatively, the water use values derived from the indirect method are lower than the estimates based on field interviews as presented in Figure 4. The indirect method values of water use imply the amount of water available for withdrawal from the dams in an ideal situation where environmental flows are maintained. This already suggests that the dams would not be able to sustain the current water requirements of the communities for a long period of time.

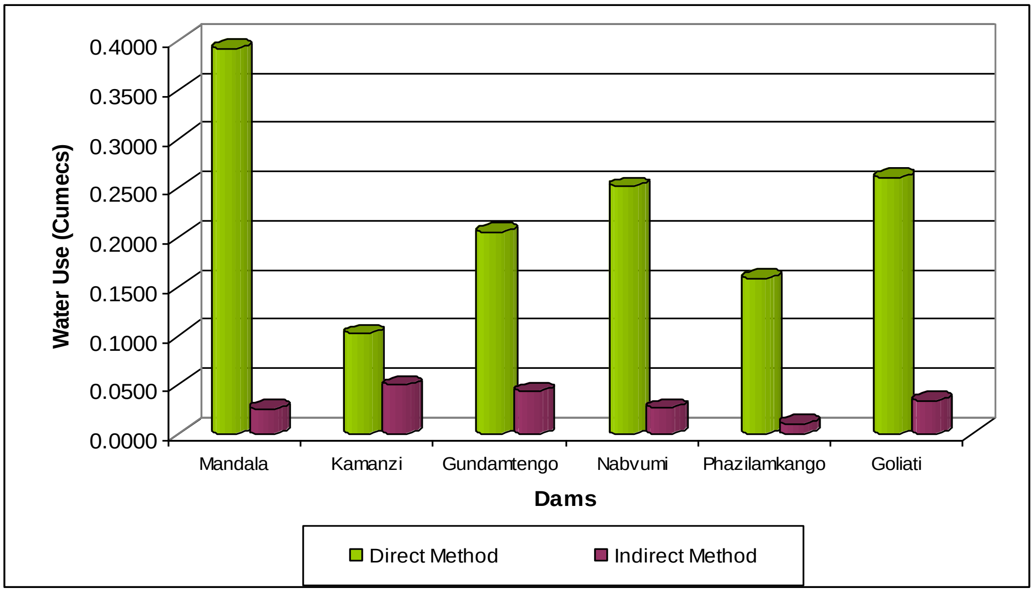


Figure 4: Comparison between direct and indirect values of rural water use.

For purposes of assessing the reliability of the dams, the study used the water use values estimated using the direct method based on field interviews. This water use values were added to evaporation figures for each catchment and plotted on the FDCs to come up with total amount of water consumed from the dams.

4.2.2 Estimating Future water use

Projections for future water use were made using the linear projector (low range) and exponential projector (high range) using formulas 2 and 3 (see page 36).

Table 8: Future Water Use projections in the high and low ranges

DAM	Current Water Use (m^3/s)	Future Water Use (Low Range)	Future Water Use (High Range)
Mandala	0.391	0.506	0.508
Kamanzi	0.102	0.132	0.132
Gundamtengo	0.205	0.265	0.266
Nabvumi	0.252	0.325	0.327
Phazilamkango	0.158	0.204	0.205
Goliati	0.260	0.336	0.338

Table 8 shows the future water use projections for the dam. Very slight differences can be noted between the low and high range projections made. Water use figures ranged from 0.132 to 0.508 cumecs for the dams. This trend is in line with current consumption figures derived from the direct method of water use assessment. Projections for water use were made to the year 2015 which is the target year for the provision of potable water for domestic use for most developing countries, including Malawi, as indicated in the national strategies and global targets such as the NSSD and MDGs, respectively.

4.3 Stream Flow Trends and Patterns

4.3.1 Descriptive Statistics

Descriptive statistics for the flow data was carried out and results are shown in Table 9. Gundamtengo and Kamanzi dams had the highest flows with mean flows of 0.07 m^3/s and standard deviation of 0.19 and 0.12 respectively. Phazilamkango had a mean flow of 0 (SD= 0.01), implying a higher potential for drying out.

Table 9: Descriptive Statistics for stream flows

Dam	Mean	Standard Deviation	Auto- correlation
Mandala	0.02	0.05	0.7222
Kamanzi	0.07	0.12	0.8045
Gundamtengo	0.07	0.19	0.7212
Nabvumi	0.05	0.10	0.7782
Phazilamkango	0.004	0.01	0.7222
Goliati	0.01	0.01	0.7850

The stream flows for all the dams are highly auto-correlated, between 0.7 and 0.8. This means that daily flows are dependent on each other. Stream flows with high auto-correlation usually have a larger base flow component (Vogel and Fennessey, 1995). The autocorrelation figures for the dams suggest the presence of a large base flow component and this is an indication that the dams are perched aquifers with minimal groundwater recharge from adjacent aquifers, typical of *dambos*, as observed during the field visits. Soil types in this area are *Tenthema* (Government of Malawi, 2006), and this soil type tends to be poorly drained such that in instances of prolonged droughts of minimal precipitation, the dams are prone to completely dry up.

Time series plots for the dams also validate the notion that all the dams in the area have a large base flow component (blue areas) as indicated by Figure 5 below.

From the time series plots, Mandala, Phazilamkango and Gundamtengo are depicting the same pattern of stream flow during the period of record, with January/February 1982 having the peak flows. Kamanzi, Nabvumi and Goliati Dams also have the same pattern of flows from 1978 to 2001, with peak flows in January 1985. Low flows are apparent during the period 1991 to 1995, which is the period the nation experienced drought in terms of low rainfall levels (Benson and Clay, 1998). This flow trend confirms the view that dams in T/A Kalolo greatly depend on surface flows from rainfall.

Pattern of flows from the time series plots above are in agreement with the pattern of flows depicted by mean monthly flows plots for the dams (Figure 6). High stream flows are experienced during the wet months, from January to April and very low flows during the dry months, from July to October. All streams have February as their peak month with the highest flows and the lowest flows experienced in the month of October for all the dams. This generally suggests that the dams are greatly dependent on surface flows from precipitation and hence would only reliably supply water during the rainy season, from January to April.

