Assessment of conjunctive use of small earth dams and boreholes for sustainable rural livelihoods in a semi-arid area: Case of Lilongwe West Rural Groundwater Project area, MALAWI


By

Dwight Davison Kambuku

A thesis submitted in partial fulfillment of the requirements for the Master of Science Degree in Integrated Water Resources Management

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DEPARTMENT OF CIVIL ENGINEERING
FACULTY OF ENGINEERING
UNIVERSITY OF ZIMBABWE

JUNE, 2009

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ABSTRACT

Semi-arid Africa is well known for its unpredictable rainfall patterns, increased cases of drought and dry spells, high evaporative demands and increasing population which put pressure on water resources. Local experiences in SADC show that conjunctive use of surface and groundwater would cushion these pressures. This study was aimed at assessing water demand and availability paradigms, and water allocation process as functions of conjunctive use of small earth dams and groundwater (shallow wells and boreholes) for small scale agriculture in the study area for a period beginning April, 2005. Assessment of conjunctive use of surface and groundwater for sustainable livelihood was carried out on 10 earth dams and 23 boreholes and 5 shallow wells of 22 villages in Traditional Authorities Kalolo and Khongoni in Lilongwe district in Malawi. Traditionally, shallow wells, ponds, running rivers, swamps or marshes have been supporting the rural masses and their livestock as sources of water for drinking, domestic use and small scale agriculture. It was revealed through focus group discussions and interviews that less than 28% of the households use water from dams and boreholes/shallow wells for small scale irrigation conjunctively while 30% of the total households use shallow wells as the main source of water for small scale irrigation. 11% of the total households use water from boreholes with 31% using water from small earth dams for small scale irrigation. Presently, villages surrounding Kamanzi dam experience water shortages 93% of the time in dry season, with supply meeting only 26% of demand. However, inclusion of water from boreholes to total supply helps the system meet 31% of demand. By 2039, the villages around Kamanzi dam will experience shortage about 100% of the time with supply meeting only 11% of demand. Village Development Committees (VDC) control water allocation process and customs and traditions form basis for this process. Water Poverty Index (WPI) showed that it is resource and use based and that conjunctive use of small earth dams has advantage on both environment and people's livelihoods in the area. It is thus recommended that conjunctive use of earth dams and boreholes/shallow wells be encouraged for small scale irrigation in order to curb resource depletion and maximize resource benefits for the betterment of local people.

Key words: Boreholes, conjunctive use, groundwater, reliability, small earth dams, sustainable livelihoods, water demand

DECLARATION

I, **DWIGHT DAVISON KAMBUKU**, hereinafter referred to as researcher, stand to declare that this thesis emanates from my own work and, in as far as I am aware, all secondary sources used have been duly acknowledged through references.

I also affirm that I have, hitherto, never submitted this thesis for an award of any other academic qualification at any other institution but for the Master of Science Degree in Integrated Water Resources Management tenable at the University of Zimbabwe.

SIGNED:…….…………………………………………..

DATE D: ……………………………………………...

DEDICATION

This thesis is heartily dedicated to my parents, future family, brothers and sisters for their present and anticipated moral and spiritual support.

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When things go wrong many of us would ask ‘why me?’ I asked ‘why me?’ when WaterNet Secretariat granted me full scholarship to study for this course. Not that I was better than those left out but because I saw God’s grace. Am grateful and will always be.

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ABBREVIATIONS

A	Area
AAR	Average Annual Rainfall
ADF	Average Daily Flow
BFI	Base Flow Index
CBM	Community Based Management
EI	Evaporation Index
EVAP	Evaporation
FAO	Food and Agriculture Organization
FDC	Flow Duration Curves
FGD	Focus Group Discussion
IWRM	Integrated Water Resources Management
MCDA	Multi-Criteria Decision Analysis
MoIWD	Ministry of Irrigation and Water Development
VGD	Village Group Discussion
WHT	Water Harvesting Techniques
WPI	Water Poverty Index
WUA	Water User Association
Y_{max}	Maximum Dry Season Yield

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

A semi-arid Africa is well known for its unpredictable rainfall patterns and increased cases of drought and dry spells that are usually coupled with high evaporative demands (Falkenmark and Rockstrom, 2004). These escalate the issues of water scarcity. Most of the countries falling under semi-arid region are developing countries. A lot of economic activities are taking place in these countries thus putting pressure on the available water resources (Swatuk, 2008). Deforestation, as a function within the poverty vicious matrix in the region, exacerbates issues of storm flow and hence reduce groundwater recharge, turning a relatively water rich region into one with seasonal water scarcity (Savenije, 1998).

One of the challenges facing semi-arid regions is growing population. NSO (2008), states that population in Malawi is to date pegged at 13.1 million with a population growth rate of 2.8% per year. FAOSTAT (2002) estimated the world population to be 9.5 billion by 2050. Water managers face the challenge of making available adequate quantities of water for drinking and to produce enough food for the growing human population and the malnutrition spectrum of the same population. Falkenmark and Rockstrom (2004) estimate that globally, there is a dietary water demand average of 1200m^3/person/year with about 1800m^3/person/year for developed countries and 850m^3/person/year for developing countries. These figures provide a measure of future water needs assessments and the actual water requirements by the agriculture sector (Molden et al, 2004). One of the measures to meet this rising demand of water is to conjunctively use surface and groundwater resources. This balances up issues of quantity and reduces chances of depletion that could occur if water resources were used singularly (Randell, 1999). Conjunctive use of water therefore means the integrated use of water from multiple sources. The goal of conjunctive use of water resources must be to improve the management of water resources and people's livelihoods in an area (Simpson, 2006).

However, literature reviewed for this research project shows insignificant evidence on water sectors in semi-arid region conjunctively using surface and groundwater to meet drought challenge. In Malawi, for example, there is only scanty data depicting conjunctive uses of surface and groundwater and their extent in both smaller and larger farm plots for longer term food requirements.

Studies in semi-arid Pakistan by Qureshi et al., (2004) indicated that conjunctive use of surface water and groundwater could almost double the water productivity and improve the livelihoods of small scale farmers. It would also reduce cases of competing water demands that occur due to increased economic activities, environmental needs and growing human population. According to Falkenmark and Rockstrom (2004), semi-arid SADC experiences lower evaporative demand in rainy season (November to March). This creates a runoff surplus potential which reduces infiltration and makes water harnessing in small and large dams alike, a viable and important water resource management option. Despite its long term cost effectiveness, groundwater is seldom used as an equally important source of water for irrigation in larger farm plots in the region (Shah et al., 2007).

The history of groundwater development in Malawi dates back to the early 1930s. By 1994, there were about 9 600 boreholes and 5 600 protected shallow wells, the majority of which were constructed by the government. However, since then the increase in boreholes drilled by the government, non-governmental organizations and the private sector has been dramatic, and according to the Ministry of Water Development there were about 19 000 boreholes drilled by 2001. This trend is continuing and the number of boreholes is continually increasing as a result of demand. Furthermore, due to the recent frequent occurrence of droughts, the number of hand-dug shallow wells has considerably decreased because they are highly vulnerable and prone to drying up, and therefore people have opted for boreholes instead of shallow wells. To date, Malawi has about 47,000 boreholes. These sources supply drinking water to about 60% of the rural population in Malawi. Very little amount (less than 3%) goes to small-scale irrigation. Most boreholes and wells are supplied by basement complex aquifers, which cover approximately 70% of the total land surface area which is about 118,484km^2. The groundwater-surface water relationship has vital bearing to the water use in the country. As reported by the Ministry of Irrigation and Water Development (2005), groundwater aquifers contribute between 15-35% of the total annual stream and river flow in Malawi and are the main supplier during the dry season.

1.2 Problem Statement

Notwithstanding the potential to use groundwater in the event reservoirs dry up for small scale irrigation, about half of the subsistence farmers in Malawi have a 6-month food deficit a year (Longwe and Peters, 2004) and there seems to be insignificant evidence if people conjunctively use surface and groundwater in Malawi and if the water resources available particularly in the study area are adequate to support their livelihoods.

With extreme high spatial and temporal variability of rainfall and increased cases of meteorological droughts and dry spells in semi-arid regions of the world, food production for human consumption is greatly compromised and reliability of water resources is perennially reduced (Falkenmark and Rockstrom, 2004). Failure to maximize benefits from water resources through conjunctive use in times of dwindling resources impacts on livelihoods of the people (De Wrachien and Fasso, 2006). Malawi in particular has experienced droughts associated with El Nino and the Southern Oscillation (ENSO) in 1948/49 and 1991/92, 1993/94, and 1997/98 seasons. Limited total water resources therefore pose a water resources management challenge to water managers. Conjunctive evaluation and use of surface and ground water while discussed by water professionals for decades remains largely an accepted but little implemented concept of balancing water demand and supply (Kennedy, 2004). In semi-arid SADC, there is little readily available documentation regarding extent of conjunctive use of surface and groundwater for sustainable rural livelihood. In Malawi, there is only scanty data depicting conjunctive uses of surface and groundwater and their extent in commercial and small-scale farming systems.

1.3 Justification

This research work was carried out to establish the level of conjunctive use of small earth dams and boreholes in the study area, evaluate the water availability versus demand situation and assess people's welfare associated with water; the findings of which would be presented for academic purposes and recommended to the Ministry of Irrigation and Water Development (MoIWD) for proper follow-ups since it is within the overall goal of the MoIWD to achieve sustainable and Integrated Water Resources Management (IWRM) and development that will make water readily available and equitably accessible to, and used by, all Malawians in pursuit of their human development and socio-economic advancement of the country's natural ecosystems, the outputs of which include increasing crop production by irrigation smallholder farmers (MoIWD 2001).

It was pertinent, however, to carry out this study because most parts of semi-arid SADC largely rely on a single source of water for commercial and small-scale farming systems (Foster et al., 2006), and as such, awareness about its risk need to be made. Over-reliance on a single source, for example, surface water subjects the resource to demand pressures and compromises its overall availability. Some natural forces also affect availability of the single resource. For example, Foster et al., (2006) argues that open water evaporation reduces firm yields of reservoirs, leading to water losses sometimes exceeding 20 percent of the average annual runoff. These losses are even higher when the width of the impounded valley is considerable, and induces a larger open water area unlike when the reservoirs are relatively small. Cases of soil erosion in a catchment result in siltation in the surface reservoirs and in the equivalent reduction of the storage capacity (Ashraf et al., 2007; Sibanda, 2002). Over abstraction of groundwater as a single source of water, at a rate higher than recharge in order to meet demands also threatens the sustainability of the resource (Danton et al., 2006).

Conjunctive use of surface and groundwater strives to strike a balance in harmoniously combining the use of both sources of water in order to minimize the undesirable physical, environmental and economical effects of each solution and to optimize the water demand/supply balance (Qureshi et al., 2004). It is reported that subsistence farmers are usually marginalized in the allocation of water from surface reservoirs (FAO, 2005) and usually if allocation is there, the process does not take into account groundwater resource.

While it is true that large-scale irrigation systems have been constructed in this region, their performance records indicate failure in regard to their anticipated benefit (Adams, 1992). As a result of the shortcomings of these large-scale systems, small-scale irrigation was subsequently advocated (Turner, 1994). Although recent focus has turned towards management and performance improvement, new small-scale irrigation projects continue to be promoted (FAO, 2006). Vincent (2003) recognizes the importance of these small, sometimes marginal, farmers in water management strategies and calls for a new approach that recognizes their importance.

There must be empowerment of small-scale farmers by giving them water through equitable and reliable water allocation process. This would curb food insecurity that sometimes occurs because of lack of water for crop production (Mugabe et al., 2003; Falkenmark and Rockstrom, 2004). It was imperative therefore that this study be carried out so that it bridges the data gap as to what extent conjunctive use of surface water and groundwater is and how it is promoting sustainable rural livelihoods in an area where its citizens have a 6 month food deficit a year (Longwe and Peters, 2004).

1.4 Objectives

1.4.1 Main Objective

The study was aimed at evaluating water demand and availability in small earth dams and boreholes, water allocation process and the conjunctive uses of small dams and groundwater (boreholes/shallow wells) and their extent in small scale irrigation in the study area since 2005.

1.4.2 Specific Objectives

The study specifically,

- Examined the yearly dry season water demand versus water availability situation of the study area
- Appraised whether water allocation process acknowledges both surface and groundwater sources
- Assessed quality of groundwater from wells and boreholes for irrigation in both wet and dry seasons as a conjunctive use function.
- Evaluated the economic and environmental benefits of using small earth dams and groundwater conjunctively for small scale irrigation as seen from users' welfare
- Developed conjunctive use strategy pointers for Malawi's Ministry of Irrigation and Water Development.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Background

There have been or are debates in the water resources management forums world over that the world's fresh water resources are unequally distributed both in time and in space. De Wrachien and Fasso (2006) state that nowadays there are signs that water resource availability is dwindling – due to both population growth and increased per capita water use and that ecosystems are being damaged in the process. They argue that in order to effectively face this challenge a new holistic approach which includes conjunctive use of surface and groundwater resources and takes account of social, economic and environmental factors is needed. This concept was first coined by Todd in 1959.

By 1982, proponents of the concept started distinguishing conjunctive use, one which deals with short-term use from the long-term discharging and recharging process known as the cycle storage (Lettenmaier and Burges, 1982). Up until the late fifties, planning for management and development of surface and groundwater were dealt with separately, as if they were unrelated systems.

2.2 The present

Although the adverse effects have long been evident, it is only in recent years that conjunctive use is being considered as an important water management practice. According to De Wrachien and Fasso (2006), conjunctive use of surface and groundwater implies the planned and coordinated management of surface and groundwater, in order to maximize the efficient use of total water resources. Because of the interrelationship existing between surface and groundwater, it is probable to store during critical periods the surplus of one to tide over the deficit of the other. Thus groundwater may be used to supplement surface water supplies, to cope with peak demands for municipal and irrigation purposes, or to meet deficits in years of low rainfall

(Randell, 1999). On the other hand, surplus surface water may be used in overdraft areas to increase the groundwater storage by artificial recharge (Danton et al., 2006). Besides, surface water, groundwater or both, depending on the surplus available, can be moved from water-plentiful to water-deficit areas through canals and other distribution systems. By and large, the integrated system, if correctly managed, is believed to yield more water at more economic rates than separately managed surface and groundwater systems (Garduño, et al., 2003; Danton et al., 2006 and The Water for Food Team, 2006).

The Food and Agriculture Organization of the United Nation (2006) acknowledges that water is essential for all socio-economic development and for maintaining healthy ecosystems and that as population and economic activities increase, the pressure on water resources is inevitable, leading to tensions, conflicts among users, and excessive pressure on the environment. This increasing stress on freshwater resources brought about by ever rising demand and profligate use, is of serious concern and therefore there is need for holistic approach to water resources management.

Application of conjunctive use concept in a wake of dwindling water resource availability and amid escalating water demand pressures as advocated for by De Wrachien and Fasso (2006) is been carried out in some parts of the world by proponent firms and organizations. The city of Bulawayo (Zimbabwe) has been practicing conjunctive use of water from dams and boreholes as a way of managing its water supplies. Groundwater is used during the times of water shortages in the dams to supplement supply to the city (Sibanda, 2002). Currently many residents in the city of Harare appear to be incorporating borehole water into their supply systems in order to cushion the intermittent surface water supply. In Indian State of Uttar Pradesh, the state faced a growing problem of rising groundwater levels in areas that were well-served by canals, and falling groundwater levels in areas not served by canals. There was general agreement among water professionals that conjunctive use of surface and groundwater was required to maximize crop production and stabilize groundwater levels. However, save the extensively availability of the technology and the exercise’s economic feasibility, governance arrangements did not support implementation. Several projects under the World Bank funded Water Sector Restructuring Project were/are directed at addressing these resource management issues, including consultancies for the institutional strengthening and restructuring of the Uttar Pradesh Irrigation

Department and the development of a decision support system for management of conjunctive use in the Ghaghra-Gomti basin (Danton et al., 2006).

In a semi-arid Venezuela, the Yacambu-Quibor Water Project initiated as long ago as 1973 was/is aimed at providing conjunctive use of surface and groundwater to avoid the depletion of groundwater resource which was the main source of water for irrigation for decades. By 2003 a program for a new Water Law incorporated conjunctive use recommendations as devised by the Project. To date, Yacambu-Quibor Water Project has become a model in its integrated approach to water resources management at national level and beyond (Garduño, et al., 2003).

In South Africa, polluted mine water is used to complement inputs from rainfall and stream flow. This approach is inherently conjunctive and this potential of irrigating with mine water is increasingly viewed favourably as a way of solving the twin problems of wastewater disposal from mines and shortage of irrigation water. Research led by the University of Kwa-Zulu Natal is continuing to assess the impact of scaling-up of mine wastewater on the volume and quality of surface and groundwater (The Water for Food Team, 2006).

In Malawi, private farmers particularly in the warm district of Salima use borehole water to irrigate or supplement irrigation of their orchards and annual crops. This exercise is more pronounced in dry season. However, national scale of conjunctive use of surface and groundwater is not well captured and documented (MoIWD, 2005).

2.3 Underlying Issues

Conjunctive use of surface and groundwater in semi-arid region and Malawi in particular is advocated for from most forums because of the issues that affect availability of the water resource. Some of the underlying issues in the region for conjunctive use to be deemed an important concept are as outlined;

2.3.1 Surface and groundwater sources

Literature provides that a single water source, surface water as separated from groundwater source is unreliable particularly in semi-arid Africa (Querish et al., 2004). The Food and Agriculture Organization (FAO, 2005), state that in most climates of the world, peak runoff corresponding to a significant part of the total discharge of rivers, occur during a particular season of the year which usually coincides with the smallest water demand. Water development therefore consists of transferring water from the high supply season to the high demand season, which is usually dry season. Surface reservoirs are a common solution to this problem. However, surface water resource has many drawbacks. Large open water areas are exposed, during several months and even years, to high evaporation rates leading to water losses sometimes exceeding 20 percent of the average annual runoff. This is particularly an issue in arid and semi-arid areas (Ashraf et al., 2007; Foster et al., 2006; Sibanda, 2002).

Soil erosion in most catchments results in siltation in the surface reservoirs and in the equivalent reduction of the storage capacity (Kamtukule, 2008). The soil vulnerability to erosion, and therefore the importance of the siltation problems in surface reservoirs, grow as the vegetation cover shrinks, so the more arid the climate, the less the vegetation cover, the higher the probability of sediment accumulation in the surface reservoirs (Chanson et al., 1998). Also, the environmental impact of surface reservoirs may often be highly undesirable for human health; flooding of inhabited or good agricultural land. Distribution of water from the reservoirs may be expensive and requires the construction of costly canals because of the distance between dam and utilization area.

In contrast, groundwater is not exposed to evaporation; does not suffer from reduction of storage capacity because of siltation; is seldom harmful to environment and offers a natural water distribution up to the users.

However, groundwater aquifers seldom offer large storage capacity able to absorb large volumes of flood in a short period of time, and are unable to return them as significant discharge per unit production system of well or borehole. Also surface water storage, because of the large investments involved, is often preferred because it offers a much higher political visibility and because high construction costs give an opportunity for private profit and corruption, opening the way for improper influence on decision making (McCartney, 2007).

The Water for Food Team (2006); Simpson (2006); Querish et al., (2004), and Prasad (1993), among others state that conjunctive use of surface and groundwater would harmonize the shortfalls of each source of water and thus minimize the undesirable physical, environmental and economical effects of each solution and to optimize the water demand/supply balance.