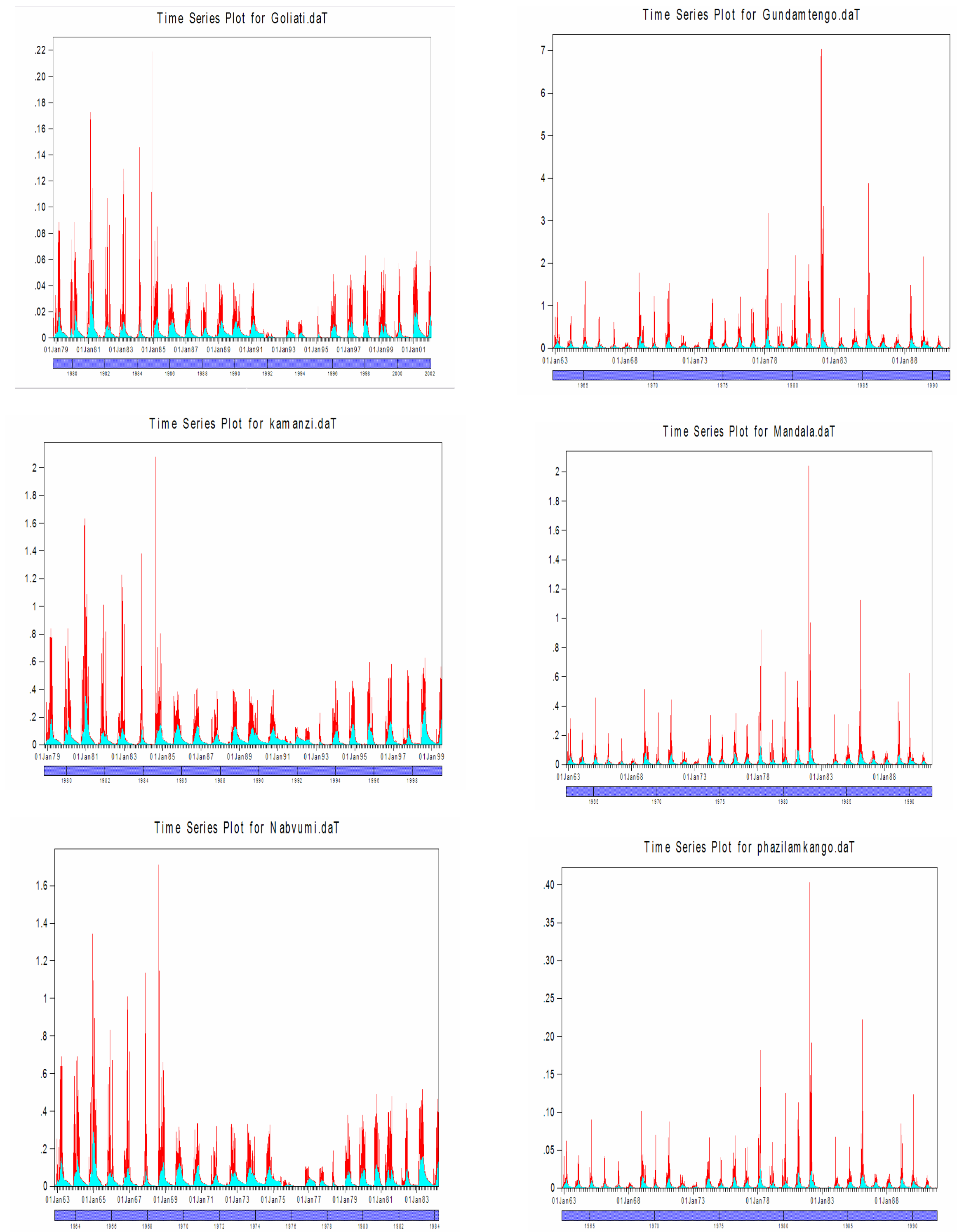
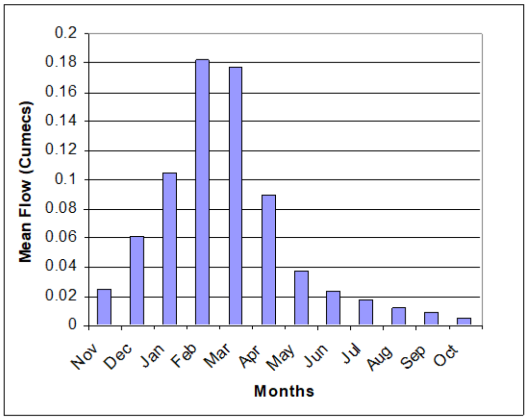


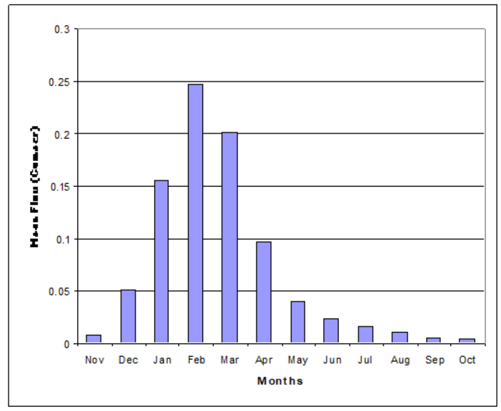
Figure 5: Time series base flow plots for dams in T/A Kalolo.

Figures 7 and 8 show annual stream flow series for dams for the period of record. The general pattern of stream flows for Phazilamkango, Goliati and Mandala is constant, with very little flows. Gundamtengo, on the other hand is portraying an upward stream flow trend during the record period (1962 to 1992), while Kamanzi and Nabvumi are on the decline.

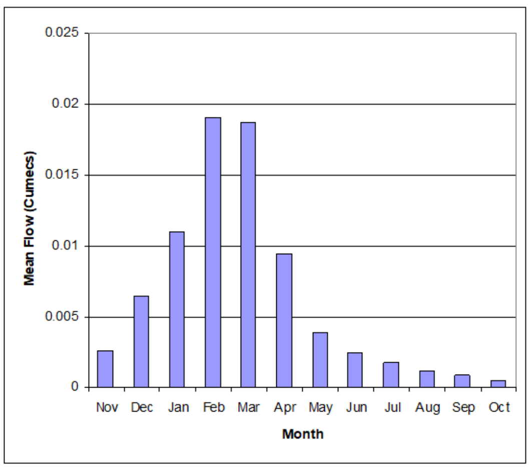
The declining trends for Kamanzi stream (feeder stream for Kamanzi and Nabvumi Dams) could be as a result anthropogenic activities upstream which lead to high rates of sedimentation (UNEP, 2006) and possibly from climatic factors like changes in rainfall duration and frequency in Malawi.



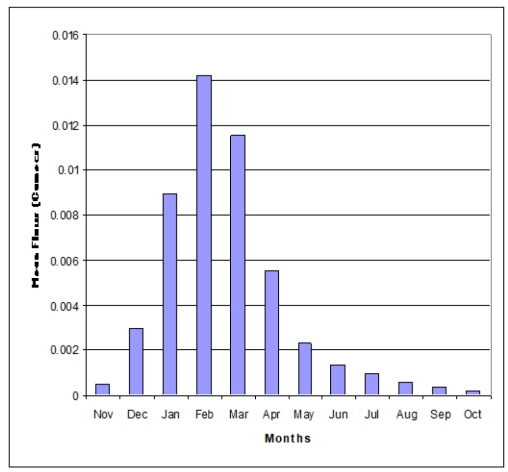
Kamanzi Mean Monthly Flows



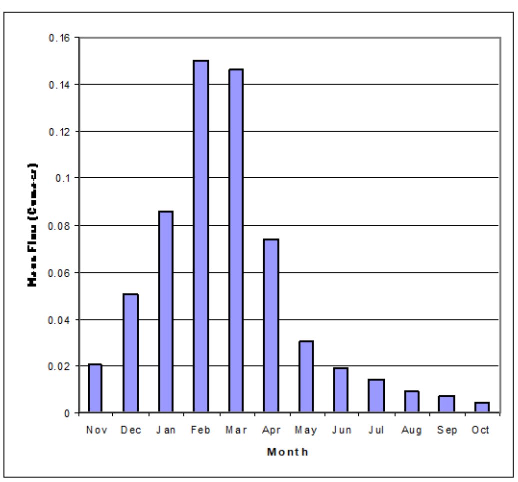
Gundamtengo Mean Monthly Flows



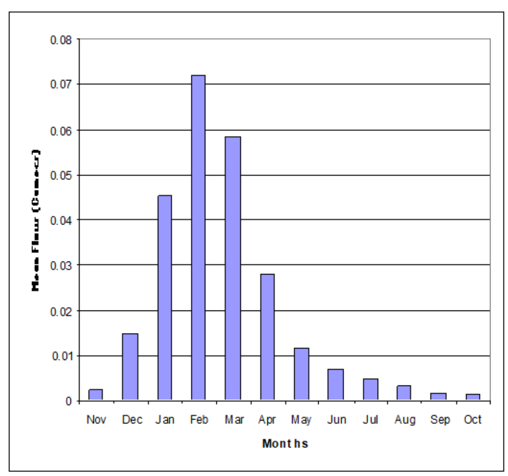
Goliati Mean Monthly Flows



Phazilamkango Monthly Flows



Nabvumi Mean Monthly Flows



Mandala Mean Monthly Flows

Figure 6: Mean monthly flows for dams in T/A Kalolo.

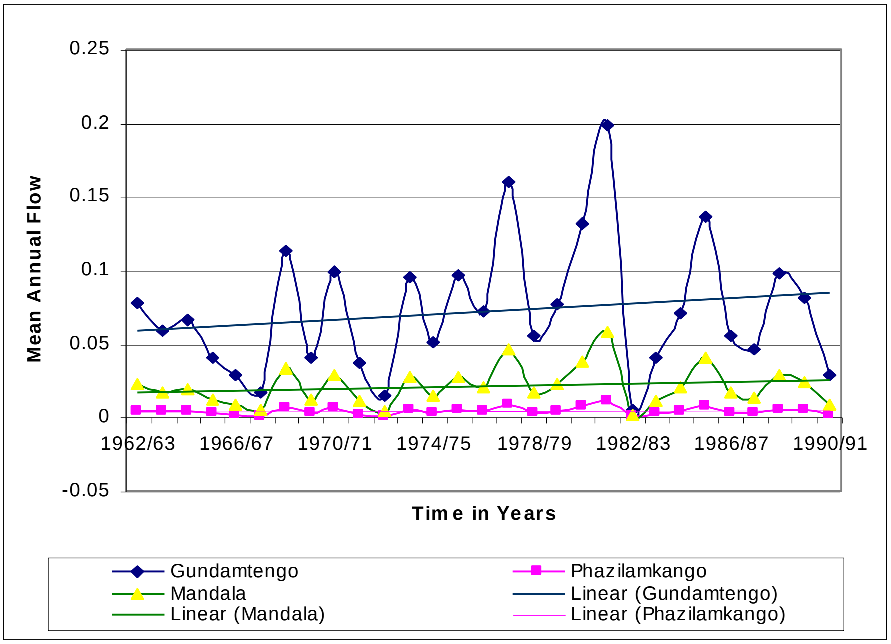


Figure 7: Flow Trends for Gundamtengo, Mandala and Phazilamkango Dams from 1962-1991.

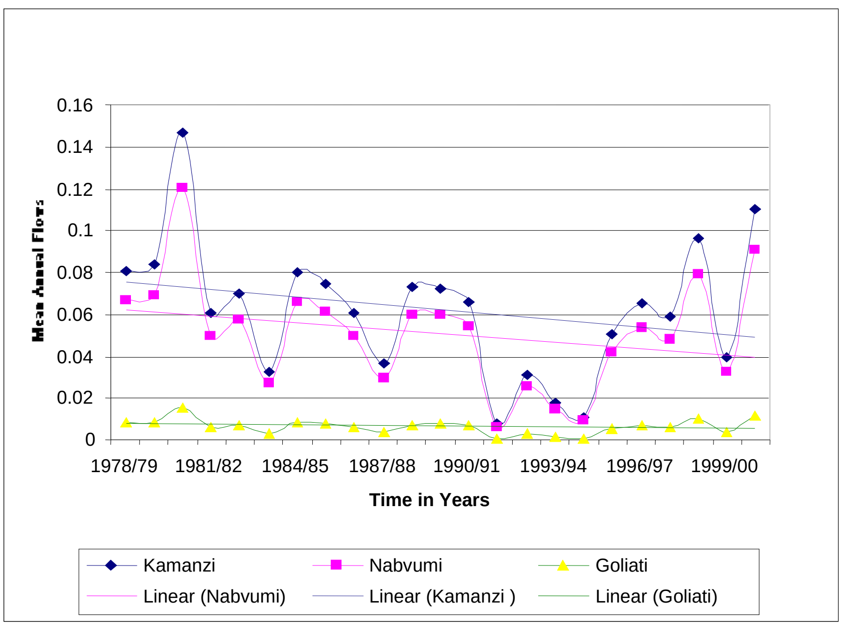


Figure 8: Flow Trends for Kamanzi, Nabvumi and Goliati Dams from 1978-2002.

4.3.2 Estimated Evapo-transpiration

Thornthwaite's method of estimating evapo-transpiration was used in this study and the results are summarized in Table 10. Catchment area figures for the gauging stations were collected and used in the estimation of evapo-transpiration.

Table 10: Estimated Evapo-transpiration (Ep) from catchment areas within T/A Kalolo

Dam	Ep (mm/y)	Ep (m/y)	Ep (m/s)	Catchment area (m^2)	Ep per area (m^3/s)
Mandala	115.7613	0.1158	3.67077E-09	10629000	0.0390
Kamanzi	115.7613	0.1158	3.67077E-09	9844000	0.0361
Gundamtengo	115.7613	0.1158	3.67077E-09	10144000	0.0372
Nabvumi	115.7613	0.1158	3.67077E-09	8099000	0.0297
Phazilamkango	115.7613	0.1158	3.67077E-09	4852000	0.0178
Goliati	115.7613	0.1158	3.67077E-09	1039000	0.0038

Evapo-transpiration figures were lowest (0.004 cumecs) for Goliati area and highest for Mandala area (0.039 cumecs). The variations in evapo-transipration figures is due to the different corresponding sizes of the catchment areas for the dams.

4.3.3 Flow Duration Curve Analysis

Flow Duration Curves were plotted for each dam (Figures 9 to 14). In this study, environmental flows were set at Q_{90}, which are the flows that are equaled or exceeded 90% of the time. Current human and livestock water use values derived from the direct method of estimating rural water use, future water use, and estimated evapo-transpiration figures were plotted on the FDCs in order to determine ability of the flows to supply water for use.

The FDCs indicate that water requirements of the communities would be met only less than 20% of the time for all the dams, meaning that the dams are not reliable, since according to Smathkin (2001), all flows below the median flow (Q_{50}) are not reliable.

Table 11 below shows the percentage of time that stream flows are sufficient to meet water requirements from the communities at the time the study was undertaken (W: 2006, in red) and projected water requirements (W: 2015, in green). Environmental requirements at Q90 are plotted in sky blue.

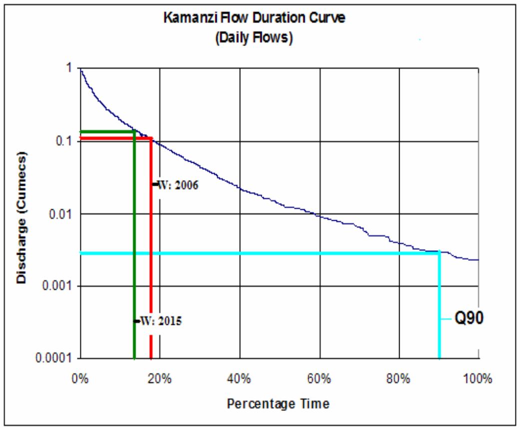


Figure 9: Kamanzi FDC showing percentage of time of flow supply.

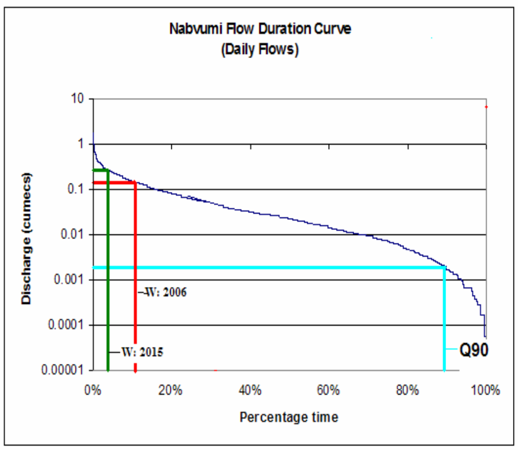


Figure 10: Nabvumi FDC showing percentage of time of flow supply.

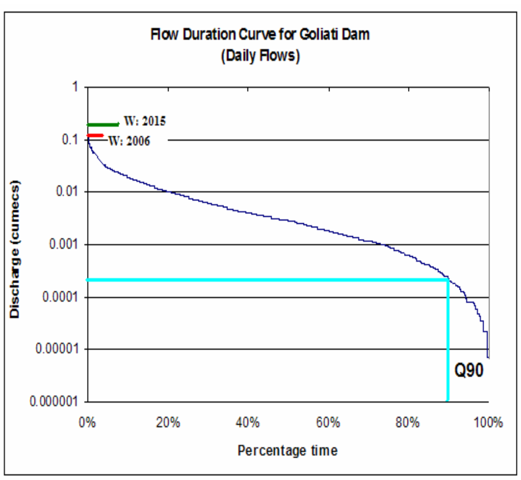


Figure 11: Goliati FDC showing percentage of time of flow supply.