2.3.2 Water Scarcity

Literature shows that semi-arid Africa is a more water scarce region than temperate region (Savenije, 1998; Falkenmark and Rockstrom, 2004; Inocencio et al., 2003). Water scarcity as per definition is two-fold; physical and perceived. Physical water scarcity is determined by hydroclimatic factors such as rainfall and potential evaporation, and soil and vegetation factors that determine the partitioning of rainfall into blue and green water flows. Perceived water scarcity is feasibly related to human needs and demand for water (Savenije, 1998). Population pressure and socio-economic development increase the needs and demands for particular water flows, for example blue water for the city and green water for food production, (Falkenmark et al., 2004). Deforestation, as a direct result of demand and environmental squalor, can result in more storm flow and less groundwater recharge and may turn a relatively water rich region into one with seasonal water scarcity (Savenije 1998). This may therefore render the region and the people in it water insecure.

On a global scale, water scarcity is increasingly becoming an issue. Inocencio et al., (2003) stated that the physical water scarce countries like South Africa and region like North Africa may not have the adequate water resources to meet their projected water demands in 2025 and yet more than a quarter of the world's population will be living in this region. For economically water scarce countries, that potentially have enough water resources to meet their future demands, it might be difficult for them to additionally do investments to harness and use this resource (Hallowes et al., 2008). However, Kamara and Sally (2002) argued at 3rd WARFSA symposium in Tanzania that absolute scarcity is far unlikely in this region.

2.3.2a Meteorological Drought

Semi-arid region is also usually hit by meteorological droughts that stifle both blue and green water requirements of the region. Meteorological droughts occur when rainfall is 1-2 deviations below the long term average. According to Falkenmark and Rockstrom (2004), meteorological droughts occur when the cumulative rainfall over the growing season in a certain ecosystem is lower than the minimum green water requirement to sustain existing vegetation in that system throughout a growing cycle from seed to grain or fruit. Malawi in particular has experienced droughts associated with El Nino and the Southern Oscillation (ENSO) in 1948/49 and 1991/92, 1993/94, and 1997/98 seasons. However, Rockstrom (2000) states that meteorological droughts as naturally occurring phenomena should not cause alarm among the citizens as they can be managed since they seem to occur in natural cycles, often after consecutive years and hence can be predicted and mitigated. The fundamental ecohydrological challenge in dealing with this type of droughts in semi-arid region therefore, is to maximize ecological and social resilience to cope with them and to adopt land management strategies that reduce the occurrence of other forms of droughts, for example, agricultural droughts (Hallowes et al., 2008).

2.3.2b Agricultural and physiological droughts

Savenije (1998) argued that water availability in semi-arid region is also compromised by the human-induced droughts that usually occur when land degradation changes rainfall partitioning to the extent that the soil moisture available to plants drops below the minimum green water requirement to carry the plant through a whole growth cycle. The effect on the partitioning points in the water balance also heavily affects infiltration and hence groundwater recharge. Poor agricultural practices and general land management techniques aggravate soil erosion and consequentially affect partitioning points of the water balance (Rockstrom, 2000).

Water with high salinity is toxic to plants and poses a salinity hazard. Soils with high levels of total salinity are called saline soils. High concentrations of salt in the soil can result in a physiological drought condition. That is, even though the field appears to have plenty of moisture, the plants may wilt because the roots are unable to absorb the water (Fipps, 2003). These conditions compromise quantity of water 'available' for plants.

2.3.2c Dry spells

Apart from rainfall in most semi-arid areas being highly erratic, most of it falls as intensive convective storms with high rainfall intensity and extreme spatial and temporal rainfall variability. This results in high risk of intra-seasonal dry spells which are short periods of no rainfall, usually not more than 2-4 weeks long that cause water stress in plants and hence affecting growth (Savenije, 1998; Rockstrom, 2000; and Falkenmark and Rockstrom, 2004). The frequent occurrence of dry spells cause water scarcity and negatively affects crop yields (if it happens at a critical period of germination, flowering and yield formation) by close to 60% drop in crop yield (Molden et al., 2004) without necessarily causing reductions in seasonal or annual rainfall. In realization of this problem and in pursuit of reducing this vulnerability to dry spells, players in the water and agricultural sector are advocating for supplementary irrigation that may among other techniques, involve construction of smaller dams to harness water for this course (Qureshi et al., 2004).

2.3.3 Water Security

Debates on the need to have conjunctive use of surface and groundwater also try to justify that the concept may promote water security among citizens. According to van Hofwegen (2007), water security is the perception of having the possibility of being provided under varying circumstances with the needed quantity and quality of water and of being protected against the adverse and destructive effects water may bring. Water Security is usually pegged with the available resource potential in a competitive environment of multiple uses and users to satisfy basic human needs, to enable improvement of livelihoods, to warrant a healthy living environment and to pursue a sustainable social and economic development for generations. Water security has many dimensions and is perceived differently by various water users in different geo-socio economic locale. Beyond securing basic needs, water security is relative and is perceived differently by individuals, communities, industries, nations and societies to the level of being assured of access to the needed amounts and quality of water for their particular purposes (Hofwegen, 2007). A break in the water flow-stock virtuous cycle, be it by natural or human-induced, may create water scarcity condition. Schultz and Uhlenbrook (2007) argued that water scarcity heavily compromises the water security perception unto the people in every hit area. It profoundly affects the farming pattern and consequentially yields from the farms and hence deprives people of their right to access to the primal necessity - food.

2.3.4 Water for Rural Livelihoods

One of the underlying issues of conjunctive use of surface and groundwater is the need to provide water for rural livelihoods in developing countries. According to Vincent (2001), livelihoods are the means people secure necessities of life; to support themselves, to survive, and to prosper. They are an outcome of how and why people organize to transform the environment to meet their needs through technology, labor, power, knowledge, and social relations. Livelihoods are also shaped by the broader economic and political systems within which they operate.

Water is the essential element in rural livelihoods because of the food security and income options it generates in rain-fed and irrigated crop production, industry, domestic processing, aquaculture, livestock, recreation, navigation and transport, and electricity supply. Safe water and sanitation also shape health through potable water supply, safe food preparation, hygiene, better nutrition, and relaxation. Environmental security depends on peoples' actions to control salinity, drainage, and water pollution; manage droughts and floods; and manage land and water to guard those resources (FAO, 2005).

Unfortunately, most rural water supply programmes in semi-arid SADC tend to focus on only two social aspects that is improved access to domestic supply and improved sanitation. Less attention is given to how communities prefer to use water to sustain their livelihoods (Hallowes et al., 2008). Water for agriculture has for a long time not been considered a priority to most projects targeting rural citizens in developing countries. For example, Bie (2007), associate poverty to lack of productive use of water in Malawi which emanates from lack of adequate attention to water for agriculture in the remotest set up of the community.

Traditionally, shallow wells, ponds, running rivers, lakes, swamps or marshes have been supporting the rural masses and their livestock as sources of water for drinking, domestic use and small scale (household) vegetable gardening. Unless there is new action to recognize both the roles water plays in rural livelihoods and people's capacity to manage their water sustainably and with social justice, water scarcity threatens to change people's options in production, employment, and exchange, and the relations among these activities, in ways that will exclude the small producer (Hallowes et al., 2008).

As argued by Van de Giessen, (2007) and Chavula (2000), small earth dams contribute significantly to ensuring reliable domestic water supply, support small scale irrigation and regulate seasonal flows to provide reliable flow all year round. They at times directly support local and commercial community initiatives that guard against water scarcity due to droughts for small farmers to realize the ultimate goals of increased food production, reduced poverty and improved rural livelihoods.

Senzanje et al., (2006) report that people living in arid areas with highly variable rainfall, droughts and floods usually have insecure livelihoods. Small dams would therefore provide water storage and flood attenuations to the advantage of these citizens.

Small reservoirs play very important economic and non-economic roles especially for rural community livelihoods (Balazs, 2006; van Kinderen, 2006 and Chavula, 2000). In the presence of small dams, farmers can irrigate their crops even in dry season and thereby supporting a market oriented crop production. Balazs further states that small reservoirs can also provide a nutritional supplement to daily diets on the perspective of livelihoods well being. Small reservoirs also help to narrow the inequality gaps in accessing water by rural communities and that when the small reservoirs are unequally distributed, there is a problem of inequalities in as far as access to safe water is concerned. To what extent conjunctive use of surface and groundwater promotes sustainable rural livelihoods is an issue research has to establish (Shah, 2007; De Wrachien and Fasso, 2006; Zahid et al., 2006).

2.3.5 Conjunctive Use in IWRM context

The Integrated Water Resources Management (IWRM) paradigm also underscores the need to have well managed water resource systems to maximize potential of the resources, benefits of which should improve welfare of the citizens. The UN World Summit on Sustainable Development in Johannesburg, South Africa in September, 2002 re-affirmed the UN Millennium Development Goals of which Goal 1 seeks to eradicate extreme poverty and hunger. Target 1 seeks to halve between 1990 and 2015, the proportion of people whose income is less than US$ 1 a day. Target 3 seeks to halve, between 1990 and 2015, the proportion of people who suffer from hunger. Therefore water as a fundamental basis of all life sits in the middle of an equation to achieving this goal and IWRM is proving to be one of the tools to effectively realize this (Van der Zaag, 2008). No one can be lifted out of extreme poverty without adequate access to water (FAO, 2005). That is why Malawi has to date, included the IWRM principles into her policies and strategies.

The principles of IWRM include Economic efficiency, Equity and Environmental sustainability (GWP, 2000). Proponents of conjunctive use of surface and groundwater say this concept tries to augment surface water supply with groundwater or vice versa in order to mitigate the impacts of drought/dry spells and also try to balance supply with the ever-growing water demand. Augmented water supply through conjunctive use also addresses the issue of inequitable water allocation that usually favours commercial farmers in most parts of semi-arid SADC (Hallowes et al., 2008).

Conjunctive use as demonstrated in other countries, for example, Yacambu-Quibor in Venezuela provides a leeway in over-reliance on a single water resource (Garduño, et al., 2003). This over-reliance, say on groundwater alone, would lead to depletion of the resource since abstraction could be more than recharge. This would cripple calls for environmental sustainability. IWRM calls for integrated planning so that water, land and other resources are utilized in a sustainable manner. According to Global Water Partnership (GWP, 2000), IWRM is a process that promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. Requirements of IWRM therefore form an underlying core to employing conjunctive use of small dams and groundwater.

2.4 Conjunctive Use Challenges: The Future

De Wrachien and Fasso (2006) state that at the beginning of the twenty-first century, conjunctive use of surface and groundwater has come under pressure on a number of fronts. The expected demand for water exceeds available resources, plans fall short of targets, population is increasing, though growth rates are slowing down, and economic crises coupled with environmental concerns further complicate and exacerbate efforts to tackle these problems. The scientific and professional communities recognize the causes and effects of the problem. These, in turn, create a number of challenges, which the International Association of Hydrological Research (IAHR, 1999) summarized as rainfall-runoff processes, groundwater management, monitoring and remediation, conflict resolution in water management and water resource management under climate change.

2.4.1 Rainfall-Runoff Relationship

The International Association of Hydrological Research (IAHR, 1999) states that many physical and systems approaches to the study of rainfall-runoff processes which may be useful in understanding surface water contribution to conjunctive use concept have been proposed and evolved over the last decades. The choice of a particular approach still depends on the requirements of the problem, the data availability, the economic constraints and its systematic evaluations which may entail construction of an objective function, use of goodness-of-fit criterion, sensitivity and error analyses (Hoestra, 1998). The quality and performance of most approaches have improved but there is still room for further perfection (De Wrachien and Fasso, 2006). In calibration for example, parameter interdependence can be a problem, particularly when the model is physically based. Data quality affects both calibration and validation, introducing uncertainty to both model predictions and observed records for conjunctive use of surface water resource and groundwater. De Wrachien (1976) stated that comparison of model output to field data depends more on the quality of the data used than on the model mechanisms themselves.

De Wrachien and Fasso (2006) also state that sensitivity analysis and associated techniques such as error analysis deserve further attention. The criteria used for evaluation of model performance have also received little attention and remain often biased towards important components of the hydrologic records, such as peak discharge and event timing. Model mobility is often given little care. Most hydrologic models tend in fact to be site specific, and little work is usually done to assess the potential for application of a given model to a new site (Dodson, 1992; Mazvimavi, 2003). To this end, scale research in hydrology is deemed one of the most rewarding challenges to bridge the gap between theory and practice. All these categories represent areas of where further research is required and if surface water is to be of any importance in conjunctive use process, these issues must be addressed (De Wrachien and Fasso, 2006).

Presently, Rainfall-Runoff models provide a crude index of the available water resources from the average annual runoffs in a catchment. For example, a regional equation for calculating Mean Annual Runoff (MAR) based on data from 102 catchments for use in Malawi, Tanzania and Zimbabwe was developed by Bullock et al (1990). This equation is suitable for ungauged catchments and can be used for a research like the one at hand. It is provided as follows:

$$\mathrm{MAR} = 0.0000467\mathrm{AAR}^{2.204} \qquad \text{Equation 2.1}$$

Where *MAR* is mean annual runoff (mm) and *AAR* is average annual rainfall (mm).

Mazvimavi (2003) also developed a model for estimating runoff in an ungauged catchment as;

$$Q_{yr} = 0.393P_{yr} - 197.4 \qquad \text{Equation 2.2}$$

Where Q_{yr} is annual runoff and P_{yr} is average annual rainfall.

Comparatively, Hill and Kidd (1980) developed a non-linear relationship for estimating Mean Annual Rainfall from catchments that contain dambos. This relationship is given as follows:

$$\mathrm{MAR} = -92 + 0.16\mathrm{AAR} + 0.00018\mathrm{AAR}^2 - 640\mathrm{DAMBO} \qquad \text{Equation 2.3}$$

Where *DAMBO* is proportion of the catchment that is dambo, as determined from 1:50000 maps (takes value 0-1)

Jones (1988) devised a way of calculating Runoff coefficient, which gives the proportion of rainfall that is converted to runoff as:

$$C = \frac{MAR}{AAR} \qquad \text{Equation 2.4}$$

Where *C* is the Runoff coefficient

The measured flows can be validated by use of an equation as cited in Mamba (2007) which is as follows:

$$Q_{in} = R \times C \times CA \qquad \text{Equation 2.5}$$

Where *R* is total monthly rainfall in mm, *C* is catchment coefficient and *CA* is catchment area of reservoir in m^2. *MAR* is also used to determine how easily the reservoir in a particular catchment will fill by estimating the reservoir capacity as a proportion of the mean annual runoff, thus;

$$RV\,(\%) = \left\{\frac{RC}{MAR * A}\right\} * 0.1 \qquad \text{Equation 2.6}$$

Where *RV* = reservoir volume, a percentage of average annual runoff.

RC = reservoir capacity (m^3)

MAR = mean annual runoff (mm)

A = catchment area (km^2)

There are many ways of estimating storage capacities of small dams. There are direct and indirect methods of estimating reservoir capacities with direct methods grouped into two; quick and detailed methods (Saunyama, 2005). The direct methods include hydrographic surveys, and quick survey methods. However, if one is doing detailed analysis of the reservoir capacities like when studying sedimentation of reservoirs, these direct methods are not reliable as they provide inaccurate results most of the times. Saunyama (2005) therefore recommends detailed methods like Mid Area Method and Prismoidal Method. GIS and Remotely Sensed Surface Area methods are some of indirect methods that can be used in estimating reservoir capacities.

In the direct methods, however, the first step to estimating water available in a reservoir is to estimate the shape of that reservoir. This becomes easier for very small reservoirs but it is usually a difficult task since most reservoirs have irregular shapes (Saunyama, 2005).

Since most of semi-arid region experiences high evaporative demands (Falkenmark and Rockstrom, 2004), evaporation values or 'losses' are a critical parameter in reservoir capacity estimation. In order to do this, an assumption must be made that reservoirs have a storage-area relationship given as;

$$RA = cV^{0.667}$$ Equation 2.7

Where *RA* is surface area of the reservoir (m^2), *V* is volume of reservoir and *c* = constant. The constant c is derived from the area and volume of reservoir at full supply level. The open water evaporation 'loss' was calculated as:

$$EVAP = \frac{RA * E}{1000} * \frac{2}{3}$$ Equation 2.8

Where *EVAP* is the volume of water evaporated in a year (m^3), and E is the open water evaporation (mm).

Evaporation has therefore a strong bearing on sustainable yields of most reservoirs. As such, the most critical time regarding water availability and subsequent demand is dry season. Mitchell's method (1987) is one of the methods which are used to calculate dry season yields of reservoirs. This method is based on the four assumptions that reservoirs are full at the end of wet season, during the dry season, inflows into the reservoirs are negligible, draw-off and evaporation of water are at a constant rate and that reservoirs are non carry-over.

In order to use this method, the subsequent steps must be followed;

(a) Calculating Evaporation Index (EI)

$$EI = \frac{0.001\,(E_d * RA_{max})}{RC_{max}}$$ Equation 2.9

Where: E_d is evaporation over dry season (mm), RA_{max} is surface area of the reservoir at full supply level (m^2) and RC_{max} is full supply capacity of the reservoir (m^3)

(b) K-factor

$K = e^{-(0.9EI)}$ Equation 2.10

Where K is the parameter of variation between reservoir capacity, *(RC)* and reservoir surface area, *(RA)*

(c) Maximum dry season yield (Y_{max}) calculation:

$$Y_{max} = \left\{\frac{0.9K}{(1-K)} - 0.15\right\} * EI * RC_{max}$$ Equation 2.11

2.4.2 Groundwater Management, Monitoring and Remediation

Literature review shows that for groundwater to be a valuable component in conjunctive use process, some of the problems in groundwater management today like overexploitation, water table lowering, water deficit and pollution should be addressed (Randell, 1999). Improved land management, to increase groundwater replenishment by reducing evaporation and, where appropriate, runoff, also warrants investigation. Further problems are created by land subsidence due to overexploitation. Any groundwater management activity has to be based on an adequate and thorough field investigation, calling for improved methods in this area (Shah et al., 2007)

Accurate monitoring of the groundwater flow and quality, including estimated discharges and storage is also important (Sharma et al., 2006). Restoring the quality of polluted groundwater entails not only the elimination of pollution sources but also the remediation of contaminated groundwater in both the saturated and unsaturated zones (Zahid et al., 2006).

De Wrachien and Fasso (2006) state that there are tremendous uncertainties that plague groundwater pollution and remediation problems. Dynamic and stochastic simulation models of water flow and solute transport in saturated and unsaturated zones, combined with carefully selected field experiments, are crucial tools for proper assessment and management of groundwater contamination, and therefore need to be further improved if good quality groundwater is to be used as conjunctive use resource (Sharma et al., 2006).

Groundwater can naturally be susceptible to contamination by substances migrating from a pollution load that has been imposed on land surface (Sharma et al., 2006). This susceptibility strongly depends upon the features of the underground environment been affected by pollutants' migration, from the land surface down to the water table of the aquifer and, then eventually, to the boreholes or wells. An understanding of how vulnerable groundwater is to pollution in the area should therefore be established before formulation and adoption of conjunctive use of surface and groundwater resources (Shah, 2007).

2.4.3 Conflict resolution in water management

Water, an increasingly scarce resource, is already a source of conflict and likely to become even more so. Conflict is therefore a challenge that stalls progress to sound implementation of water resources strategies in most water management systems. To facilitate the solution of these problems an increasing number of states established permit programs to coordinate and control water resource allocations and withdrawals (Gopalakrishnan, et al., 2005). In this context, the water management agencies should be the river basins rather than national or regional administrative units (De Wrachien and Fasso, 2006).

Permit programs allow water management agencies to allocate water in a manner that reflects the state or regional values and mitigates transboundary impacts and conflicts. The first task in allocating water withdrawals is to determine and explicitly formulate the overall goals of the permit system and to establish permit rules that reflect those goals. In this context, scientists are faced with the challenge of developing suitable methodologies for emergency management and conflict resolution strategies. To this regard, simulation models linked with programming techniques for optimal management are crucial tools for proper planning and design of efficient and equitable integrated surface and groundwater use projects (Shah, et al., 2007; Sharma, et al., 2006 and Mhango et al., 1998).

Technology and expertise transfer from the scientific community to practitioners should be encouraged and enhanced. Decision makers also need to be able to recognize the potential of problem-solving measures, including emergency management and conflicts among different water uses and users. To this end, procedures for supporting negotiations for water allocation should be developed and tested for international, national or watershed applications. A methodological framework for comprehensive environmental risk and impact assessment also needs to be developed to assess environmental vulnerability and resilience before recommending any conjunctive use programmes (De Wrachien and Fasso, 2006).

2.4.4 Water Resource Management under Climate Change

The ongoing debate about climate change has raised questions about possible effects of such a change on the hydrologic environment. According to the Intergovernmental Panel on Climate Change (IPCC, 1996), the planet warming was projected to affect precipitation patterns, evapotranspiration rates, the timing and magnitude of runoff, the frequency and intensity of storms and, therefore, both the quality and quantity of surface and groundwater resources. In addition, temperature and precipitation changes were a probability to affect the water demands for agricultural, municipal and industrial purposes. Nijssen et al., (2001), affirm that on a global scale, the hydrological response predicted for most of the basins around the world, in response to global warming is a reduction in annual stream flow in the tropical and mid-latitudes. In contrast, high-latitude basins tend to show an increase in annual runoff, because most of the predicted increase in precipitation occurs during the winter, when the available energy is insufficient for an increase in evaporation. Instead, water is stored as snow and contributes in stream flow during the following melt period. Climate change is therefore a challenge that water managers have to bear in mind when planning and executing water resources programmes.

For example, by 1997, the degree of uncertainty on how climate change would impact on water resource systems remained significant and the adequacy of existing water planning principles and evaluation criteria in the light of these potential changes was unclear (Frederick et al., 1997).

Ragab et al., (2002) argue that uncertainties as to how the climate will change and how water resource planning and management systems have to adapt to these changes are issues that water authorities are compelled to cope with. The challenge is to identify short-term strategies to face long-term uncertainties. The main factors that will influence the worth of incorporating climate change into the process are the level of planning, there liability of the forecasting models, the hydrological conditions and the time horizon of the plan or the life of the project (IPCC, 1995). The development of a comprehensive approach that integrates all these factors into surface and groundwater resource use and planning systems, requires a better understanding of the processes governing climate change, the impacts of atmospheric carbon dioxide on vegetation and runoff, the effects of climate variables on crop water requirements and the impacts of climate on infrastructure performance (Ragab et al., 2002). So, research needs to be encouraged to improve the scientific knowledge about the relationships between climate patterns, land use and conjunctive use of surface and groundwater. This, in turn, will help water planners and managers to reassess operational principles currently being applied (De Wrachien and Fasso, 2006).

2.5 Concluding Remark

At all the debates that have been going around at the water forums, one thing still stands out; water resources are under pressure either due to meteorological factors, for example climate change or anthropological factors like increasing water demands and poor land use practices that accelerate silting up of surface water reservoirs . One of the holistic approaches to address this challenge is conjunctive use of surface and groundwater. This is believed to maximize the efficient use of total water resources. However, not much literature is readily available for the situation analysis of conjunctive use of surface and groundwater and the coping mechanisms employed by people in the event of inadequate total water resources in Malawi and most parts of semi-arid Africa. This research tried to do a situation analysis of water resources and subsequent conjunctive use of surface and groundwater in Lilongwe West Groundwater Project area in Malawi. The following chapter therefore provides background information to the research area.

CHAPTER THREE

3.0 BACKGROUND OF RESEARCH AREA

3.1 Location of Study Area

The assessment of conjunctive use of small dams and groundwater for sustainable rural livelihoods in a semi-arid area was conducted in the western part of Lilongwe rural (see Fig 3.1). It covers two traditional authorities (T/As) that is T/A Kalolo and T/A Khongoni with a band of ferruginous latosols type of soils. T/A Kalolo is about 590Km^2 in area while T/A Khongoni is about 415Km^2. Lilongwe district has a warm tropical climate typified by one rainy season of about five (5) months, lasting from November to April, and dry weather in the remaining months of the year. The district has Mean Annual Temperatures of about 20^o to 22.5^o C. The passage of the inter-tropical convergence zone, experienced between December and June, is the major rain-bearing system in the district (Malawi Government, 2006). Mean Annual rainfall (MAR) is from 800 mm to 1, 200 mm. Rainfall distribution is to a greater extent also influenced by orographic effects, with windward slopes receiving more than the leeward sides of hills or mountains, and areas with higher elevation receiving more rainfall than lower lying areas.

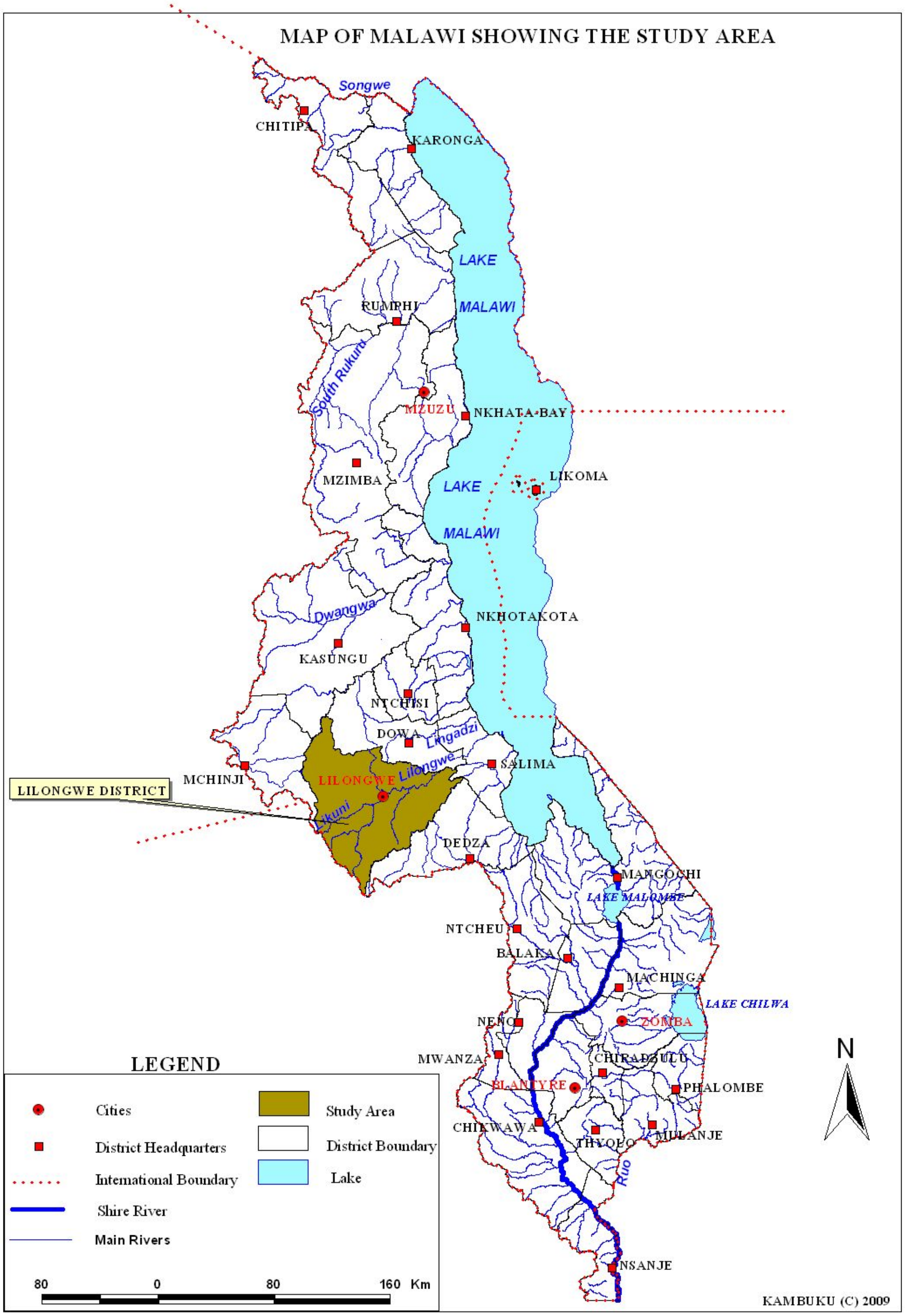

Fig 3.1: Map of Malawi showing Study Area

3.2 Population and its Socio-economic activities

T/A Kalolo and Khongoni have a population of 143,155 and 100,458 respectively (UNFPA, 2008) with an average population density of 215 people per square kilometre. About 70% of the population lives on less than US$2/day and with about 40% living on less than a dollar a day (Swatuk, 2008). Their main income generating activity is agriculture with corn and burley tobacco as the main crops. Corn is grown on an average farm piece of 0.5 ha for one family, giving average yield of 800 kg / ha and a monthly consumption of 70 kg per family. Half of the homes are usually in deficit diet for 6 months per year (Longwe and Peters, 2004).

The Malawi Government, like most governments in the region has enclave economy which makes it relatively difficult to invest in large water infrastructures for example large dams to harness water and meet the conflicting sectors' demands. Water productivity is low in the country due to inefficient farming practices, inadequate farm inputs and unreliable rainfall patterns (MoIWD, 2005).

3.3 Geology and Water Resources

Malawi Water Resources Management Policies and Strategies (MoIWD, 2001), spell out groundwater resources' occurrence in Malawi to be associated with three major aquifers; basement, alluvial and escarpment which can yield up to 3litres per second, 20litres per second and 12 litres per second respectively. The Lilongwe West Groundwater Supply Project area falls under the Precambrian weathered basement complex type of aquifers that yield up to 3 litres per second. However, report on some boreholes indicates yield of up to about 4 litres per second which is substantial to irrigate neighbouring small-scale farms but not much literature is available to show the extent of this use. On average, 1 litre/s yield can irrigate up to one hectare of land. Figure 3.2 shows sub-catchment of the study area, dams, boreholes and shallow wells.

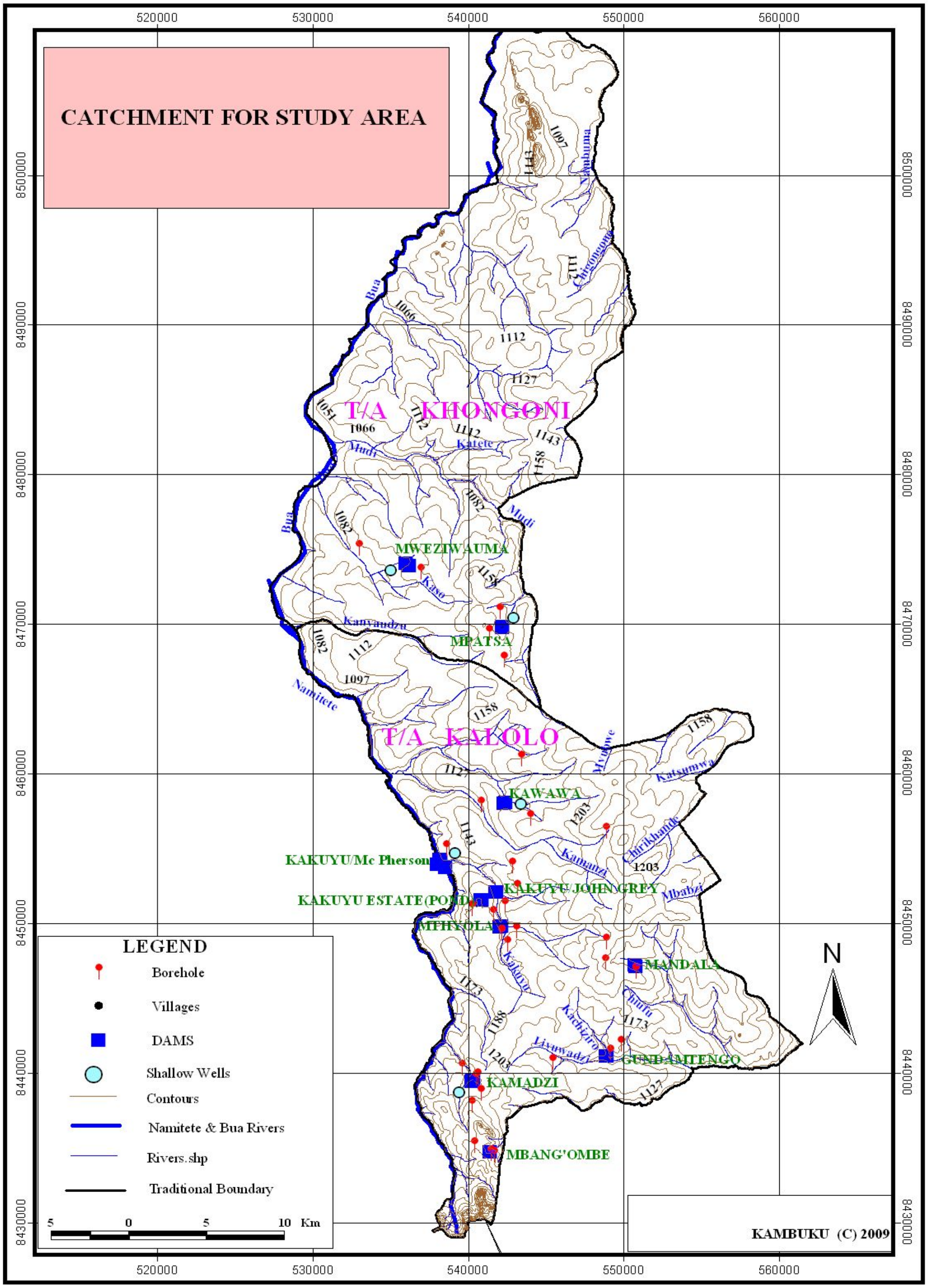

Fig 3.2: Catchment of the study area.

3.4. Dam classification

A dam (reservoir) is defined as any structure capable of diverting or holding back water. In Malawi, dams are classified based on either reservoir capacity or height (Kamtukule, 2008). Dams under study fall under very small dams' category. Table 3.1 below gives classification of dam sizes as reported by PEM Consult (1999), viz:

Table 3.1: Classification of Dams in Malawi

Size	**Reservoir Capacity (10^3 m3)**	**Height (m)**
Very small	<50	<4.5
Small	50-1000	4-8
Medium	1000-5000	8-15
Large	5000-20,000	15-30
Major	>20,000	>30

Adopted from PEM Consult (1999)

According to PEM Consult (1999), a very small dam in Malawi is any structure capable of diverting or storing water of less than $0.05Mm^3$ volume and whose height is less than 4.5m while a small dam is any structure capable of diverting or storing water of less than $1Mm^3$ volume and whose height is between 4 and 8m. Other countries lump very small dams into small dams as seen in Table 3.2 below:

Table 3.2: Classification of dams in some countries

Country/Organization	Unit	Dam/Reservoir Classification			
		Small	Medium	Large	Major
Malawi	$x10^6m^3$	<1	1 - 5	5-20	≥20
	Height (m)	<8	8-15	15-30	≥30
Zimbabwe	$x10^6m^3$	$<1x10^6$	$<1x10^6$-$3x10^6$	$3x10^6$-$20x10^6$	$\geq 20x10^6$
	Height (m)	<8	8-15	15-30	≥30
South Africa	$x10^6$ m^3	-	-	-	-
	Height (m)	5-12	12-30	≥30	-
United States of America *	$x10^6$ m^3	<0.123	0.123-5	≥5	-
	Height (m)	≤6	6-12	≥12	-
World Bank *	$x10^6$ m^3	-	-	-	-
	Height (m)	<15	-	≥15	-
World Commission on Dams *	$x10^6$ m^3	0.05-1	-	-	-
	Height (m)	<15	-	-	-

Adopted from *Saunyama (2005) and PEM Consult (1999).

3.5 Criteria for selecting this area

Lilongwe West Rural Groundwater Supply Project area that covers T/A Kalolo and Khongoni has a good distribution of boreholes (about 700 boreholes) and small dams (about 20). It is about 70Km from the capital city on the Lilongwe-Mchinji main road. It has economically challenged communities who live on less than US$1 a day (Longwe and Peters, 2004). Subsistence farmers in this area fail to have enough food for themselves for the whole year despite readily available water in some perennial rivers (for example Kamanzi River) of the area. It is one of the rural areas with the highest population densities of about 215 people per km^2 (NSO, 2008). Its Precambrian weathered basement complex aquifer makes it relatively easier to predict yields from boreholes. Figure 2.3 shows spatial distribution of earth dams, boreholes and shallow wells in the study area.