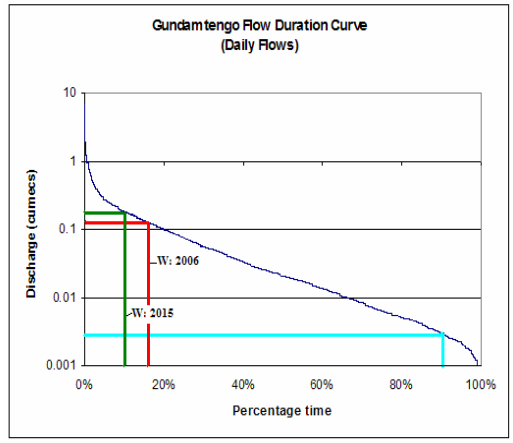


Figure 12: Gundamtengo FDC showing percentage of time of flow supply.

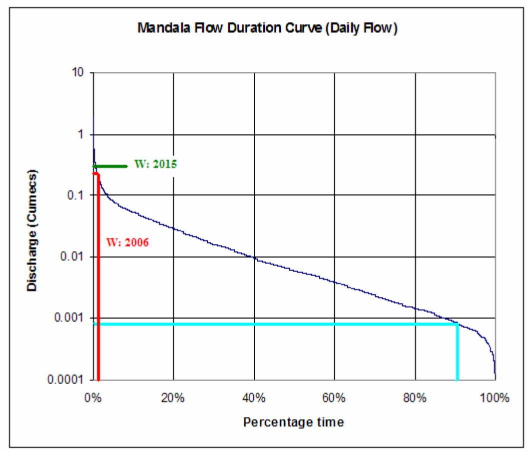


Figure 13: Mandala FDC showing percentage of time of flow supply.

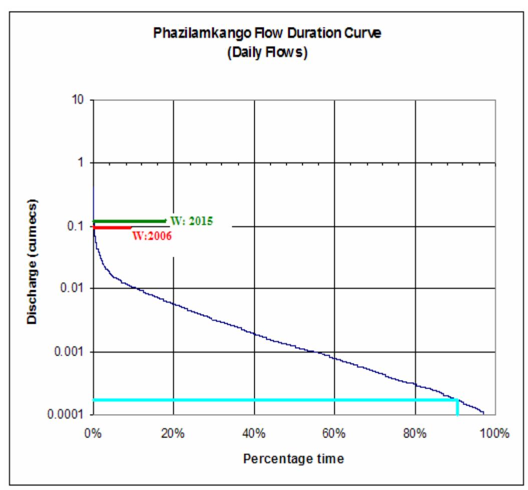


Figure 14: Phazilamkango FDC showing percentage of time of flow supply.

Table 11: Percentage of time flows are sufficient to meet water requirements in T/A Kalolo.

DAM	Current water use (%) (W:2006)	Future water use (%) (W:2015)
Kamanzi	18	14
Gundamtengo	16	10
Nabvumi	10	4
Mandala	2	1
Phazilamkango	0	0
Goliati	0	0

Current water use in Kamanzi dam is met 18% of the time and future requirements are met 14% of the time. Gundamtengo dam is able to meet current water use 16% of the time and future requirements are met 10% of the time. Mandala dam is able to meet current uses 12% of the time and future requirements only 1% of the time. Current water use in Nabvumi dam is met 10% of the time and 4% of the time is the dam able to meet future water requirements. Phazilamkango dam is able to meet the current requirements only 1% of the time and future requirements will not be met at all. Goliati dam is neither able to meet current water requirements nor future requirements (0%).

Reliability of water withdrawals was also done based on water allocation derived from the indirect method of assessing rural water demand, which is the amount of water available for withdrawal from the dams in an ideal situation where environmental flows are maintained. For the reliability of water withdrawals, FDCs were only plotted for

Kamanzi and Phazilamkango dams as an illustration of the difference between curves for the highest and lowest stream flows respectively (Figure 15).

It is apparent that even in the ideal situation, the amount of water available for use from the dams is still less than Q_{50}, with Kamanzi Dam having water flows available for use only 25% of the time and Phazilamkango Dam having flows available for use only 5% of the time. This implies that the dams are not able to meet the water demand from the communities at least 75% of the time, which according to Smathkin (2001) is an indication of unreliability.

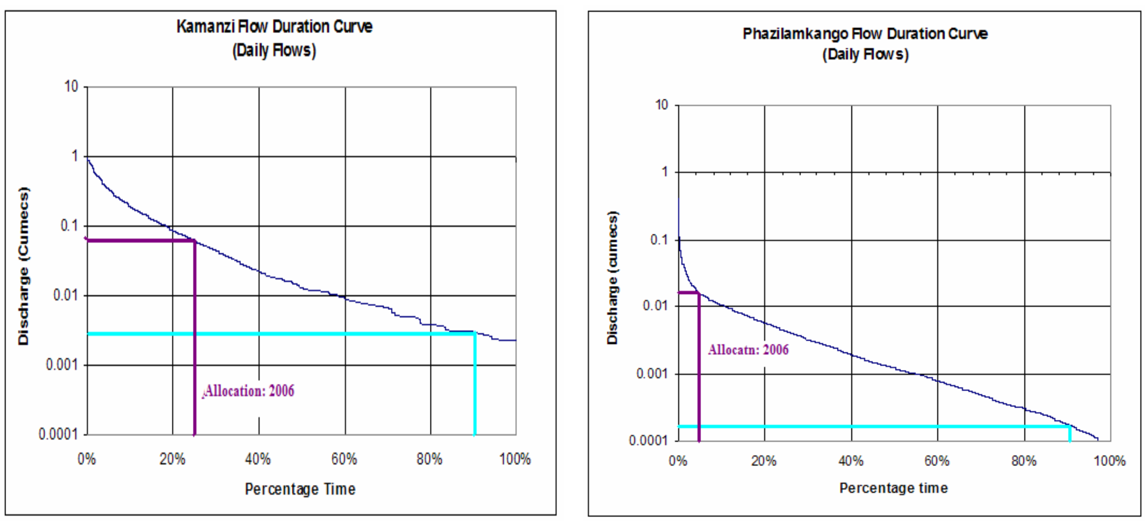


Figure 15: Flow Duration Curves for Kamanzi and Phazilamkango Dams showing Water Allocation Plots

4.3 Ecological Management Classes

The study attempted to establish the habitat integrity of the catchment of the stream with the use of digital pictures and from individual interviews. Based on the responses and assessment of the pictures taken, the dams have been duly classified into ecological management classes (Table 12). Gundamtengo, Goliati and Kamanzi dams have been classified into class C which is moderately modified and Mandala, Nabvumi and Phazilamkango dams have been classified into class D which is largely modified.

Table 12: Ecological Management Classes of the Dams

Dam	Riparian Modifier	Score	Class	Description
Mandala	Bank erosion	0	**D**	Largely modified. A large loss of natural habitats, biotas and basic ecosystem functions has occurred.
	Indigenous vegetation removal	18		
	Water abstraction	4		
	Water quality	8		
	Exotic vegetation encroachment	3		
	Channel modification	0		
	Flow modification	21		
	Inundation	0		
	Total Score	**54**		
Gundamtengo	Bank erosion	2	**C**	Moderately modified. A loss of and change from natural habitats and biotas has occurred but the ecosystem functions are still predominantly unchanged.
	Indigenous vegetation removal	15		
	Water abstraction	4		
	Water quality	13		
	Exotic vegetation encroachment	5		
	Channel modification	0		
	Flow modification	21		
	Inundation	0		
	Total Score	**60**		
Phazilamkango	Bank erosion	0	**D**	Largely modified. A large loss of natural habitats, biotas and basic ecosystem functions has occurred.
	Indigenous vegetation removal	15		
	Water abstraction	4		
	Water quality	13		
	Exotic vegetation encroachment	4		
	Channel modification	0		
	Flow modification	21		
	Inundation	0		
	Total Score	**57**		
Nabvumi	Bank erosion	0	**D**	Largely modified. A large loss of natural habitats, biotas and basic ecosystem functions has occurred.
	Indigenous vegetation removal	20		
	Water abstraction	4		
	Water quality	2		
	Exotic vegetation encroachment	3		
	Channel modification	0		
	Flow modification	21		
	Inundation	0		
	Total Score	**50**		
Kamanzi	Bank erosion	15	**C**	Moderately modified. A loss of and change from natural habitats and biotas has occurred but the ecosystem functions are still predominantly unchanged.
	Indigenous vegetation removal	14		
	Water abstraction	4		
	Water quality	7		
	Exotic vegetation encroachment	3		
	Channel modification	0		
	Flow modification	21		
	Inundation	0		
	Total Score	**64**		
Goliati	Bank erosion	15	**C**	Moderately modified. A loss of and change from natural habitats and biotas has occurred but the ecosystem functions are still predominantly unchanged.
	Indigenous vegetation removal	15		
	Water abstraction	4		
	Water quality	18		
	Exotic vegetation encroachment	3		
	Channel modification	0		
	Flow modification	21		
	Inundation	0		
	Total Score	**76**		