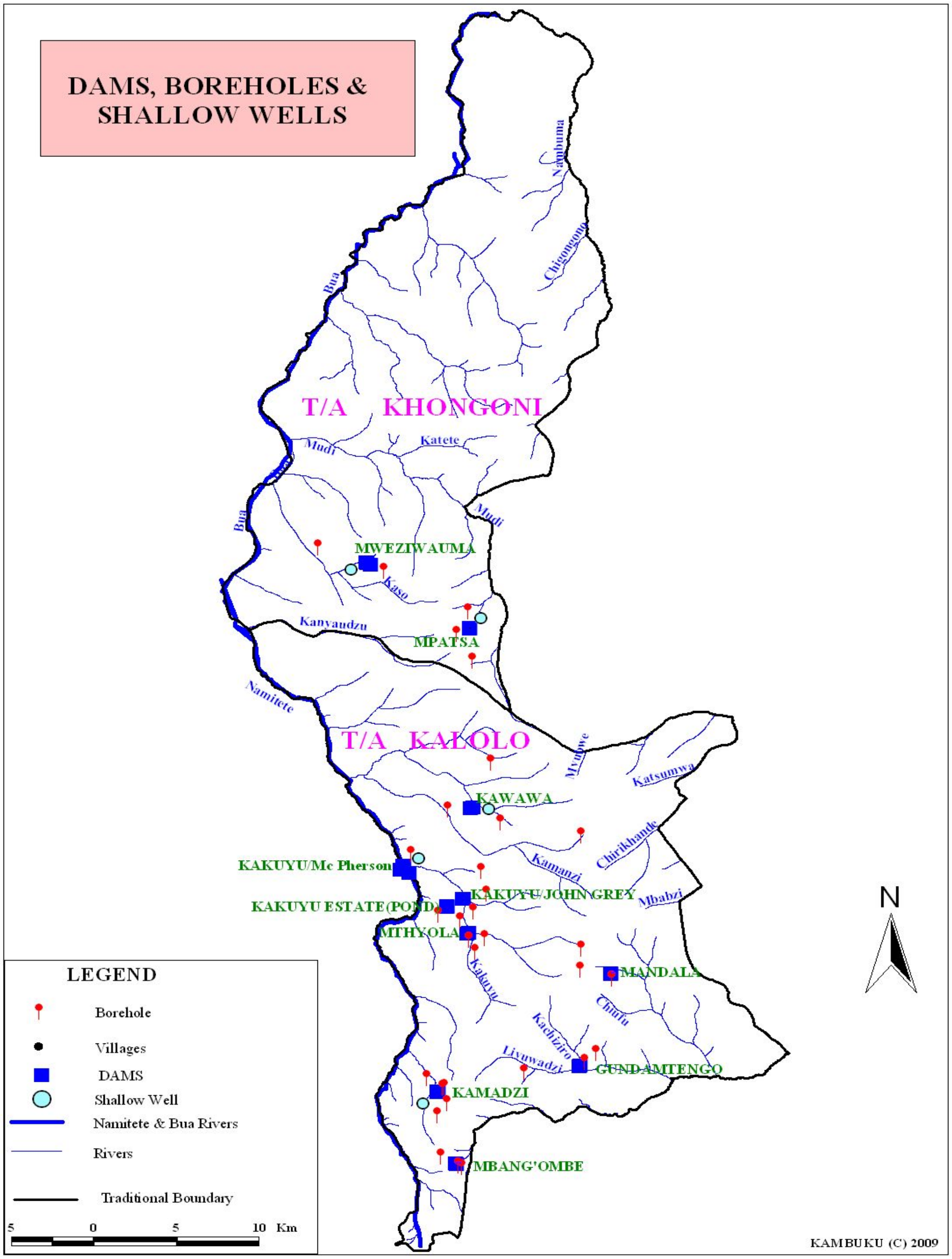

Fig 3.3: Dams, boreholes and shallow wells of interest in the study area

CHAPTER FOUR

4.0 METHODS AND MATERIALS

4.1.0 Research Design

The study employed systematic or purposive random sampling approach. 220 households (mostly those very close to the reservoirs) were purposively randomly selected out of 1636 households living within 0.5km radius from the reservoirs, giving about 14% representation of this total. 11 earth dams out of about 20 in the area were assessed, giving a 55% representation. These dams were then classified into two groups, one of those which dry up and the other of those that still hold water up to the next season. Kamanzi dam represented those that hold water all year round while Mweziwauma dam represented those that dry up. A total of 40 household were assessed in details from these dams. 28 out of 40 boreholes within 0.5km radius were selected, representing 70% coverage with 10 of the remaining at the furthest point of the radius. Methods were tied to each specific objective in order to achieve the intended results. Tests and physical measurements were also conducted on dams and boreholes.

4.1.1 Water Availability in the Catchment

Interviews were conducted on 40 households on available sources of water, their minimum domestic water requirement and their other uses of water. A 41 year Annual Rainfall data for the study area was obtained from Chitedze Research Station of the Meteorological department. Average Annual Rainfall (AAR) was therefore calculated by using:

$$AAR_K = \frac{\sum(\text{AAR from } 1968 - 2008)}{n}$$ Equation 4.1

where AAR_k is Average Annual Rainfall for the area and n is number of years.

Water available in the catchment was calculated as:

Water available = Annual Average Rainfall (m) x *Catchment Area* (m^2) Equation 4.2

Potential evaporation from the catchment was calculated as:

EVAP = Annual Open Water Evaporation (m) x *Catchment area* (m^2) Equation 4.3

4.1.2 Rainfall – Runoff Relationship

Equations 2.1 and 2.2 developed by Bullock et al, (1990) based on data from 102 catchments for use in Malawi, Tanzania and Zimbabwe and Mazvimavi (2003) respectively were used to determine the Mean annual runoff (mm) which was later used to validate the collected river flows from Surface water department. Average annual rainfall for 41 years was collected from Chitedze Weather Station of the Meteorological Department.

The MAR was used to estimate how easily the reservoir would fill by approximating the reservoir capacity as a proportion of the mean annual runoff using the equation 2.6.

The area surrounding M'bang'ombe, Gundamtengo, Mandala and Kamanzi dams was estimated from contour map to be about 13Km^2. Average daily flow (ADF) from this area was then calculated as;

$$ADF = MAR * \frac{A}{31600}$$

Equation 4.4

Where ADF is in m^3/s, MAR in mm and catchment area A is in km^2

The calculated ADF over time was also used to validate collected river flow data.

4.1.3 Reservoir Capacity

Quantification of the available water in the reservoirs was carried out using equation in Saunyama's (2005) postulation which states that reservoirs that have shapes of a pyramid and with dam wall acting as bases, their capacities can be calculated as:

$$C = \frac{(D * W * T)}{6}$$

Equation 4.5

Where D is depth of reservoir, W is width and T is throwback, a distance from dam wall to where river enters reservoir.

According to classification of dams given by PEM Consult, (1999), most of these reservoirs are very small and pyramidal in shape such that it was very easy to estimate their volumes as provided for by equation 4.5. The calculated reservoir volumes were validated using Simpson's Rule. Current dam depths were measured during a hydrographic survey exercise conducted from

22nd to 28th March and from 14^{th} to 18^{th} May 2009. 2 Staffs with a small flat bottom plate, 2 tape measures, a boat, 2, 200m tarpaulins, 1 panga knife, 2 mason hammers, floaters, 1, 4x4 vehicle, 2 technicians, 1 GPS and 2 labourers were used.

Evaporation was calculated using equation 2.8 while the maximum dry season yield was calculated using equation 2.11.

4.1.4 Population and Demand Projections

Data on domestic water requirement per capita per day was collected using questionnaires administered to 40 households around Kamanzi and Mweziwauma dams. Minimum domestic water requirement of 50L/capita/day, as set by Gleick (1996) was used as benchmark for comparison with what the villages use. Minimum green water requirement (based on crop water requirements to produce different food stuffs, the composition of different diets and the food needs for a nutritionally acceptable diet) of 2.33m^3 per capita per day in a poor semi-arid area as researched and reported by Falkenmark and Rockstrom, (2004) was used. Population growth was assumed to be an exponential function as below

$$P_t = P_0 e^{rt} \quad \text{Equation 4.6}$$

Where P_t is population at time t and P_0 is population at time 0. Population growth rate of 3.1% (NSO, 2008) was used from 2009 to 2019; 3.3% from 2020 to 2029 and 3.4% from 2030 to 2039.

4.1.5 Reliability of flows and reservoir storage

The system was modeled using WAFLEX package to examine the water demand versus water availability situation of the area. The Waflex Simulation Model is a water resources package with a monthly time step that can be used as a management tool in a catchment. It is a spreadsheet model that provides transparency and flexibility. The Waflex model has been developed to tackle problems such as the allocation of scarce resources like water. Its network functions are based on the equation of continuity and the fact that water flows from upstream to downstream. These network functions are relations between cells that can be copied to any location in the sheet to mould the network (de Groen, 2008). This spreadsheet model is accessible, easy to debug, cheap and widely available as a standard computer package.

Boreholes and shallow wells were modeled into WAFLEX package to evaluate their contribution to readily available water in the area. As an assessment tool, the zero scenarios (2009) with and without inclusion of boreholes were considered for Kamanzi and Mweziwauma dams. 2039 scenario with inclusion of boreholes was also assessed to see the general trend of readily available water resource for Kamanzi dam. Flow Duration Curves (FDCs) and Baseflows as output of AQUAPAK were also used to determine reliability of the water supply systems.

As a general purpose program, AQUAPAK software was used for hydrologic analysis of the Kamanzi and Mweziwauma River flows (Sinclair Knight Merz, 2008).

4.2 Appraising water allocation process as a conjunctive use function

Four (4) focus group discussions (FGDs) with village development committee (VDC), community based management team (CBM), and interviews with commercial farmers and small-scale farmers' households within a 0.5 km radius to these small earth dams on how water allocation process is done (or had been done) and if it considers both surface and groundwater sources were conducted. The collected data was analyzed using the Statistical Package for Social Sciences (SPSS).

4.3 Assessing quality of groundwater from wells and boreholes for irrigation as available water function

Desk study on the results of water quality tests carried out in dry season of 2007 on all boreholes in the area by Lilongwe West Rural Groundwater Supply Project was conducted. A total of 20 water quality parameters were analysed at The Central Water Laboratory which included pH, TDS, nitrates, sulphates, phosphates, iron, potassium, sodium, conductivity, salinity, sodium adsorption ratio (SAR) and faecal coliforms. pH was determined using a pH meter, Metrohm Model 744, in the range 0 to 14 (APHA, 1995), after calibration with buffers of pH 4.0 followed by pH 7.0. TDS was determined by evaporation (APHA, 1995). Nitrates, phosphates, sulphates and iron were determined by spectrophotometry (JENWAY 6405 UV/Visible spectrophotometer) (APHA 1995; AOAC, 1990). Na^+ and K^+ were determined using flame photometry (APHA, 1995). Faecal coliform counts in the water samples were determined using the Membrane Filtration Method as illustrated in APHA (1995).

The most influential water quality guideline on crop productivity however was the water salinity hazard, and it was measured by in-situ electrical conductivity (EC_w). According to Fipps (2003), the primary effect of high EC_w water on crop productivity is the inability of the plant to compete with ions in the soil solution for water (physiological drought). The higher the EC, the less water is available to plants, even though the soil may appear wet. Because plants can only transpire "pure" water, usable plant water in the soil solution decreases dramatically as EC increases. Comparison of this data and the collected in wet season was carried out see the seasonal variation of quality which could affect conjunctive use of small earth dams and groundwater.

4.4 Economic and environmental benefits of using small dams and groundwater as seen from users' welfare

Questionnaires, observatory assessment by the researcher and informal interviews were employed to assess the welfare of those households that have been using water from small earth dams and groundwater conjunctively for agriculture and those that have not.

Water Poverty Index (WPI) first developed in 2000, revised in 2002 and 2003 by Sullivan et al., (2003) as a composite, inter-disciplinary tool, linking indicators of water and human welfare to show the degree to which water scarcity (either anthropogenic or natural) impacts on human population was used. This index (which ranges from 0 to 100) as developed through pilot projects in South Africa, Tanzania and Sri-Lanka was reviewed and accepted by Blackwell Publishing (Oxford) in 2003 and was cited by the United Nations (UN) in the same year. Its weakness as provided by literature (Heidecke, 2006) is that data collected may be subject to local and institutional politics.

<u>Formula:</u>

$$WPI = \frac{(\sum_{i=1}^{N} WiXi)}{(\sum_{i=1}^{N} Wi)}$$

$$= \frac{(wrR + waA + wcC + wuU + weE)}{(wr + wa + wc + wu + we)}$$

Equation 4.7

Where R is resource, A is access, C capacity; U is use and E environmental Integrity. w is weight and X is component value.

Weights, w:

Weights applied according to the level of confidence demonstrated by respondents. Level of education of respondents and their involvement in water related matters were critical in generation of weights. These weights are dependent on judgment of the researcher. Since the study area shares the same socio-economic factors, for example population growth rate and education levels, geology and climate, same weights were generated for all villages under study.

4.5 Developing conjunctive use strategy pointers for Malawi's Ministry of Irrigation and Water Development

As a synthesizing approach, all data collected and analyzed as above helped in development of conjunctive use strategy pointers. The Multi-Criteria Decision Analysis (MCDA) tool as devised by Vazquez, (2003) was used to analyze these strategy pointers that may help government of the Republic of Malawi develop full strategies that could broadly support joint use of surface and groundwater in the wake of more demands, droughts and erratic rainfalls. Costing and unit values for the indicators were based on technical reports and budgets from the Ministry of Irrigation and Water Development. Using MCDA does not try to obtain the right answer but makes subjective judgments explicit and the process by which they are taken into account transparent, which is very important when a large number of actors are involved in the decision process.

CHAPTER FIVE

5.0 RESULTS AND DISCUSSION

5.1 Primary Use of Small Earth Dams and Boreholes/Shallow wells.

It was revealed through this study that in addition to using its water for domestic purposes, only three (3) of the 28 boreholes under study were also used for watering small gardens within their vicinity using watering canes. This was noted at Ching'anga, Dzuluwanda and Chinkhombo villages. The remaining twenty five (25) boreholes were used for domestic purposes only because the Village Development Committees (VDCs) responsible for management and maintenance of these boreholes do not allow any uses but domestic. This is in agreement with what the Ministry of Irrigation and Water Development reported in 2005 of low practice of conjunctive use of small earth dams and groundwater in most parts of the country. Water for piggery was reported at Gundamtengo and Kansengwa villages (about $4.7m^3$ and $5.3m^3$ per day respectively). This formed part of the green water requirements for the people as researched and reported by Falkenmark and Rockstrom, (2004). All the five shallow wells at Mweziwauma, Mpatsa, Kamchimba, Kamanzi and Kawawa villages investigated under this study had small scale irrigation and domestic uses as main water demands. All but Chisumphi borehole in T/A Khongoni (which has a very low yield of about 0.3L/s in dry season) have potential for multiple uses.

All the 22 villages under study benefitted either through irrigation, fishing or water for livestock from eleven (11) dams within their environs. M'bang'ombe, Mandala, Kamanzi, Kakuyu (John Grey), Kakuyu Estate, Mweziwauma, Gundamtengo and Mthyola dams are primarily used for irrigation. Kakuyu (Mc Pherson) is mainly used for irrigation and fishing. Mpatsa is used for fishing while Kawawa is for livestock and small scale irrigation see table 5.1.

Table 5.1: Primary Use(s) of Small Earth Dams under study

	Dam	Primary Use(s)	Comment
1	Kamanzi	Irrigation	Small scale livestock watering
2	Mandala	Irrigation	Potential for Livestock
3	Gundamtengo	Irrigation	Small scale livestock watering
4	M'bang'ombe	Irrigation	Small scale Fishing
5	Mthyola	Irrigation	Small scale Fishing
6	Kakuyu Estate	Irrigation	-
7	John Grey	Irrigation	-
8	Mc Pherson	Irrigation, Fishing and Livestock	Recreational
9	Kawawa	Irrigation and Livestock	-
10	Mweziwauma	Irrigation	Potential for Livestock
11	Mpatsa	Fishing and Groundwater Recharge	Nearby wells never dry up, all year round except drought time

5.2 WATER AVAILABILITY VERSUS DEMAND SCENARIOS

5.2.1. Water Availability at Catchment Level

Data collected from Chitedze Research Station (1968-2008) and application of equation 4.1 provides that the area has an average rainfall of 980.79mm per annum. Figures 5.1 and 5.2 below present the Monthly totals and annual average rainfalls for 2000-2008 and 1968-2008 respectively.

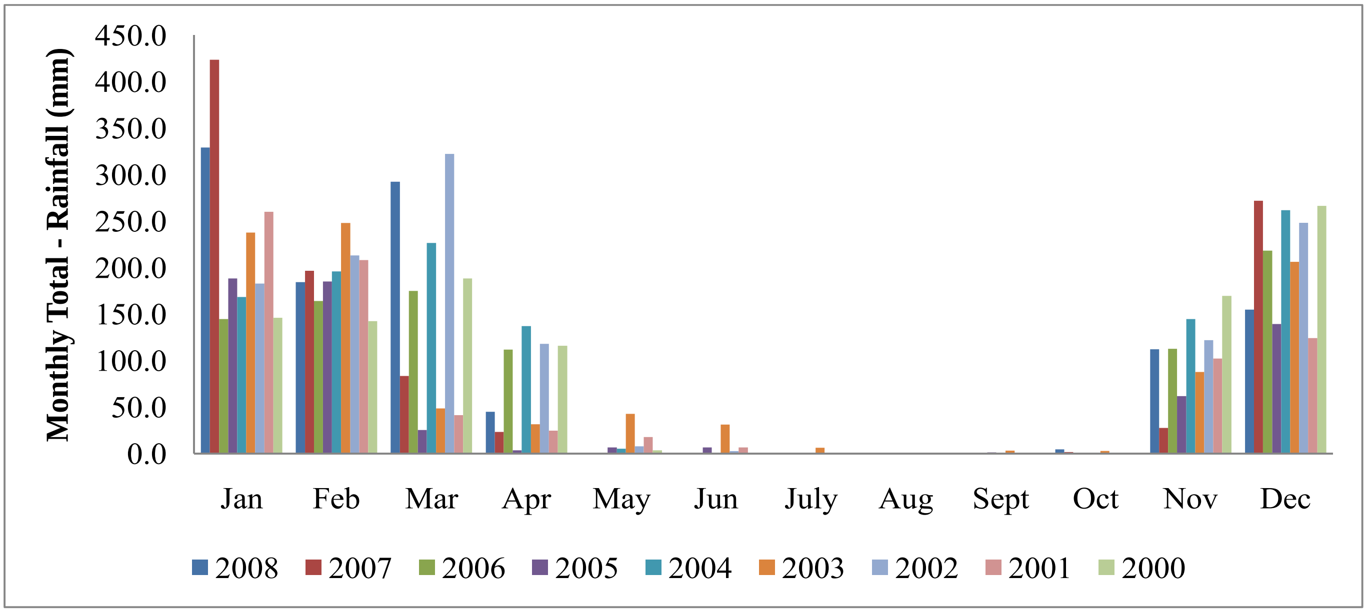

Fig 5.1: Monthly Total - Rainfall for the area (2000-2008)

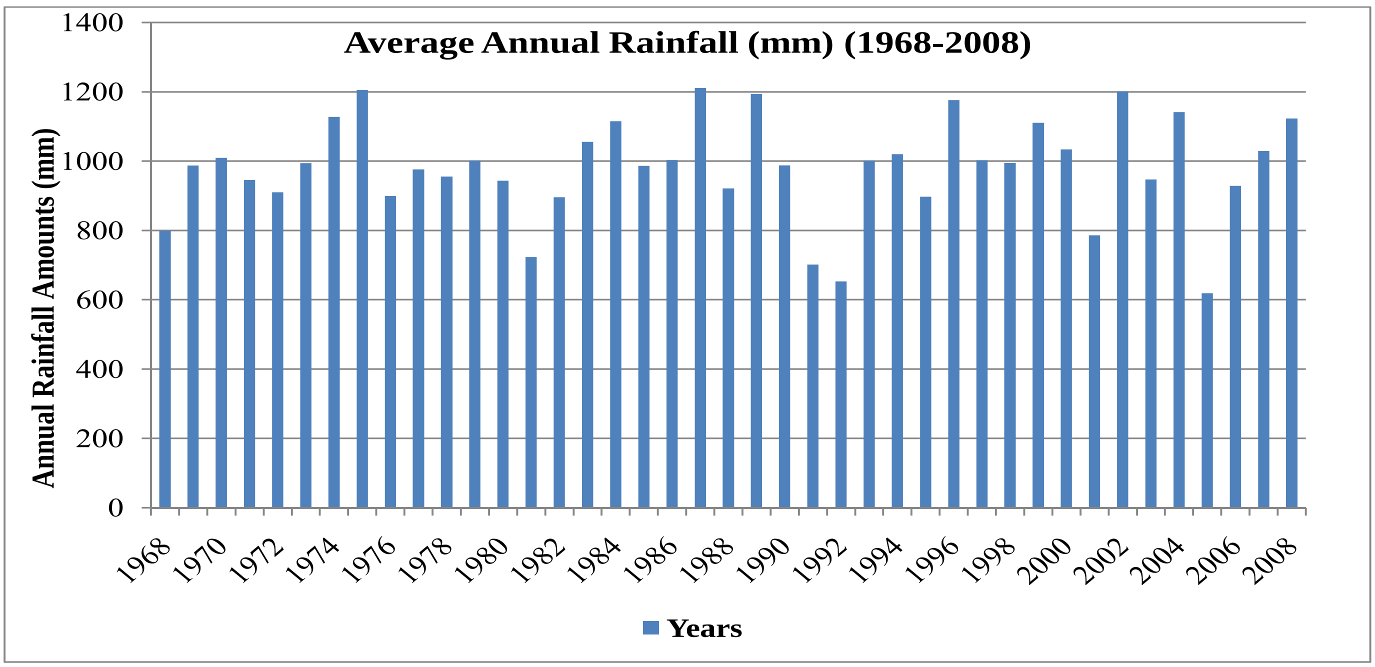

Fig 5.2: Average annual rainfall for the area (1968-2008)

Since over 90% of the dams were assessed from Traditional Authority Kalolo, area 590Km^2 for Kalolo was used. Water available in the catchment therefore was calculated using equation 4.2 and was found to be 578.7Mm^3 per year. Evaporation was calculated to be about 930.88Mm^3 per year which is higher than the annual rainfall.