4.4 Water Quality Assessments

This study selected to determine pH, colour, turbidity and levels of iron, nitrates, sulphates, phosphates, potassium, faecal coliforms and total dissolved solids (TDS) as indicators of the suitability of the dams' for domestic water supply. The results of the water quality assessment are summarised in Tables 13, 14, 15 and 16. The corresponding Malawi Standards (MS 214 and MS 733) parameters are also included. *P* values, at 95% level of confidence, for comparison of each measured parameter at the two sampling points in the dams are annexed as Appendix 4.

4.4.1 Colour, pH and TDS

The pH (6.60–7.99) of the water samples in the rainy season and for the dry season (6.50-7.82) is within the safe limits (6.5–8.5) as prescribed by MS 214. There are no big variations in pH between the seasons and between the inlet and outlet of the dams ($p > 0.05$). The pH of water is important because it affects chemical speciation as chemical dissolution and precipitation depends on pH. Low pH increases metal dissolution and hence bioavailability (and toxicity) whilst high pH values favour precipitation, making them unavailable for uptake by biota and humans. The pH of 'clean' rain or of any other pure water sample in equilibrium with atmospheric carbon dioxide is approximately 5.7 (Van Loon and Duffy, 2005). The pH values from the dams indicate a well buffered system with carbonates (CO_3^{2-}), bicarbonates (HCO_3^-), $H_3SiO_4^-$ and HPO_4^{2-} being the most probable proton acceptors in the water system.

Colour affects aesthetics of water and indicates the presence of dissolved and suspended organic materials, inorganic materials, sediments from soil erosion and overland flow. In the rainy season the water from the dams was generally muddy and unattractive as can be evidenced by the high mean levels of colour (Table 13). These results show the apparent colour of water, as opposed to the true colour (since the samples were not filtered before analysis).

Table 13: Mean levels of TDS, Colour and pH

Dam	Parameters											
	pH				TDS (mg/l)				Colour (TCU)			
	Rainy season		Dry Season		Rainy season		Dry Season		Rainy season		Dry Season	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
Mandala	7.29± 0.09	7.27± 0.06	7.79± 0.01	7.37± 0.17	53± 1.8	47± 1	169± 2.5	217± 3.8	120± 2.9	145± 5.8	40± 2.9	30± 0
Gundamtengo	7.28± 0.03	7.19± 0.02	6.68± 0.03	7.06± 0.21	16± 1	15± 0.8	156± 1.5	72± 1.2	145± 5.8	145± 5	10± 2.8	5± 2.9
Nabvumi	7.36± 0.09	7.99± 0.04	7.42± 0.04	7.82± 0.31	18± 0.8	25± 0.4	224± 3.5	141± 1.0	80± 5.8	50± 2.9	20± 2.9	20± 5
Phazilamkango	6.62± 0.02	6.6± 0.2	6.5± 0.03	6.55± 0.13	18± 0.7	37± 0.3	44± 1.5	40± 1.1	70± 0	140± 5.8	40± 2.9	30± 2.9
Kakoma	7.13± 0.06	7.38± 0.05	7.16± 0.02	7.15± 0.38	30± 1	52± 0.6	57± 2.0	75± 0.5	140± 5.8	140± 2.9	35± 2.8	20± 2.8
Kamanzi	ND	ND	7.02± 0.08	7.21± 0.03	ND	ND	16± 1.5	52± 0.6	ND	ND	30± 5	35± 2.8
MS 214	**5.0 – 9.5**				**450 - 1000**				**5-10**			
MS 733	**6.0 - 9.5**				**2000**				**50**			

SD = standard deviation; ND = Not determined; NA = not available; x = mean, n =3

Apparent colour is the colour of the whole water sample, and consists of colour due to both dissolved and suspended components. Colour levels ranged from 50 ± 2.9 TCU to 145 ± 5.8 TCU for the rainy season, exceeding the recommended 15 TCU from MS 214 and 50 TCU from MS 733. These levels could be indicative of the presence of sediments and dissolved natural organic matter carried as run off with overland flow. The results indicate a significant difference between the rainy and dry seasons in levels of colour ($p < 0.05$).

TDS is a measure of total dissolved solute in water (US EPA, 2005; WHO, 1996). Results for the rainy season ranged from 15 ± 0.8 to 53 ±1.8 mg/L and dry season levels for TDS ranged from 16±1.5 to 224±3.5 mg/L. These levels imply that the water can be categorised as fresh and the values are low when compared with the guidelines from Malawi Standards 214 and 733. There is however significant difference in TDS values ($p < 0.05$) between the seasons, with higher values in the dry season than the rainy season, which may be attributable to concentration by evaporation during the dry season and dilution in the rainy season.

4.4.2 Levels of nitrates, sulphates, phosphates and faecal coliforms

Excessive nitrates (NO_3^-) in drinking water can cause a number of health disorders, such as methemoglobinemia, gastric cancer, goitre, birth malformations and hypertension (Majumdar and Gupta, 2000). In the rainy season, levels of nitrates ranged from 0.002±0.001 mg/l to 0.165±0.002 mg/l and were within recommended local water quality standards (Table 14). Compared with the levels of nitrates in the dry season, which were

<0.001 mg/l, the wet season levels were higher and may be attributable to run off from agricultural fields washing away inorganic fertilizers into the dams. Low usage of inorganic fertilizers, as indicated during informant interviews, coupled with uptake of nitrates by aquatic plants can be responsible for the generally low levels of nitrates especially in the dry season.

Presence of sulphates in very high concentrations in drinking water is associated with respiratory problems (Subba Rao, 1993). In conjunction with sodium and magnesium, sulphates may also exert a cathartic effect on digestive tracts. Further, water containing magnesium sulphate at levels above 600 mg/l acts as a purgative in humans (Majumdar and Gupta, 2000). Wet season levels of sulphates were much lower than the recommended standards (Table 14). The wet season levels ranged from 0.013 ± 0.01 mg/l to 20.6 ± 0.59 mg/l and the dry season sulphate levels were within the range of 7.21 ± 0.22 mg/l to 23.3 ± 0.35 mg/l. According to GEMS/WATER, a global network of water monitoring stations, typical sulphate levels in fresh water are in the vicinity of 20 mg/l and range from 0 to 630 mg/l in rivers. The generally low levels could be due to geology of the area which affects sulphate levels in surface water and low loading from runoff. Some organics will release sulphate on breaking down thus making sewerage contamination a possible explanation for high sulphate content in water if no natural source is obvious. Sulphates are mainly derived from the oxidation of pyrite in igneous and sedimentary terrains, and the dissolution of gysum and angydrite in sedimentary environments (Chavula and Mulwafu, 2007).