The average annual open water evaporation as calculated from data collected from Chitedze Research Station is 1577.77mm with 982.9mm (about 62%) occurring in dry season (April – October for this study). This is in tandem with what Falkenmark and Rockstrom (2004) stated that semi-arid areas have high evaporative demands than temperate regions.

5.2.2 Reservoir Level

Water availability and water demand calculations of the catchment in this study was concentrated on the dry season (April – October) since this is the time when most subsistence farmers need water from reservoirs (and not rainfall) for small scale irrigation (Longwe and Peters, 2004). The study area had, by the time of conducting this research, no gauging stations for flow records on most rivers on which the earth dams were built.

Using equation 2.1, Mean Annual Runoff for T/A Kalolo (MAR_k) was found to be 183.13mm, 5mm less than what equation 2.2 by Mazvimavi (2003) gives. The MAR was used to estimate how easily the reservoir will fill by approximating the reservoir capacity as a proportion of the mean annual runoff using the equation 2.6. The catchment area supplying Kamanzi, Gundamtengo, M'bang'ombe and Mandala dams was estimated from a topographic map of scale 1:50,000 to be about 13Km^2. Reservoir Capacity for Kamanzi as of May, 2009 was measured through hydrographic surveys and was 5705m^3. Reservoir Volume as a percentage of MAR for Kamanzi dam was therefore calculated to be 0.24%. Mweziwauma dam had a 5 Km^2 catchment area and a capacity of 671m^3. Its Reservoir Volume (RV) was calculated to be 0.1% of MAR. This means that these reservoirs are very small and will therefore be easy to fill in the event of MAR of 183.12mm magnitude. However, it was noted that most of the reservoirs in this area were under heavy siltation as was also researched and reported by Kamtukule (2008).

Flow data collected by the Surface water division of the Ministry of Irrigation and Water development from January to April and then April to October 2008 on Kadyatsiru, Kamanzi, Mtsukanthanga, Phazilamkango and Mweziwauma rivers as part of dams assessment exercise, indicate that Kadyatsiru has an average of 20L/s, Kamanzi, 17L/s, Mtsukanthanga, 25L/s, Phazilamkango, 15L/s and Mweziwauma river has about 10L/s.

Results of the Correl (Pearson) correlation between rainfall and measured inflows showed a correlation of 0.543 at a significance of 0.041 ($p<0.05$). This means that the measured flows into the reservoirs were reliable and a reflection of catchment's rainfall regime.

Results of calculations of reservoir capacities MAR and Reservoir Volumes are presented in table 5.2 below:

Table 5.2: Calculated (Both dry and wet seasons), and Design Reservoir Volumes (RV) for all dams under study.

HYDROGRAPHIC SURVEY DATA FOR DAMS UNDER STUDY (14th -18th MAY, 2009)										
Dam	**Average Depth (m)**	**Area (m^2)**	**Calculated Volume (m^3) MAY, 2009**	**Current Full Capacity (m^3) MAR, 2009**	**Design Volumes (m^3)**	**Beneficiaries**	**Irrigation Technology**	**Average Annual Rainfall, AAR (mm)**	**Mean Annual Runoff, MAR (mm)**	**Reservoir Volume (%)**
Chipamphale/ Mweziwauma	1.5	450	671	2,382	3500	1,245	Treadle Pumps + Water cans	980.79	183.13	0.06
Dzuluwanda/ Mthyola	2.4	4,840	11,445	14,797	19,125	53	Treadle Pumps + Water cans	980.79	183.13	1.06
Gundamtengo	1.4	1,278	1,799	2,269	8,316	87	Furrow	980.79	183.13	0.17
Kawawa	1.8	1,097	1,937	2,658	4,000	170	Water can	980.79	183.13	0.18
Kakuyu Estate (Pond)	0.6	750	420	1,010	1,125	375	Sprinkler	980.79	183.13	0.04
M'bang'ombe	1.3	1,536	2,041	3,915	5,250	1,035	Treadle Pumps + Water cans	980.79	183.13	0.19
Mandala	1.6	1,689	2,734	3,466	5,250	1,500	Treadle Pumps + Water cans	980.79	183.13	0.25
Mpatsa	1.3	1,800	2,301	3,071	4,500	120	Water can	980.79	183.13	0.21
Mtete (Mc Pherson)	2.0	14,333	29,144	46,335	65,625	555	Sprinkler	980.79	183.13	2.70
Nabvumi/ Kamanzi	1.7	1,716	2,853	7,240	10,500	1,385	Treadle Pumps + Water cans	980.79	183.13	0.26
Kakuyu (John Grey)	1.0	639	619	854	2,000	700	Water can	980.79	183.13	0.06
		C = (D*W*T)/6 forpyramid-like dams except Kakuyu Estate								

5.2.3 Estimation of Average Daily Flow (ADF)

The sub-catchment area surrounding nearly located M'bang'ombe, Gundamtengo, Mandala and Kamanzi dams was estimated to be $13Km^2$. The Mean Annual Runoff (MAR) for the area is

183.13mm. The Average Daily Flow (ADF) was then calculated using equation 4.4 and was found to be 0.075m^3/s or 75L/s. This was a combined flow for all the four dams. The average for each dam was calculated to be 0.019m^3/s or 19L/s. This value does not depart much from the measured inflows for M'bang'ombe, Gundamtengo, Mandala and Kamanzi dams. Either method would therefore be used to determine flows into the dams. Measured inflows were preferred since they were specific to each dam.

5.2.4 Reliability of flows in the area

The flows into Kamanzi and Mweziwauma dams were plotted using AQUAPAK software. Descriptive statistics for the flow data from AQUAPAK indicate that Kamanzi River had the standard deviation of 1956.77, an average flow of 1480m^3/day and an auto correlation of 0.9977. Mweziwauma River had standard deviation of 1224.80, an average flow of 813.2m^3/day and an auto-correlation of 0.9962. The disparity between standard deviation and average flows portray a significant potential for drying up.

The stream flows for all the dams are highly auto-correlated, between 0.9962 and 0.9977. This means that daily flows are dependent on each other. According to Vogel & Fennessey (1995), stream flows with high auto-correlation usually have a larger base flow component. The autocorrelation figures for the dams suggest the presence of a large base flow component. According to the Ministry of Irrigation and Water Development Report (2005), this could be an indication that the dams are on perched aquifers with minimal groundwater recharge from adjacent aquifers. The soils with this behavior tend to drain poorly such that in instances of prolonged droughts or minimal precipitation, the dams are prone to complete dry up.

Fig 5.3 and 5.4 show the Flow Duration Curves for Kamanzi and Mweziwauma dams depicting the number of times the flows have been exceeded.

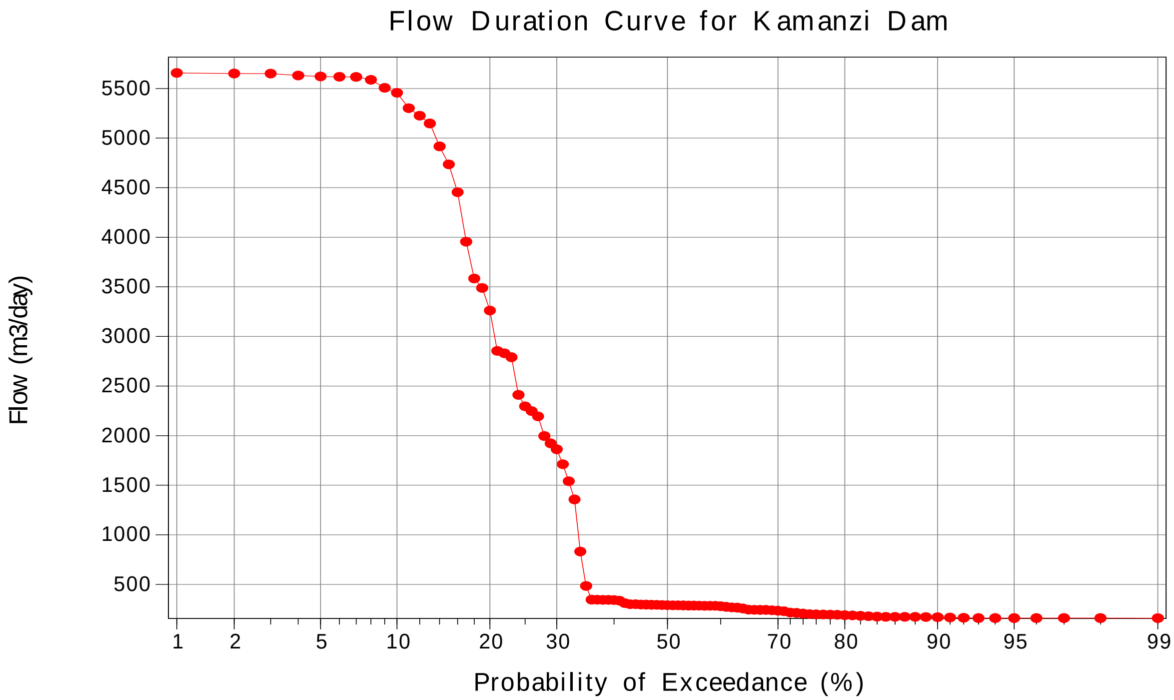

Fig 5.3: Flow Duration Curve for Kamanzi Dam (Inflow)

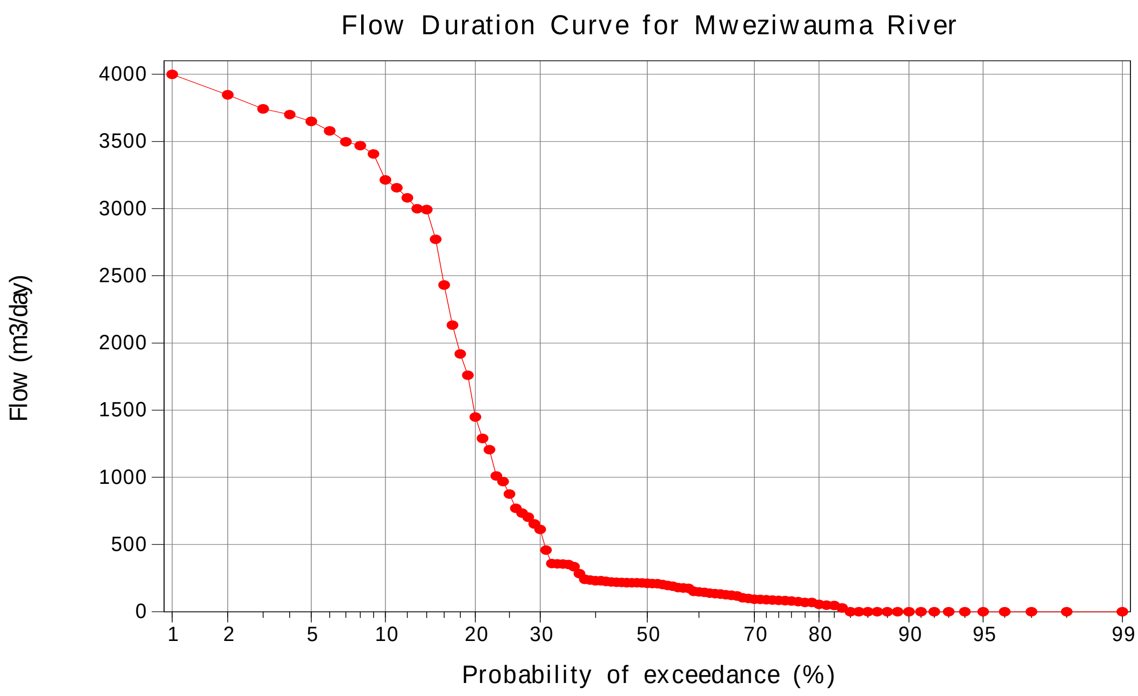

Fig 5.4: Flow Duration Curve for Mweziwauma Dam (Inflow)

According to Smakhtin (2001), Flow Duration Curves (FDCs) relate magnitude of the flows and its frequency of occurrence. Inflows for Kamanzi dam were measured in m^3 per day. FDC analysis is based on several critical indices such as the Q_{100}, which is the river's firm yield; the Q_{95}, the index of natural low flows or the environmental flow defines the upper threshold of abstraction (Dyson et al, 2003); the Q_{50}, an index of groundwater contribution to stream flow indicates hydrogeologic conditions. In this study, environmental flows were set at Q_{90}, in line with what Mhango and Joy, (1998) recommended for Malawi.

The firm yield Q_{100} for Kamanzi was 157m^3/day while Mweziwauma River had Q_{100} = 0.0 indicating that the river is ephemeral. Table 5.3 below provides percentile flows for the two rivers.

Table 5.3: Percentile flows for Kamanzi and Mweziwauma Dams

Dam/River	Q_{100}	Q_{95}	Q_{90}	Q_{80}	Q_{50}
Kamanzi (m^3/day)	157	160	170	189.91	290.65
Mweziwauma (m^3/day)	0	0	0	54	211

From these results, it is evident that Mweziwauma River is ephemeral while flows from Kamanzi River are not reliable since its mean flow (1224.8m^3/day) is not exceeded in 50% of the time and according to Smathkin (2001) all flows below the median flow (Q_{50}) are not reliable.

Fig 5.5 and Fig 5.6 below show baseflow components for the two rivers. It is indicative that the flows are mainly derived from groundwater.

As stated earlier on the auto-correlation results without significance levels by AQUAPAK (0.9977 and 0.9962) for Kamanzi and Mweziwauma dams respectively suggest presence of a large component of baseflow (Vogel & Fennessey (1995). This therefore indicates that in as much as baseflow component is bigger in dry months, its contribution is not good enough to make the flows reliable.

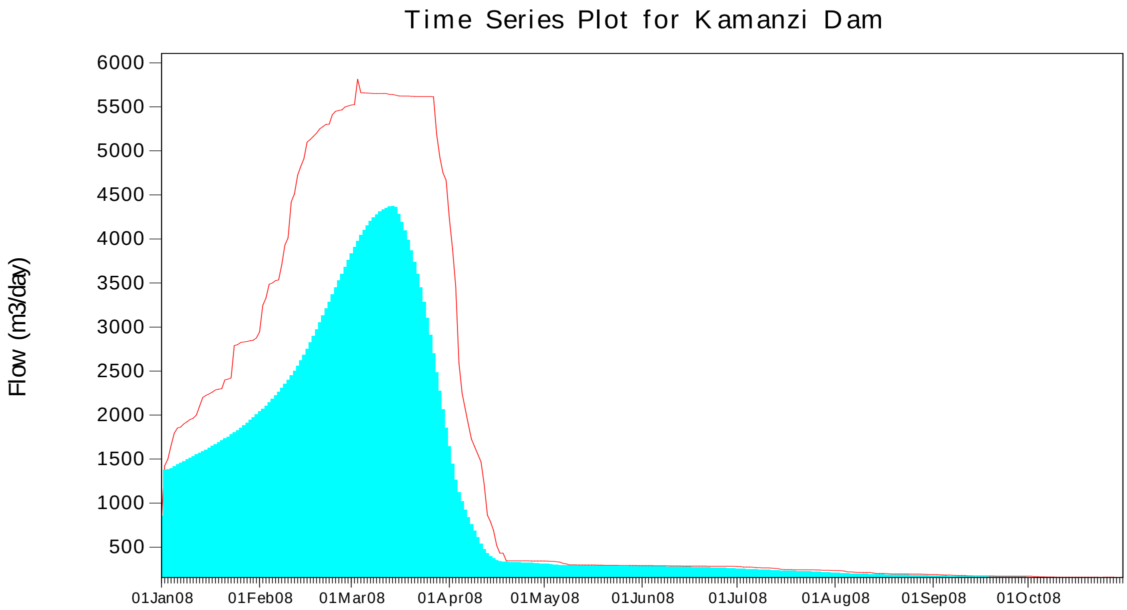

Fig 5.5: Baseflow Component for Kamanzi Dam

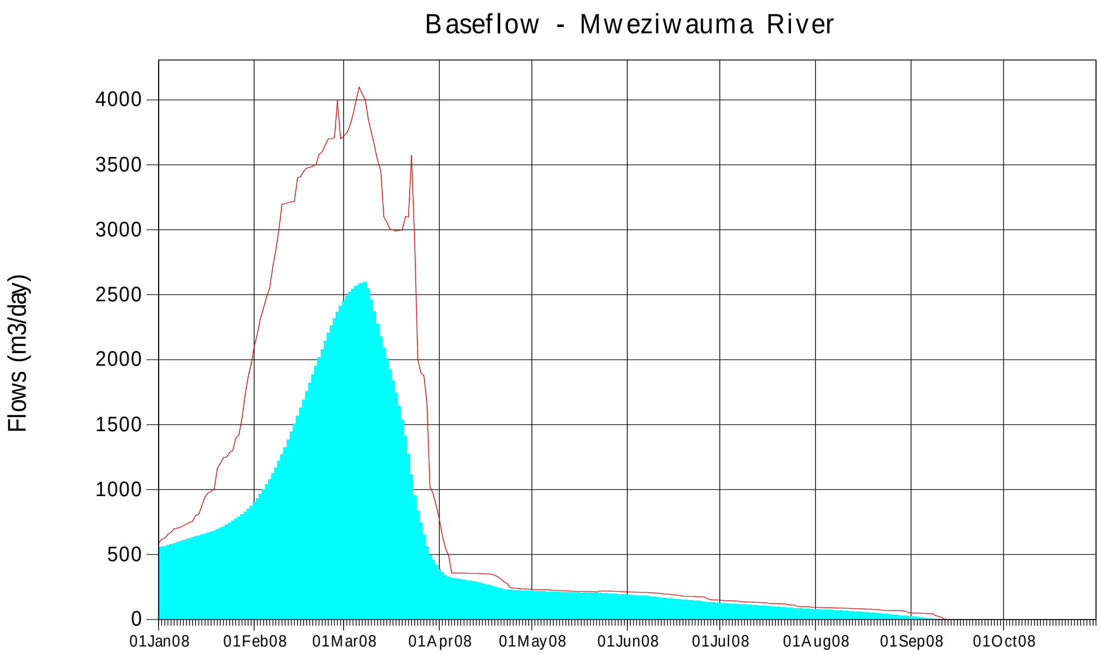

Fig 5.6: Baseflow Component for Mweziwauma Dam

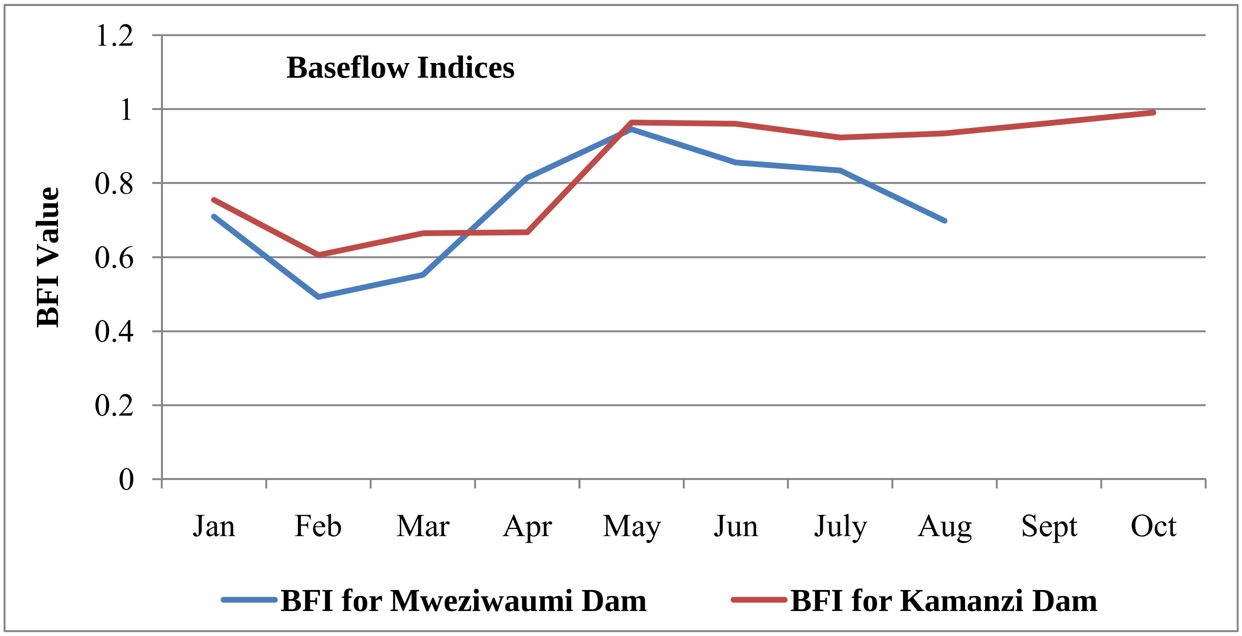

Fig 5.7: Baseflow Indices for Kamanzi and Mweziwauma Dams

The Baseflow trend as observed in the figure above is that the Baseflow Indices for the two dams increase as season moves away from the wet months. BFI for Mweziwauma starts decreasing from May since it is an ephemeral river. The trend as depicted above is suggestive of a perched type of aquifer which does not usually have recharge from the other nearby aquifers (MoIWD, 2005). It is pertinent therefore that further studies be carried out to check relationship of this type of aquifer to the baseflow components as indicated since this area is known to be underlain by Precambrian basement complex aquifer.