Phosphates enter water bodies from human and animal wastes, phosphate-rich rocks, waste from laundries, cleaning and industrial processes, and farm fertilizers. There are no standards available for recommended levels of phosphates for water in Malawi, but WHO set recommended levels of phosphates in water at 0.05 mg/l. Rainy season levels of phosphates ranged from 0.036±0.003 to 0.053±0.002 mg/l and dry season levels were between 0.005±0.002 and 0.068±0.002 mg/l. The source of phosphates could be from animal wastes considering the livestock watering practices observed and sanitary facilities available in the area.

Faecal coliform was used as an indicator of faecal pollution in water. In the rainy season, levels of faecal coliforms in the dams ranged from 600 to 2,300 counts per 100ml of the sample. Dry season levels of faecal coliforms ranged from 0 to 3000 counts (Table 14). Faecal coliform levels for both seasons exceed the guidelines of the Malawi Standards 214 and 733. There were significant differences ($p < 0.05$) in levels of faecal coliform between the rainy and dry seasons with the dry season being higher due to dilution during the rainy season. There were also significant differences in levels of faecal coliform between the sampling points ($p < 0.05$) with the dam inlets exhibiting higher levels of faecal coliform. These very high levels can be attributed to run off in the rainy season, disposing both cattle and human excreta into the dams, followed by concentration by evapo-transpiration in the dry season. The key informant interviews that were carried out in the study area revealed that cattle stop for a drink of water at the dams on their way to communal pastures. In addition there are limited sanitary facilities in the area, with people using bushes for toilets. The high levels of faecal coliform render the water unsuitable for drinking without prior treatment.

4.4.3 Levels iron, potassium and sodium

Iron is an essential element in human nutrition. Although iron has got little concern as a health hazard, it is still considered as a nuisance (stains clothes and plumbing) when available in excessive quantities (Berlan, 1980; Pederson and Vaultonburg 1996). The iron usually exists in water as dissolved Fe^{2+} species but gets oxidised to insoluble forms of Fe^{3+} upon contact with air. Levels of iron in the dams ranged from 0.02 ± 0.01 mg/l to 0.98 ± 0.01mg/l in the rainy season and from 0.06 ± 0.03 mg/l to 0.48 ± 0.016 in the dry season. Both seasons had iron levels within the guidelines of the Malawi Standards (Table 15). During sampling, red colour was observed at the inlet of Phazilamkango dam and at the outlet of Mandala dam (Figures 16 and 17). This red colour is presumably due to precipitated hydrous iron (III) oxide ($Fe(OH)_3$), formed after the oxidation of soluble iron in the iron (II) form:

$$4Fe^{2+}(aq) + 3O_2 + 6H_2O \longrightarrow 4Fe(OH)_3\,(s)$$

This oxidation is plausible at the pH conditions as long as the dams have an Eh value in the oxidation range (Eh > 0.2 volts) (Hem, 1985). The red colour affects water aesthetics and hence acceptability of the water for use.

Figure 16: Iron deposits at the inlet of Phazilamkango Dam.

Figure 17: Iron deposits at the outlet of Mandala Dam

Levels of potassium in the dams ranged from 0.21 ± 0.01 to 0.8 ± 0.01 mg/l in the rainy season and dry season ranges were from 0.2 ± 0.01 to 1.96 ± 0.12 mg/l. All the values are below those given in MS 214 (Table 15). The low levels of potassium in the dams are possibly due to low use of NPK fertilizers in the area. In drinking water, the concentration of Na^+ should not exceed 200 mg/l (Table 16). A sodium-restricted diet is recommended to patients suffering from hypertension or congenial heart diseases and also from kidney problems. For such people, extra intake of Na^+ through drinking water may prove critical (Holden 1971). The values of sodium in the earth dams ranged from 3.04 ± 0.1 mg/l to 10.1 ± 0.4 mg/l for both seasons and these levels are within the Malawi guidelines (100-200 mg/l for MS 214 and 500 mg/l for MS 733).

Table 14: Mean levels of Nitrates and Phosphates.

Dam	Parameters, *x* ± SD							
	Nitrates (mg/L)				**Phosphates (mg/L)**			
	Rainy season		**Dry Season**		**Rainy season**		**Dry Season**	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
Mandala	0.027± 0.004	0.016± 0.002	0.001± 0.00	0.001± 0.00	0.036± 0.003	0.053± 0.002	0.04± 0.02	0.02± 0.003
Gundamtengo	0.021± 0.002	0.009± 0.002	0.001± 0.00	0.001± 0.00	0.048± 0.003	0.05± 0.002	0.02± 0.005	0.01± 0.002
Nabvumi	0.165± 0.002	0.002± 0.001	0.001± 0.00	0.001± 0.00	0.047± 0.002	0.05± 0.002	0.023± 0.003	0.02± 0.002
Phazilamkango	0.006± 0.003	0.202± 0.003	0.001± 0.00	0.001± 0.00	0.049± 0.002	0.072± 0.003	0.045± 0.004	0.043± 0.003
Kakoma	0.127± 0.002	0.093± 0.003	0.001± 0.00	0.001± 0.00	0.039± 0.002	0.045± 0.002	0.009± 0.002	0.005± 0.002
Kamanzi	ND	ND	0.001± 0.00	0.001± 0.00	ND	ND	0.062± 0.003	0.068± 0.002
MS 214	6 – 10				NA			
MS 733	45				NA			

SD = standard deviation; ND = Not determined; NA = not available; x = mean (n =3)

Table 15: Mean levels of Sulphates and Faecal Coliforms

Dam	Sulphates (mg/L)				Feacal Coliforms (counts/100ml)			
	Rainy season		Dry Season		Rainy season		Dry Season	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
Mandala	20.6±0.59	16.2±0.4	23.3±0.35	22.2±0.25	20.6±0.59	1304±6.9	0	504±6
Gundamtengo	2.4±0.23	3.3±0.11	7.3±0.19	7.21±0.22	2.4±0.23	1155±5	48±7.6	252±4.9
Nabvumi	0.02±0.01	0.013±0.003	8.9±0.2	8.5±0.17	0.02±0.01	701±6.6	2996±5.77	903±5.8
Phazilamkango	2.6±0.1	6.2±0.18	14.1±0.3	14.4±0.23	2.6±0.1	1800±9.5	2251±6.1	1505±6.03
Kakoma	15.4±0.4	17.5±0.16	10.1±0.25	10.8±0.38	15.4±0.4	2248±7.6	1504±5	406±5.3
Kamanzi	ND	ND	11.7±0.28	14.7±0.14	ND	ND	552±6.4	1002±3.8
MS 214	200 - 400				0			
MS 733	800				50			

SD = standard deviation; ND = Not determined; NA = not available; x = mean (n =3)

Table 16: Mean levels of iron, potassium and sodium for the dry and rainy season

Dam	Parameters, x ± SD											
	Iron (mg/L)				Potassium (mg/L)				Sodium (mg/L)			
	Rainy season		Dry Season		Rainy season		Dry Season		Rainy season		Dry Season	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
Mandala	0.05± 0.02	0.98± 0.01	0.07± 0.003	0.06± 0.003	0.31± 0.02	0.21± 0.01	0.2± 0.02	0.2± 0.01	10.1± 0.4	9.03± 0.08	9.2± 0.32	8.4± 0.12
Gundamtengo	0.02± 0.01	0.12± 0.02	0.11± 0.02	0.095± 0.01	0.49± 0.02	0.3± 0.02	0.21± 0.01	0.2± 0.03	9.01± 0.1	9.02± 0.03	7.2± 0.09	7.1± 0.14
Nabvumi	0.03± 0.01	0.02± 0.02	0.09± 0.004	0.12± 0.005	0.61± 0.01	0.6± 0.02	0.59± 0.03	0.59± 0.05	5.03± 0.15	5.0± 0.08	3.04± 0.1	3.05± 0.17
Phazilamkango	0.11± 0.01	0.12± 0.01	0.31± 0.004	0.34± 0.008	0.41± 0.03	0.8± 0.01	1.9± 0.17	1.96± 0.12	5± 0.04	6.12± 0.15	6.57± 0.08	6.5± 0.16
Kakoma	0.42± 0.01	0.3± 0.03	0.22± 0.005	0.15± 0.004	0.4± 0.01	0.3± 0.03	0.41± 0.03	0.39± 0.03	7.98± 0.05	7.97± 0.04	9.6± 0.35	9.3± 0.05
Kamanzi	ND	ND	0.48± 0.016	0.29± 0.02	ND	ND	0.9± 0.03	1.02± 0.06	ND	ND	7.3± 0.14	7.9± 0.07
MS 214	0.01 – 0.2				25-50				100 - 200			
MS 733	3.00				NA				500			

SD = standard deviation; ND = Not determined; NA = not available; x = mean, n =3

Chapter 5: Conclusion and Recommendations

In this study, reliability of small earth dams in Traditional Authority Kalolo for domestic water use was evaluated using Flow Duration Curve analysis in conjunction with water quality assessments and rapid assessment of habitat integrity.

The FDC analysis showed inadequacy of the small earth dams under study in meeting water demand of the target rural community. Over 80% of the time, the small earth dams under study were unable to supply the required amounts of water for domestic purposes. Autocorrelation of flows for the dams were high, implying a great dependency between daily flows, typical of perched aquifers with minimal groundwater recharge from adjacent aquifers. In this study, dams in Kalolo were categorized as being perched aquifers, considering the *dambo* sites where the small earth dams were constructed. This therefore concludes that the dams under study do not get adequate groundwater recharge from adjacent aquifers but rely on surface flows.

Pattern of flows depict the dependency of the dams on surface flow since high flows are experienced in the rainy season and very low flows in the dry months. Considering the current environmental conditions in Malawi, rainfall season is only experienced within four months, from December to April, such that reservoirs that sorely depend on precipitation would not be able to meet their intended purposes like supplying adequate water to target rural communities for their domestic requirements.

Water quality assessments showed biological contamination as the major water quality problem. Turbidity, pH, colour, TDS, nitrates, phosphates, sulphates, iron, potassium and sodium were generally within safe limits when compared with the guidelines from the Malawi Standards that were used in this study. However, there was significant seasonal dependency, with the dry season having generally better biological water quality. In view of this, it would be recommended to treat the water from the dams before using it for any of the domestic water use categories identified.

During the study period, four of the nine dams in the area were not operational due to suspected dam location problems since the dams under study were perched on *dambos* with poorly drained soils and minimal recharge from adjacent aquifers. In addition, the study categorized the dams under study as moderately to largely modified through rapid assessment method implying considerable catchment degradation affecting water quality and quantities through run off. Uncontrolled anthropogenic activities taking place in the area such as river bank cultivation and livestock watering in the dams highly influenced the quality of water, as was evidenced by high levels of faecal coliforms in the dam water. However, some management of the small earth dams is carried out in form of clearing dam surroundings, observing by-laws that were put in place such as forbidding communities to bathe, wash clothes or water their livestock at the dam site.

In view of the results obtained in this study, the following implementing strategies in construction, utilization and general management of small earth dams are recommended.

- Further systematic and detailed studies of water availability and demand would be fundamental in improving access to potable water in Traditional Authority Kalolo and other areas within the same watershed in order to effectively apply a watershed management approach which is very crucial in the management of water resources, coupled with host communities assuming ownership of the resources. In addition, it may be imperative to study the impact that existing dams have on human health in Malawi considering the various health risks that are associated with existence of small earth dams in Africa.

- There is need for catchment rehabilitation and stabilization through planting suitable trees and grass to prevent sedimentation of water bodies resulting from soil erosion.

- Appropriate hydrological, geological, geographic, environmental, ecological and engineering studies need also be carried out to determine appropriate capacities and location of dams in the area. There is need for proper surveying of the dam sites, mapping and design specifications established to ensure that the built dams would be sustainable and be able to serve the intended purposes. Information on water requirements or demand is essential in designing water supply structures for both urban and rural populations.

- Controlled use of the dam through establishment and compliance to bye-laws is essential in order to ensure that the quality of water in the small earth dams is not compromised.

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APPENDICES

APPENDIX 1: CHECKLIST FOR KEY INFORMANT INTERVIEWS

- Number of beneficiary villages for each dam
- Brief history of construction of dam
- Availability of local institutions for management of water resources
- Current uses of dams
- Any bye-laws used to govern management of dams
- Categories of domestic water uses in the village
- Estimated quantities of water used for each category per household per day
- Available sources of water for the community
- Water treatment practices
- Land uses within catchment of dam
- Agricultural activities taking place:
    - chemical usage.
- Livestock management activities
    - Types and numbers of livestock kept.
- Any dam catchment conservation activities or efforts
- Major challenges faced pertaining to water availability and quality
- Perceived future water demands

APPENDIX 2: KEY INFORMANT INTERVIEWS SUMMARY RESULTS

Brief history of construction of dam

Dam	Year Constructed	Host Village	Other Beneficiary Villages
1. Mandala	2002 by CARE International	Mandala	Chinsindo, Matunduluzi, Kagona, Chasa, Mphoyo, Mndaula, Mphunda, Chibweza and Chamsanda.
2.Gundamtengo	2002 by CARE International	Gundamtengo	Chatimba, Chinthunzi, Jolofani, Gangire, Makanga, Funsamtima, Mneku, Kalata, Mwase, Eliya and Mphunda
3. Nabvumi	2003 by CARE International	Chingondo	Mkumba, Gezani, Chawantha, Mbuto, and Chivuta
4. Kamanzi	2002 by CARE International	Chawantha	Mbuto, Maliyana and Chino
5. Goliati	2002 by CARE International	Goliati	William, Mvuto, Masula, Chipanga, Katupa, Mchambo, Zikalenga, Andiseni, Mzingeni, Sagawa, Mchadza, Chimombo and Chipukwa
6. Phazi-lamkango	2001 by CARE International	Mchambo	Chipanga, Izeki, Chinkhombo, M'bang'ombe, Katupi, Mnera and Mzingeni
7. Kakoma (Privately owned)	2005 by Press Farming	Ng'omba	Dama, Laimu, Mawindo and Nsabwetayani
8. Kanyambwe	No dam, just potential dam site		
9. Katsumwa	No dam, just potential dam site		

- Surrounding communities were involved in the construction of dams (85%) except for the privately owned Kakoma Dam. Communities were paid in cash or in kind (maize, flour)

- **Local institutions available for management of water resources**:

  Dam Committee, Health Committee, Forestry Committee, and Water Point Committee.

- **By-laws used to govern management of dams**:

  No bathing, washing, livestock drinking in dam, regulated fishing, fishing using hooks - no nets, community policing, closed season.

Current uses of dams:

	Uses						
Dam	**Irrigation**	**Fishing**	**Livestock**	**Bathing**	**Washing**	**Drinking**	**Brick making**
1. Mandala	1	1	0	0	0	0	1
2.Gundamtengo	0	1	1	0	0	0	1
3. Nabvumi	1	1	1	1	0	1	1
4. Kamanzi	0	0	0	0	0	0	0
5. Goliati	0	0	1	0	0	0	0
6. Phazilamkango	0	0	1	0	0	0	0
7. Kakoma	1	1	0	1	1	0	0
8. Kanyambwe	0	0	0	0	0	0	0
9. Katsumwa	0	0	0	0	0	0	0

- **Categories of domestic water uses in the village:**
    - Drinking
    - Cooking
    - washing dishes
    - washing clothes
    - bathing
    - livestock watering

Quantity of water use per category per household per day (5 members per household).

Water use	**Average amount (litres)**
Drinking	**8**
Cooking	**23**
Washing dishes	**27**
Washing clothes	**33**
Bathing	**100**
Livestock watering	**20**

Available sources of water for the community

Dam	Number of Water sources			
	Boreholes	Protected wells	Unprotected wells	Others
1. Mandala	0	0	3	Dam
2.Gundamtengo	1	0	3	Dam, *Dambo*
3. Nabvumi	0	0	5	Dam
4. Goliati	1	0	0	*Dambo*
5. Phazilamkango	0	0	2	Borehole at Health centre
6. Kamanzi	1	1	0	Dam

- **Water treatment practices**
  - Health Surveillance Assistants provide chlorine (water guard) for treatment of water at home
  - Disinfecting wells.
  - Nabvumi – collect water from dam, boil and sieve the water for drinking.