5.2.5 Reliability of Dams; farmers perspective

To farmers using these dams, reliability of the reservoir is its ability to have water all year round. 97% of the 20 households interviewed at Ching'anga, Utabwalero and Chisumphi villages that use water from Mweziwauma dam indicated that the reservoir is not reliable since it dries up beginning July end in a year of normal rainfall. 2% of the respondents said it was normal for the dam to dry up since even the river dries up in most part of the year. To them, the river is reliable since it follows a natural phenomenon. 1% did not know since they had no chance to use the water. 90% of the 20 households interviewed at Kamanzi village indicated that Kamanzi dam is reliable since it has water almost all year round. 9% of the respondents who live immediately downstream of the dam said it was not reliable since it were not releasing enough water for them in the river downstream. 1% of the respondents referred the matter to the chief saying they were not mandated to give comments on any subject affecting the village. According to Dyson et al., (2003) downstream flow usually set at Q_{95} percentile flow, should be adequate to sustain environmental needs and basic needs of those living downstream. However, Q_{95} for Mweziwauma and Kamanzi dams (0 m^3/day and 160m^3/day respectively) were not adequate to sustain the needs of those living downstream.

5.2.6 Estimating evaporation values for reservoirs

Since most of the semi-arid region has high evaporative demands (Falkenmark and Rockstrom, 2004) it was pertinent that evaporation from reservoirs be calculated so that actual reservoir storage can be known. The evaporation (E_d) over the dry season (April to October for this study) was found to be 982.9mm using data collected from Chitedze Research Station of the Meteorological Department (see appendix 5.2). Catchment evaporation was 1577.70mm. For reservoir evaporation, it was first assumed that reservoirs under study had a storage-area relationship. Equations 2.6 to 2.10 were used to calculate dry season yields of Kamanzi and Mweziwauma dams.

Constant, c for Kamanzi and Mweziwauma dams was calculated to be 9.32 and 7.83 respectively. Evaporation (EVAP) per year from Kamanzi and Mweziwauma dams was calculated to be 1978.16m^3 and 632.54m^3 respectively. It is evident therefore that evaporation is a major 'user' of the water in these reservoirs, that is 1978.16m^3 against reservoir volume of 2853m^3 for Kamanzi dam and 632.54m^3 against 671m^3 for Mweziwauma dam representing 69% and 94% use respectively. According to research conducted by Kamtukule (2008), siltation is a major cause of loss in reservoir capacities in Malawi. It is suggestive therefore that the reservoir capacities as of 2009 are not reliable enough to meet all the water demands. However, a further analysis of this situation was carried out by estimating dry season yield.

5.2.7 Estimation of Dry Season Yield

The study has revealed that the most critical time regarding water availability and subsequent demand is dry season. Dry season yield was estimated using equations 2.8 to 2.10.

Evaporation Indices (EI) for Kamanzi and Mweziwauma dams were found to be 0.475 and 0.578 respectively. The parameter of variation (K factor) between reservoir capacity, RC and reservoir surface area, RA for Kamanzi and Mweziwauma dams was calculated to be 0.652 and 0.594 respectively. Using equation 2.11, maximum dry season yield, Y_{max} for Kamanzi and Mweziwauma dams was found to be 5283.02m^3 and 1606.38m^3 respectively. Y_{max} for Mweziwauma Dam is higher than the dry season capacity that is 1606.38m^3 against 671m^3. It is suggestive that there is an element of leakage to groundwater aquifers. However, it is necessary that further studies be carried out to establish the source of this difference. Table 5.4 provides summary of calculated values.

Table 5.4: Summary of Calculated values

Dam	**E_d (mm)**	**C**	**EVAP (m^3/year)**	**EI**	**K**	**Y_{max} (m^3)**
Kamanzi	982.9	9.32	1978.16	0.475	0.652	5283.03
Mweziwauma	982.9	7.83	673.54	0.578	0.594	1606.38

The results also show that reservoir storage ratios (SR) ranged from 0.0026 for Mweziwauma to 0.003 for Kamanzi dams. This means that the catchments had underdeveloped water resources potential since according to Government of Zimbabwe (2000) very small storage ratios indicate underdevelopment of the resource while for storage ratios (SR) more than 2 but less than or equal to 3 is classified as developed.

5.2.8 Boreholes and Shallow Wells

Boreholes and shallow wells within 0.5Km radius of Kamanzi and Mweziwauma dams had satisfactory yields all year round. Data collected using a 20L bucket and a stop watch as of April 2009 showed that, Kamanzi, Mkumba, Gezani and Nabvumi boreholes had 1.0L/s, 0.6L/s, 1.4L/s and 3.4L/s against 0.9L/s, 0.5L/s, 1.2L/s and 3.3L/s in August 2007 as their yields respectively. Ching'anga, Utabwalero and Chisumphi boreholes had 0.7L/s, 0.7L/s and 0.5L/s against 0.8L/s, 0.2L/s and 0.3L/s in August 2007 respectively. Data collected from Groundwater Division of the Ministry of Irrigation and Water Development as of August 2007 is as given in table 5.5 below.

Table 5.5: Borehole/ Shallow well Yields (August 2007)

BOREHOLE/SHALLOW WELL YIELDS (AUGUST, 2007)							
Dam	**Dam Yield (m3/day)**	**Villages**	**Water Source**	**Yield (L/s)**	**Drawdown, s (m)**	**Specific capacity (m3/day/m)**	**Discharge/day (m3/day)**
		Chingondo	Borehole	0.5	8.6	5.0	**22.9**
Gundamtengo		Gundamtengo	Borehole	1.1	9.2	10.8	**52.9**
Kakuyu (Mc Pherson)		Kamchimba (East of Mc Pherson)	Borehole	2.1	9.0	19.8	**94.6**
		Agara Estate	Shallow well	1.3	12.0	8.7	**55.3**
Kakuyu Estate		Kakuyu Estate	Borehole	2.3	9.1	16.9	**81.5**
		Kalolo	Borehole	1.9	7.9	11.6	**48.6**
Kakuyu J. Grey		Kansengwa	Shallow well	1.5	11.8	9.6	**60.0**
		Kamanzi	Borehole	0.9	8.8	7.8	**36.4**
		Mkumba	Shallow well	0.5	20.1	2.5	**26.7**
		Gezani	Borehole	1.2	11.3	8.1	**48.5**
Kamanzi		Nabvumi	Borehole	3.3	8.6	33.4	**152.8**
Kawawa		Kawawa	Shallow well	0.5	20.1	2.5	**26.7**
Mandala		Mandala	Borehole	2.1	9.0	15.2	**72.5**
M'bang'ombe		M'bang'ombe	Borehole	1.3	13.9	9.4	**69.2**
Mthyola		Dzuluwanda	Borehole	1.7	7.9	10.5	**44.0**
		Khongoni Headquarters	Borehole	0.9	7.9	8.1	**33.9**
Mpatsa		Mpapa	Borehole	0.7	19.2	3.7	**37.2**
		Ching'anga	Borehole	0.8	9.0	7.4	**35.4**
		Utabwalero	Shallow well	0.2	11.0	5.3	**31.1**
Mweziwauma		Chisumphi	Borehole	0.3	21.0	2.1	**23.4**
		Mlera	Borehole	0.5	20.1	2.5	**26.7**
Phazilamkango		Chinkhombo	Borehole	1.1	9.2	10.8	**52.9**

98% of the households interviewed indicated that they use water from boreholes for domestic use since it is deemed of good quality.

5.3 WATER DEMAND

5.3.1 Domestic Use

Data collected through questionnaires averages the daily per capita domestic water demand for the study area at 27L/capita/day. Data collected from around Mthyola Dam, particularly Dzuluwanda village in Traditional Authority Kalolo indicated that people in this village use more water (about 40L/capita/day) for their domestic activities. Analysis has linked this to

Water, Sanitation and Hygiene (WASH) project being bankrolled in the area by UNICEF (Malawi). Mkumba village around Kamanzi dam has an average of about 35L/capita/day. Ching'anga, Utabwalero and Chisumphi villages surrounding Mweziwauma dam have an average domestic water demand of about 30L/capita/day. Mandala village that uses Mandala Dam reported the least usage of water for domestic purposes (26L/capita/day). This was attributed to lack of civic education on the importance of good hygiene and also lack of access to clean and safe water since the villagers still drink from unprotected shallow wells (See Appendix 5.5). A recommendation of 50L/capita/day as minimum domestic water requirement in semi-arid area as researched and reported by Gleick (1996) was used as a standard. Fig 5.8 below shows domestic water need per village.

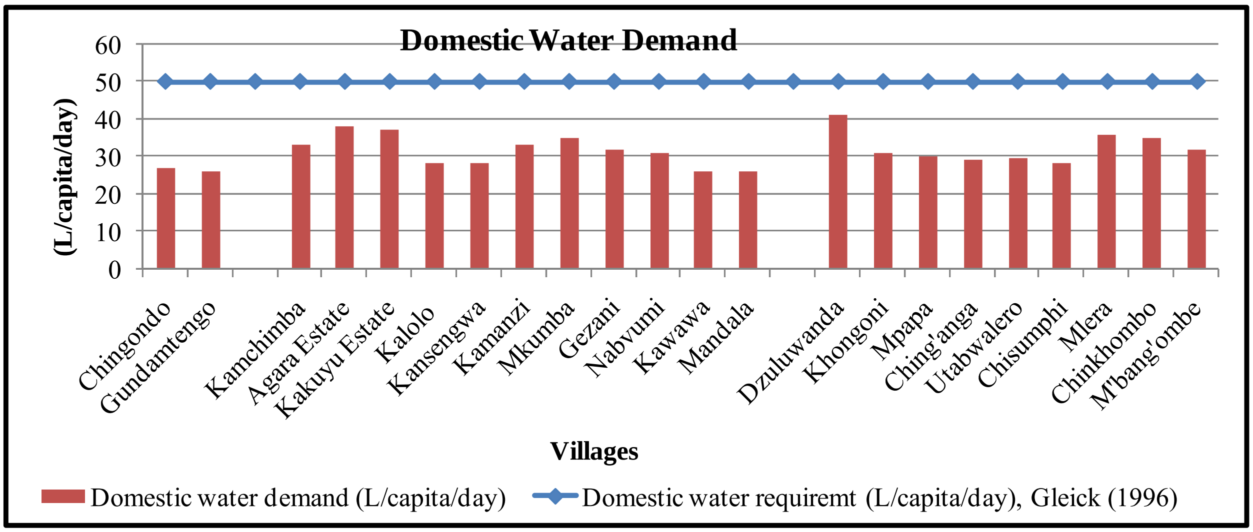

Fig 5.8: Average Daily per capita domestic water demand by village.

5.3.2 Green water Demand

Falkenmark and Rockstrom (2004) describe green water as water quantity required to produce food. Human green water requirement also includes the quantities of water needed to produce food for animals since these animals are part of man's food chain. Studies carried out in the study area in 2004 by Longwe et al showed that the populations of the study area usually have a six (6) month food deficit particularly in dry season. It was therefore assumed in this research that this population will need absolute green water requirement to meet this deficit. The total green water requirement for this period was assumed to be critical in dry season. Based on crop water requirements to produce different food stuffs, the composition of different diets and the food needs for a nutritionally acceptable diet, research by Falkenmark and Rockstrom (2004) set an average green water requirement of 2.33m^3/capita/day for most developing semi-arid countries. However, the desired green water is estimated to be 3.56m^3/capita/day. Daily green water requirement per village as a function of population were computed and results are presented as below:

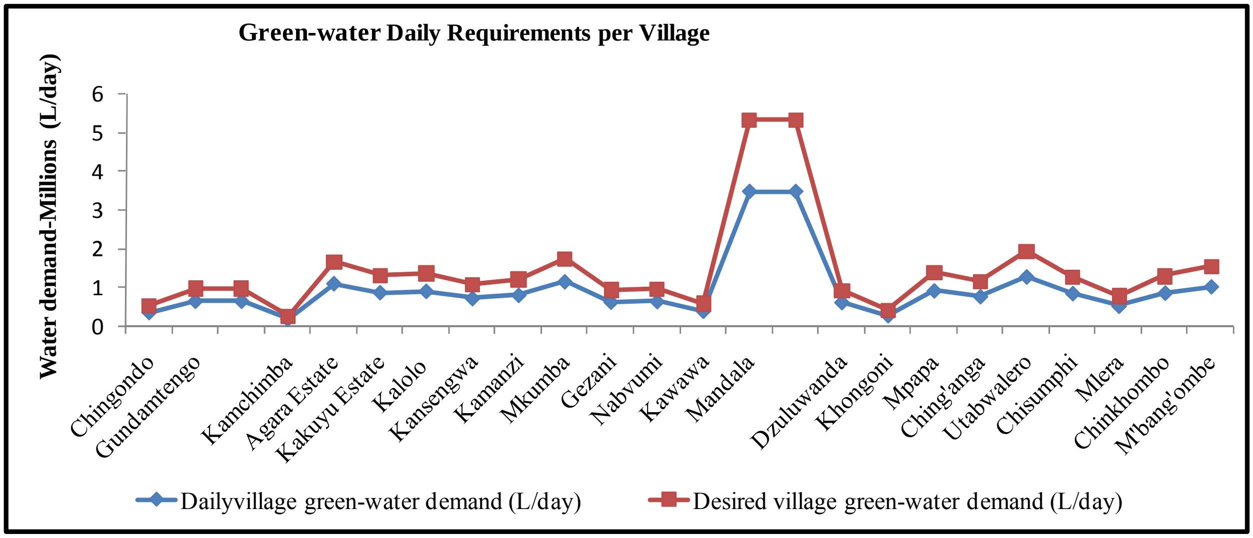

Fig 5.9: Actual versus desired green water demand.

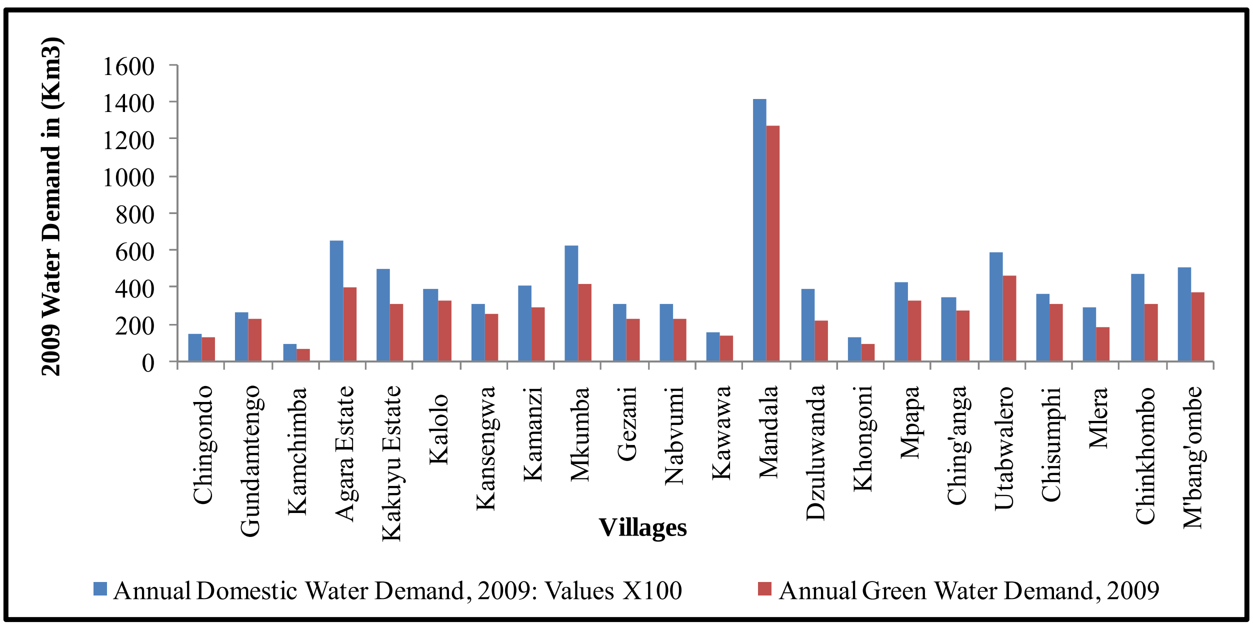

Fig 5.10: 2009 Annual Domestic and Green water demand.

Annual domestic and green water demand is, among other variables like health of citizens, dependent on population of each village. For example, Mandala is the most populous village and it has the highest demands (about 14Km^3 domestic and 1,275Km^3 for green water).

5.4 Future Water Needs

Future water demand was estimated by projecting the current water demands exponentially, assuming an exponential pattern of population growth as in equation 4.6.

5.4.1 Population

Since water demand projections depend heavily on population of the areas, it was imperative that population projections be made. The 1998-2008 Inter-censual population growth rate for Lilongwe Rural was 3.1% (NSO, 2008) hence *r* was set to at 3.1% from now to 2019. The figure below depicts trend of population growth rate since 1966.

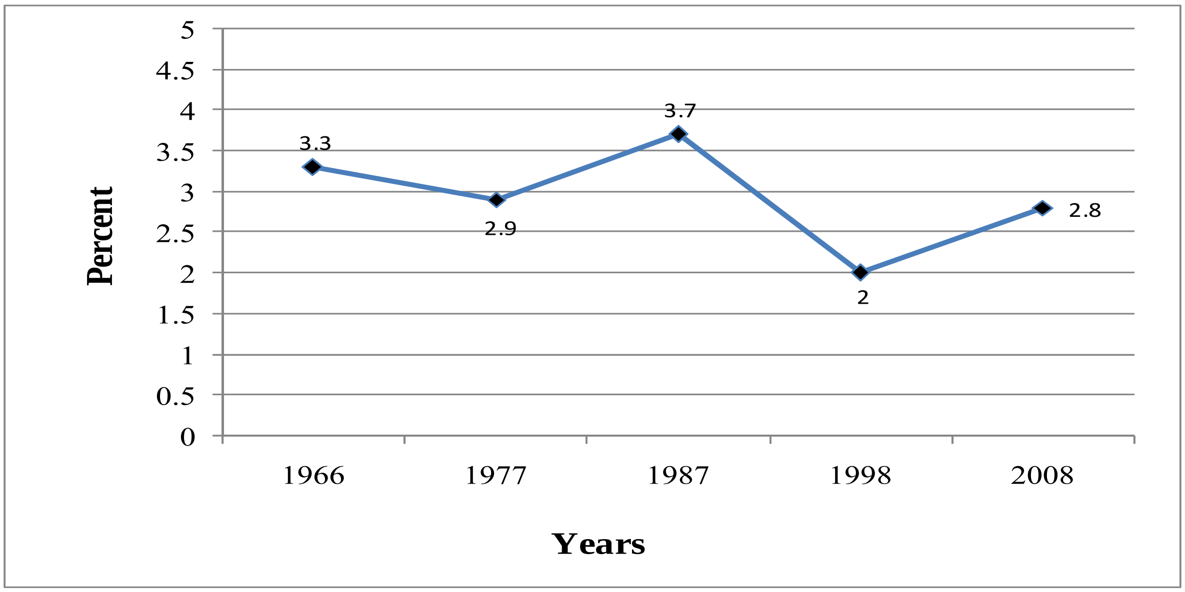

Fig 5.11: Annual inter-censual population growth rate trend since 1966. ***Source: NSO (2008)***

ASSUMPTIONS

The population growth is exponential function and the rate of growth for each village is constant until 2019, after which it is assumed to grow to 3.3% until 2029. From early 2030 to 2039, the population was assumed to be 3.4%. This was based on NSO trend (2008). It is assumed that improved health care, good nutrition and family planning measures will stabilize population increase until 2039.

Population projections for Mandala, the most populous village is presented in appendices (see appendix 5.4)

5.4.2 Water Demand Projections

The trends of population growth as highlighted above have a direct reflection on water demands in various study villages. The graphs below depict the water demand projections of these villages.

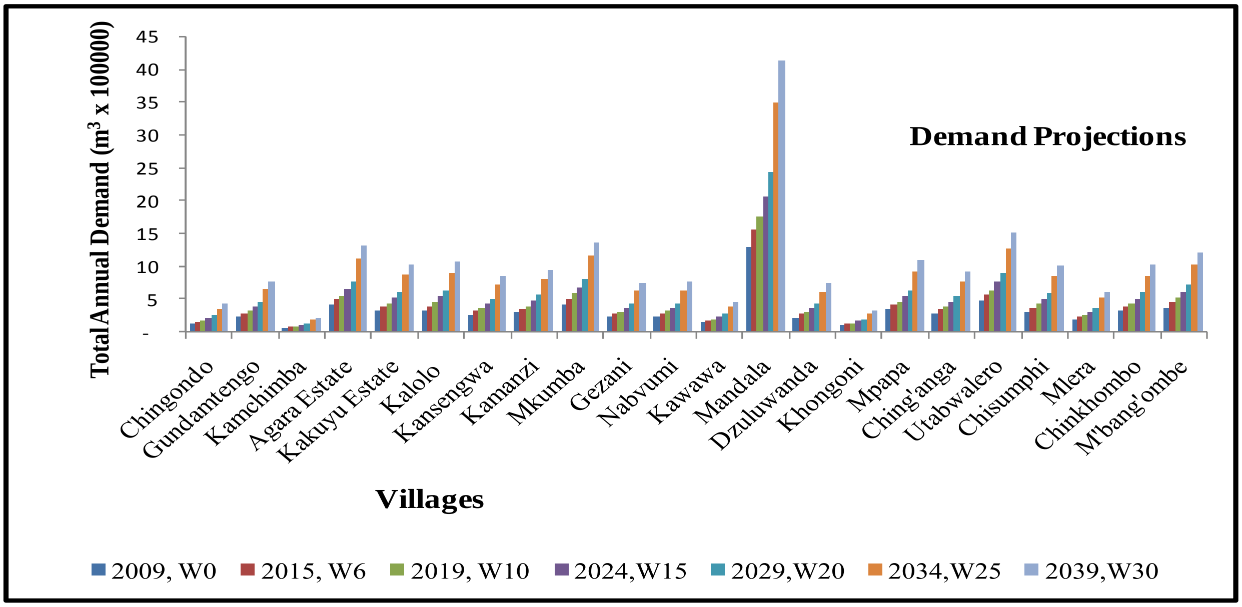

Fig 5.12: Annual Water Demand for each village, 2009-2039

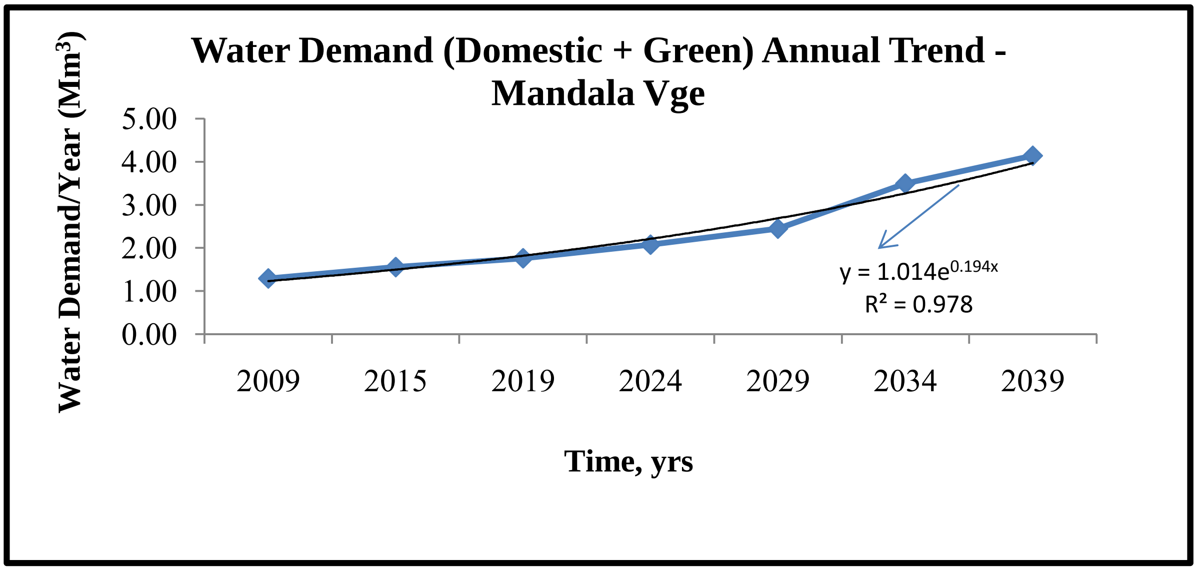

Fig 5.13: Annual Water Demand (Domestic + Green) for Mandala Village

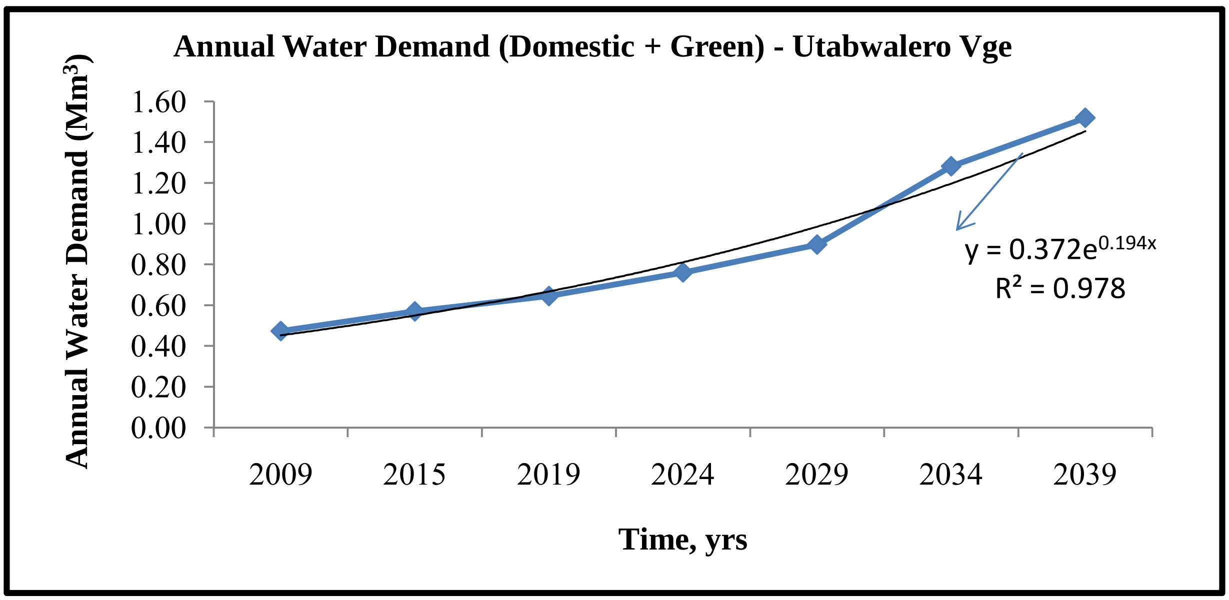

Fig 5.14: Annual Water Demand (Domestic and Green) for Utabwalero village.

Annual water demand for Utabwalero village which is serviced from Mweziwauma dam will be about 1.5Mm^3 (2039) against current 473,422m^3, representing a 221% increase. If there are no new water infrastructures developed in the area, 221% increase on demand signifies too much pressure on the water resource.

5.4.3 WAFLEX and Reliability of the Water Resources in the area

Scenarios were set for modeling of the sub-systems using WAFLEX simulation to evaluate the effect of inclusion of other sources of water and time to the water demand-availability matrix. Zero scenarios where only water from small earth dams was considered for current demand (2009) were set for both Kamanzi and Mweziwauma dams. The second scenario was set to include water from boreholes and shallow wells into the system for current demand (2009). The third scenario is when water from both sources was considered for demand in 2039.

Results from the WAFLEX Simulation Model indicate that the villages around Kamanzi could experience shortage 93% of the time in dry season with supply meeting only 26% of demand if water from boreholes and shallow wells was not considered also as readily available water. With inclusion of water from boreholes and shallow wells, the system meets about 31% of demand (5% improvement) which means that out of a population of 1,385 for Kamanzi, 69 more people are served. At Mweziwauma dam, the users experience shortage about 93% of the time with supply meeting about 30% of demand. Inclusion of water from boreholes and shallow wells makes the system meet about 32% of demand. However, despite registering improvement in the total number of people served, which in turn could improve their livelihood, this supply is still not reliable since according to Smathkin (2001), supply which fails to meet demand about 50% of the time is not reliable.

Assuming current water availability levels and neglecting climate change effects which are not easily quantifiable for the study area, a snap analysis of the future demand scenario (2039) at Kamanzi dam (with boreholes included) indicated that the system will experience shortages 100% of the time with demand being met only 11% of the time. This is suggestive that unless holistic water resources management measures are taken, available resource will not be able to meet demand. Figs 5.15, 5.16, 5.17, and 5.18 show output of WAFLEX model by means of different scenarios for Kamanzi and Mweziwauma dams.