- **Sanitary conditions**
  - Some people have no toilets – use bushes. Reasons: female headed households and mere laziness.
  - Rubbish pits available

- **Agricultural activities taking place (**chemical usage)
    - Not much chemical fertilizers used
    - Use goat manure to protect crops against pests

- **Livestock management activities**
    - Types and numbers of livestock kept.
    - Cattle, Goats, Pigs, Chicken

- **Any dam management activities or efforts**
    - Clearing dam surroundings

- **Major challenges faced pertaining to water availability and quality**
    - Experience water problems (low yield) in dry season especially for villages that rely on shallow wells as their major source of water supply.
    - Few water sources compared to populations
    - Some dams even dry up in dry season.

- **Perceived future water demands**
    - Need for hygienic sources of water
    - More boreholes

APPENDIX 3: LIST OF COMMUNITY MEMBERS INTERVIEWED

GVH Kanyambwe

GVH Chatimba

Martin Jimu

Chifuniro Matiyasi

Kenson Chomo

Loveness MacGerald

Maness Mavuto

Ellen Mainala

Lucy Higatoni

Aliness Mastala

Hazwell Austin

Chiyembekezo Totomoyo

Maclean Mandala

GVH Mchambo

GVH Mandala

Honaliya Jeke

Lemani Kabowa

Olipa Luka

Elita Zaliyo

Agness James

Lizineti Mandala

Memory Jailosi

Yesani Mtenje

Kaponda Chimphungu

Sara Loti

Annual Domestic Water Use in T/A Kalolo using Direct Method of assessing domestic use.

DAM	POPN	Consumption (L/c/day)	Human use (L/day)	livestock use (L/day)	Total Daily use (L/day)	Total Monthly use L/month)	Total Annual use(L/yr)	Water Use in m3/s
			Water use in Litres					
Mandala	1935	46	89010	4905	93915	2817450	33809400	0.391
Kamanzi	540	42	22680	1735	24415	732450	8789400	0.102
Gundamtengo	1290	34	43860	5313	49173	1475190	17702280	0.205
Nabvumi	1205	48	57840	2540	60380	1811400	21736800	0.252
Phazilamkango	875	41	35875	2008	37883	1136490	13637880	0.158
Goliati	1445	38	54910	7510	62420	1872600	22471200	0.260

Annual Domestic Water Use in T/A Kalolo using Indirect Method of assessing domestic use.

DAM	POPN	Mean Discharge (m3/sec)	Amount of Water use (m3/day)	Amount (L/day)	Livestock Consumption (L/day)	Total Water Use (L/day)	Total Water Use (L/year)	Water Use in m3/s
Mandala	1935	0.021	0.93	932.94	4905.0	5837.94	2130848.61	0.025
Kamanzi	540	0.062	9.92	9918.74	1735.0	11653.74	4253615.22	0.049
Gundamtengo	1290	0.072	4.82	4823.93	5313.0	10136.93	3699980.55	0.043
Nabvumi	1205	0.051	3.66	3657.24	2540.0	6197.24	2261991.27	0.026
Phazilamkango	875	0.004	0.41	407.61	2008.0	2415.61	881697.84	0.010
Goliati	1445	0.007	0.39	389.95	7510.0	7899.95	2883482.07	0.033

Estimated Evapo-transpiration (Ep) from catchment areas within T/A Kalolo

Dam	Evapo-trans piration (mm/y)	Evapo-trans piration (m/y)	Evapo-trans piration (m/s)	Catchment area (km^2)	Catchment area (m^2)	Evapo-transpiration per area (m^3/s)
Mandala	115.7613	0.1158	3.67077E-09	10.629	10629000	0.0390
Kamanzi	115.7613	0.1158	3.67077E-09	9.844	9844000	0.0361
Gundamtengo	115.7613	0.1158	3.67077E-09	10.144	10144000	0.0372
Nabvumi	115.7613	0.1158	3.67077E-09	8.099	8099000	0.0297
Phazilamkango	115.7613	0.1158	3.67077E-09	4.852	4852000	0.0178
Goliati	115.7613	0.1158	3.67077E-09	1.039	1039000	0.0038

APPENDIX 4: SUMMARY OF *P* VALUES FOR COMPARISON OF PARAMETERS

Summary of *p* Values for Comparison between Rainy and Dry Season

Parameter	*p* values for comparison between the inlet and outlet of dams									
	Rainy Season					Dry Season				
	Mandala	Gunda-mtengo	Nabvumi	Phazila-nkango	Kakoma	Mandala	Gunda-mtengo	Nabvumi	Phazila nkango	Kakoma
pH	0.763	0.0214	0.0022	0.88	0.0049	0.052	0.08	0.15	0.88	0.98
Turbidity	0.631	0.0061	0.13	0.0012	0.082	0.0002	0.25	0.015	0.0154	0.0002
TDS	0.011	0.19	0.0007	0.00004	0.000025	0.0001	0.0000004	0.0002	0.0324	0.0026
Colour	0.011	0.73	0.0072	0.0025	0.27	0.038	0.52	0.6495	0.0474	0.0015
Phosphates	0.0047	0.32	0.06	0.0013	0.019	0.31	0.04	0.3868	0.4240	0.033
Sulphates	0.0008	0.011	0.45	0.0001	0.0064	0.018	0.64	0.0417	0.2234	0.096
Nitrates	0.034	0.0015	0.00000004	0.0000001	0.0002	ND	ND	ND	ND	ND
Sodium	0.031	1.00	0.55	0.0036	0.81	0.0361	0.2642	0.96	0.39	0.25
Potassium	0.0062	0.0003	0.50	0.0005	0.020	0.8305	0.5942	0.92	0.77	0.52
Iron	0.0094	0.36	0.0013	0.034	0.0001	0.0094	0.3606	0.0013	0.03	0.0001
Feacal Coliform	0.00000004	0.000001	0.00004	0.0001	0.00000002	0.000048	0.000012	0.0000000002	0.00000001	0.000000001

Summary of *p* Values for Comparison between Inlet and Outlet Points in the same Season

Parameter	*p* values for comparison between the dry season and rainy season values									
	Inlet					Outlet				
	Mandala	Gunda-mtengo	Nabvumi	Phazila-nkango	Kakoma	Mandala	Gunda-mtengo	Nabvumi	Phazila-nkango	Kakoma
pH	0.0075	0.00003	0.208	0.0059	0.42	0.42	0.423	0.423	0.423	0.42
Turbidity	0.0010	0.0012	0.089	0.0012	0.0015	0.08	0.020	0.038	0.070	0.12
TDS	0.00031	0.00001	0.00008	0.00044	0.00062	0.0002	0.00038	0.00005	0.023	0.00037
Colour	0.0016	0.00046	0.0027	0.0028	0.0025	0.0009	0.00015	0.019	0.00076	0.00073
Phosphates	0.98	0.0032	0.00079	0.149	0.00012	0.0080	0.0026	0.00050	0.013	0.00007
Sulphates	0.0059	0.0023	0.00018	0.00026	0.00082	0.0026	0.00038	0.00014	0.00064	0.0021
Nitrates	0.0092	0.0035	0.00003	0.082	0.00008	0.0061	0.013	0.423	0.00005	0.00035
Sodium	0.00073	0.0041	0.0050	0.0020	0.011	0.028	0.0011	0.00129	0.206	0.0011
Potassium	0.045	0.0045	0.525	0.0055	0.80	0.423	0.0012	0.580	0.0044	0.0041
Iron	0.176	0.023	0.0039	0.00055	0.00002	0.00008	0.330	0.0154	0.0014	0.014
Feacal Coliform	0.00001	0.00004	0.00001	0.00040	0.00003	0.000002	0.00015	0.00005	0.00002	0.00029