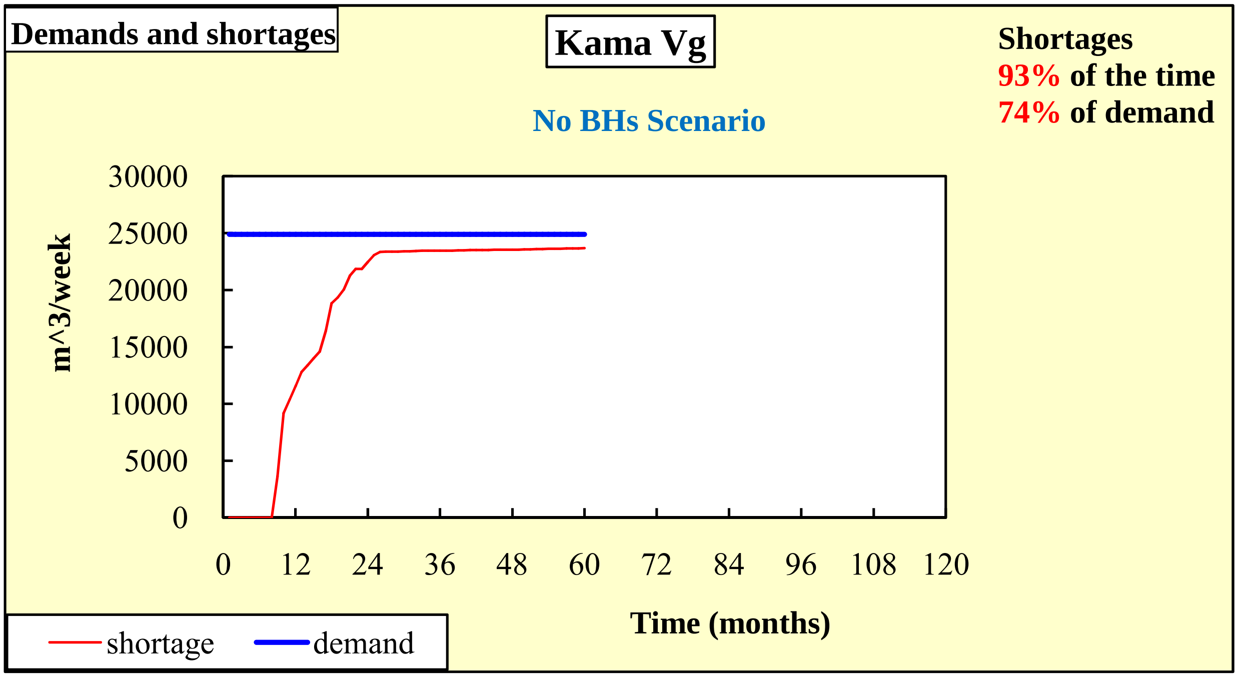

Fig 5.15: Without boreholes scenario – Kamanzi dam

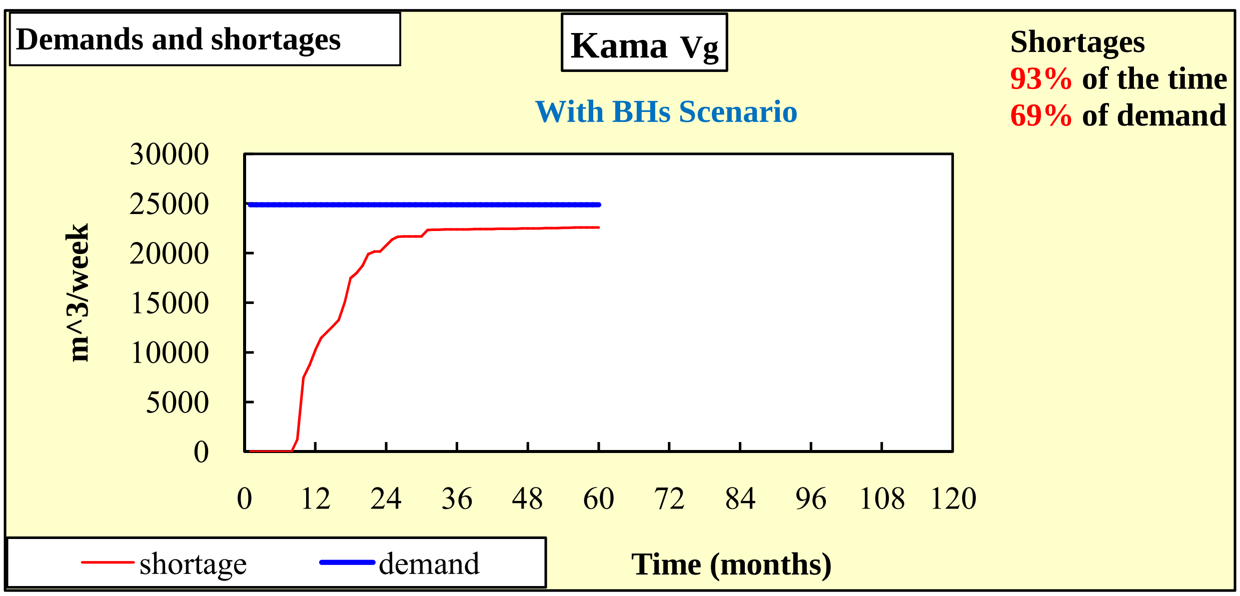

Fig 5.16: With boreholes scenario – Kamanzi Dam

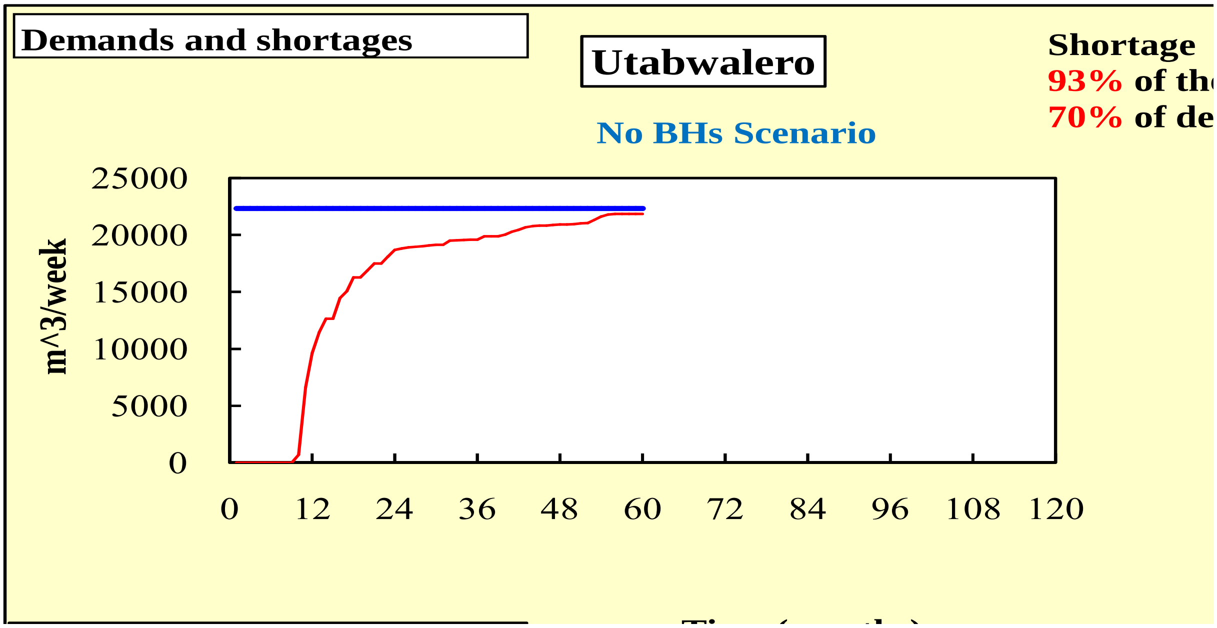

Fig 5.17: Without boreholes scenario – Mweziwauma Dam

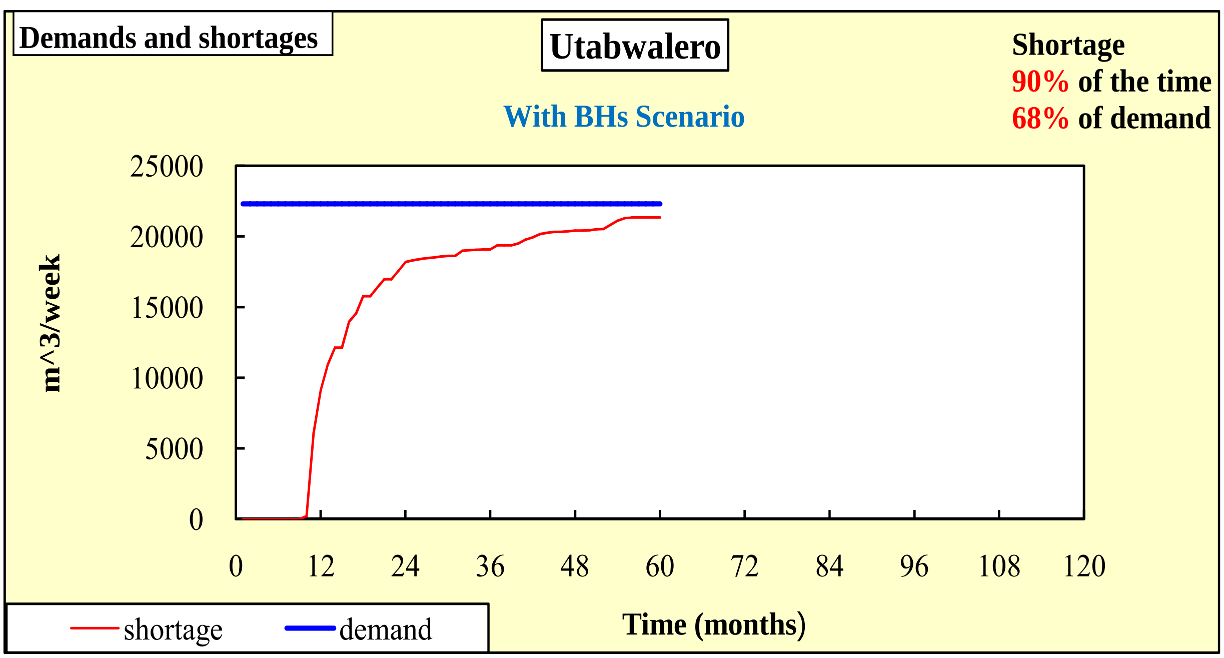

Fig 5.18: With boreholes scenario – Mweziwauma Dam

According to Kamtukule (2008) reservoir capacities are increasingly diminishing in Malawi due to siltation. This was also observed during the time of this research since maximum capacities for most reservoirs have tremendously decreased due to siltation. The design capacity for Kamanzi dam, for example was 10,500m^3 while the current capacity is only 7,240m^3 despite being in existence for only 5 years.

5.5 Water Allocation Procedures in the area as a function of conjunctive use

Seven (7) out of 10 dams under study, apply prior appropriation principle where only citizens with their customary land very close to the small earth dams have access to the water for small scale irrigation. Those with their fields away from these dams do not benefit except for fishing, water for washing and livestock. These dams include Gundamtengo, John Grey, Kamanzi, Mweziwauma, Mandala, M'bang'ombe and Mthyola. Village Development Committees (VDCs) and Water User Associations (WUAs) have been mandated to oversee water allocation process. However, VDCs and WUAs have no powers to reverse application of prior appropriation principle since it has roots in the customs and traditions of the area. Additionally, about 80% of VDCs and WUAs members own fields close to the reservoirs making it very difficult for them to push for any changes that may eventually affect them. Furthermore, there are no punitive measures applied to those who abuse this customary and geographical advantage.

Water allocation is a function of land in this area. It was indicated that for villagers to benefit from water from these small earth reservoirs, they must have somewhere near the dams to cultivate. There were only 11 plots surrounding Kamanzi dam. The study found that 80% of the households who enjoy customary and geographic advantage have holdings more than 1 ha but use less than half of it. However, about 72% of the households interviewed had holdings of less than 1 ha (49% of less than 0.5 ha, and 23% between 0.5 and 0.99 ha), 19% between 1.0 ha and 2.0 ha and the remainder, 2 ha and above. According to FAO Investment Centre Report, (2005) small-scale cultivation in Malawi is bedeviled by severe problems of decreasing holding size, falling yields, and increasing use of marginal land.

74% of the households interviewed and living within 0.5km radius from the reservoirs indicated that there is no equity in the water allocation process. According to Johansson et al., 2002, equity of water allocation is concerned with the ''fairness'' of allocation across economically disparate groups in a society. However, the centralized water allocation approach in the area benefits only those with customary and geographical advantage, which is about 5% of the population, leaving out the majority not serviced.

As stated by Seagraves & Easter (1983), an efficient allocation of water resources is one that maximizes net benefits to society using existing technologies and water supplies. All the small earth dams under study had their irrigation water conveyance systems not working. At Kamanzi dam, for example, the canal that was provided to convey water from the dam to nearby fields had completely silted up from soil erosion. A pipe to convey water out of the dam at Mthyola was vandalized. Photo 5.1 below shows irrigation water conveyance pipe at Mandala. Table 5.6 below outlines some of the notable methods of irrigation in the absence of design water conveyance ways. Treadle pumps and watering cans are the methods that are used for small scale irrigation in the area.

It was evident therefore that there were disparities in allocation of water particularly from the reservoirs. This inhibited the conjunctive use of water from the reservoirs and boreholes by the majority of the citizens at a time when only one resource could not support the demand, for example during the dry season. This forced a cross-section of the community (about 95% of the population) to stay idle in dry season despite having a 6-month deficit of food.

Table 5.6 below shows the water allocation criteria and the methods of irrigation in the area.

Table 5.6: Water Allocation Criteria and Method of Irrigation

DAM	Village	Water allocation	Allocation Criteria	Type of Irrigation	Equity
Gundamtengo	Chingondo	VDC	Prior appropriation principle	Treadle pump	No
	Gundamtengo	VDC	Prior appropriation principle	Treadle pump	No
Kakuyu J. Grey	Kalolo	VDC	Prior appropriation principle	Water cans	No
	Kansengwa	VDC	Prior appropriation principle	Water cans	No
Kamanzi	Kamanzi	VDC	Prior appropriation principle	Treadle pump	No
	Mkumba	VDC	Prior appropriation principle	Treadle pump	No
	Gezani	VDC	Common plot	Treadle pump	Yes
	Nabvumi	VDC	Common plot	Treadle pump	Yes
Kawawa	Kawawa	Village headman	Chief's prerogative	Water cans	Yes
Mandala	Mandala	VDC	Prior appropriation principle	Treadle pump	No
Mthyola	Dzuluwanda	VDC	Prior appropriation principle	Treadle pump	No
Mpatsa	Khongoni Headquarters	Village head	Chief's prerogative	Water cans	Yes
	Mpapa	VDC	Common plot	Treadle pump	Yes
Mweziwauma	Ching'anga	Estate Mgt	Rotational	Treadle pump	Yes
	Utabwalero	VDC	Prior appropriation principle	Treadle pump	No
	Chisumphi	VDC	Prior appropriation principle	Treadle pump	No
M'bang'ombe	Mlera	VDC	Prior appropriation principle	Treadle pump	No
	Chinkhombo	VDC	Prior appropriation principle	Water cans	No
	M'bang'ombe	VDC	Prior appropriation principle	Treadle pump	No

As stated by Johansson et al., 2002, these traditional, communal arrangements have often operated successfully for many years in most parts of developing world, but may not be efficient or equitable. At Kawawa for example, the dam has been solely controlled by the village headman for years but all his subordinates benefit from it, contrary from Kamanzi where Village Development Committee (VDC) oversees allocation but disparities in allocation still stand.

Photo 5.1: Conveyance Pipe at Kamanzi Dam

A successful water allocation program must combine a technically defensible methodology with an administrative process that follows legally defensible procedures and treats all users fairly (van der Zaag, 2008). However, these results show that water allocation procedures in the study area are not technically defensible. Most of the allocation procedures are tradition tailored with less impact on the improvement of people's livelihood as noted from the Water Poverty Indices **(See Fig 5.21)**

Analysis of the collected data on water allocation procedures in the area shows that there are gross water resource mismanagement issues in the study area. 47% of the responding households indicated that government officials do not make follow ups to check condition of most earth dams. It is also evident that infrastructure transfers (from government to villagers) were made before irrigation water conveyance systems were put in place at most of the dams. This has forced most farmers to be using treadle pumps and watering cans for small scale irrigation.

5.6 Level of Conjunctive Use of small earth dams and Boreholes/Shallow wells

Despite that most borehole yields in the area can support small scale irrigation, 3 out of 28 boreholes under study are the only ones used to irrigate small vegetables and maize plots, giving 11% representation. This is at Ching'anga, Dzuluwanda and Chinkhombo villages. At Nabvumi village, the borehole yield is as high as 3.3L/s but it was reported that the Village Development Committee (VDC) has instructed fellow villagers not to use its water for any other use except domestic use.

When the reservoir dries up at Mweziwauma, about 78% of small scale farmers with plots close to the dam, resort to using shallow wells for their small scale irrigation needs. Most of the crops grown during this time are vegetables and maize. 41% of the 40 households interviewed and about 20% of the comments made at Focus Group Discussions (FGDs) at Kamanzi and Mweziwauma villages indicated that the people preferred having motorized boreholes for their small scale irrigation to using treadle pumps. This was particularly strong among those without their field plots close to the reservoirs (about 95% of population at Kamanzi Dam).

Conjunctive use of small earth dams and boreholes was reported to be a non-existing concept around Kawawa dam. This is because villagers from this village still drink from shallow wells. There is no borehole in their village so it was difficult to start thinking of one which would be conjunctively used for domestic and small scale irrigation. The same situation was observed at Mandala B village (see appendix 5.5). However, according to Simpson (2006), conjunctive use of water resources is a powerful tool for eradication of rural poverty and it should be encouraged. Photo 5.2 below is one of the high yielding boreholes at Nabvumi village which could benefit small scale farmers if its water were conjunctively used for domestic use and small scale irrigation. The design of the soak pit (as in the picture) is suggestive of extending it to feed into a canal which could convey water to nearby plots.

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Photo 5.2: High yielding (3.3L/s) borehole at Nabvumi village (Kamanzi Dam)

5.7 Quality of groundwater from wells and boreholes for irrigation as a conjunctive use function.

Irrigated agriculture is dependent on an adequate water supply of usable quality. In Malawi, water quality concerns have often been neglected because good quality water supplies have been plentiful and readily available. This is one of the reasons why Malawi has not yet developed its irrigation water quality standards. However, this situation is now changing in many areas (Chavula et al., 2007). According to Fipps (2003), in most irrigation situations of the world, the primary water quality concern is salinity levels, since salts can affect both the soil structure and crop yield. Electrical conductivity (EC) and Na^+ also play a vital role in suitability of water for irrigation. Higher EC in water creates a saline soil, whilst higher salt content causes an increase in soil solution osmotic. The salts, besides affecting the growth of plants directly, also affect the soil structure, permeability and aeration, which indirectly affect plant growth.

This study used The University of California Committee of Consultants (1974) guidelines for Irrigation Water Quality. Table 5.7 below provides these guidelines;

Table 5.7: Irrigation Water Quality Guidelines UCCC (1974)

IRRIGATION WATER QUALITY GUIDELINES				
Water parameter	**Symbol**	**UNIT 1**	**Usual range in irrigation water**	
SALINITY				
Salt Content				
Electrical Conductivity	EC_w	dS/m	0 – 3	dS/m
(or)				
Total Dissolved Solids	TDS	mg/l	0 – 2000	mg/l
Cations and Anions				
Calcium	Ca^{++}	me/l	0 – 20	me/l
Magnesium	Mg^{++}	me/l	0 – 5	me/l
Sodium	Na^{+}	me/l	0 – 40	me/l
Carbonate	CO_3^{--}	me/l	0 – .1	me/l
Bicarbonate	HCO_3^{-}	me/l	0 – 10	me/l
Chloride	Cl^{-}	me/l	0 – 30	me/l
Sulphate	SO_4^{-}	me/l	0 – 20	me/l
NITRATES				
Nitrate-Nitrogen	NO_3-N	mg/l	0 – 10	mg/l
Ammonium-Nitrogen	NH_4-N	mg/l	0 – 5	mg/l
Phosphate-Phosphorus	PO_4-P	mg/l	0 – 2	mg/l
Potassium	K^{+}	mg/l	0 – 2	mg/l
MISCELLANEOUS				
Boron	B	mg/l	0 – 2	mg/l
Acid/Basicity	pH	1–14	6.0 – 8.5	
SODIUM ADSORPTION RATION	SAR	(me/l)[1]	0 – 15	
[1] dS/m = deciSiemen/metre in S.I. units (equivalent to 1 mmho/cm = 1 millimmho/centi-metre)				

ECw means electrical conductivity, a measure of the water salinity, reported in deciSiemens per metre at 25°C (dS/m) or in units millimhos per centimetre (mmho/cm). Both are equivalent. TDS means total dissolved solids, reported in milligrams per litre (mg/l).

Out of 32 samples collected, only Mpapa borehole registered highest Salinity values of about 0.61mhos/cm with minimal seasonal variations. Kamchimba (0.31mhos/cm in April to 0.41mhos/cm in August), Gezani (0.22-0.3), Dzuluwanda (0.28-0.32) and Mweziwauma (0.11-0.28) had notable seasonal variations. However, all samples had their salinity test values less than the UCCC (1974) limit of 3mhos/cm. Figs 5.19 and 5.20 below present the trend of salinity and TDS in the study area:

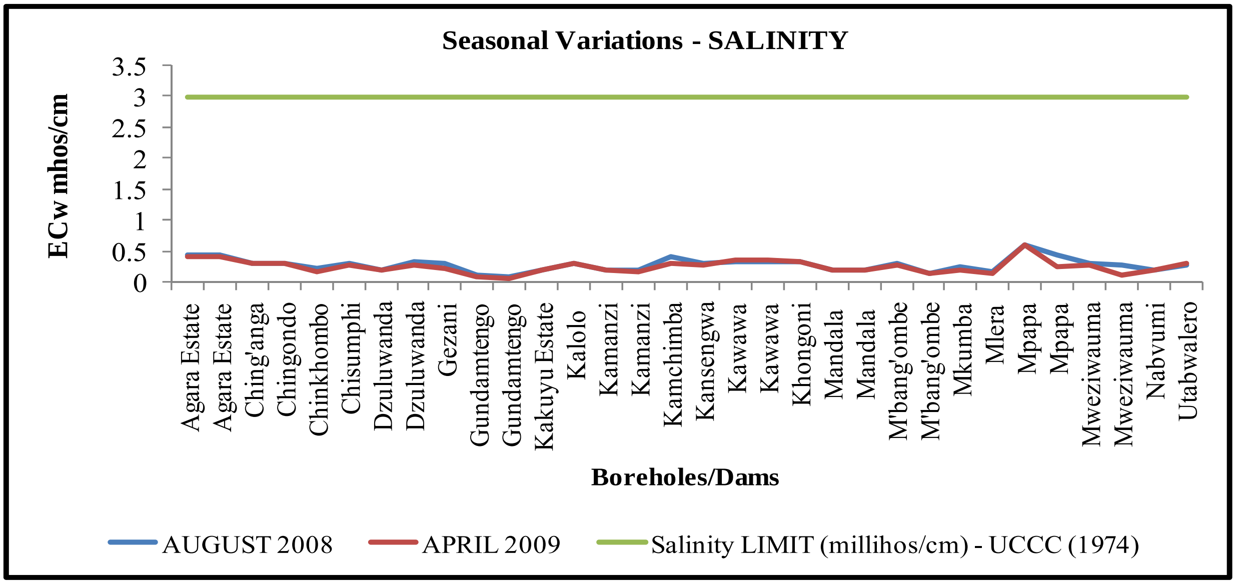

Figure 5.19: Seasonal Variations – SALINITY

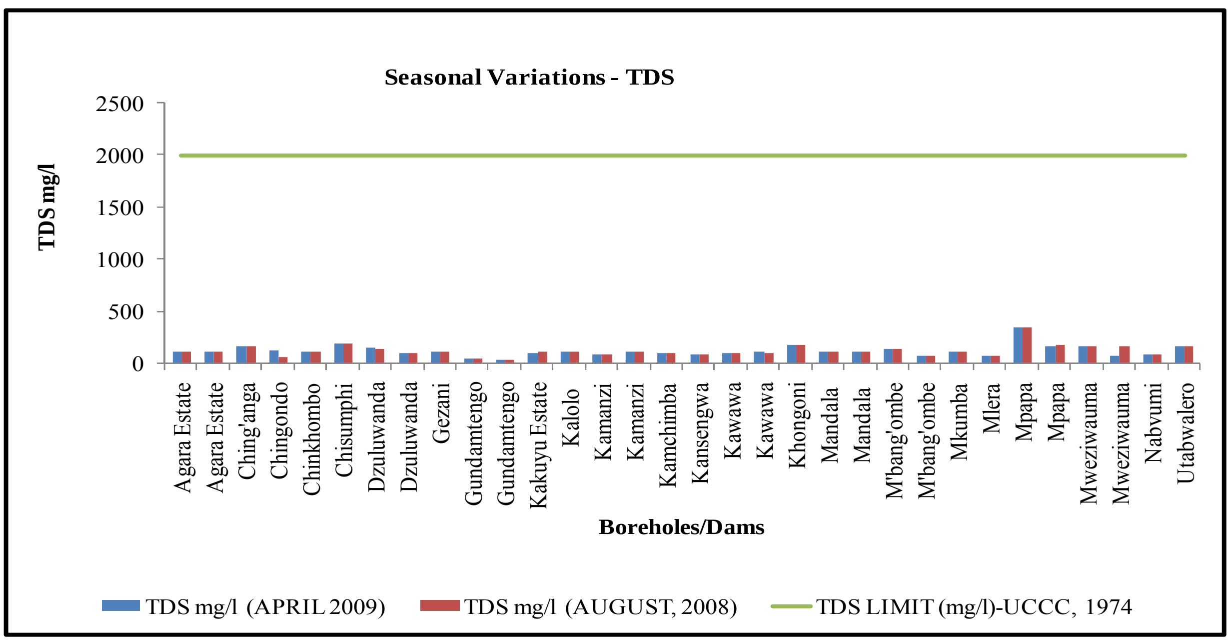

Figure 5.20: Seasonal Variations – TDS

Total dissolved solids (TDS) test results also showed that the area had lower levels of TDS. The figure above shows the trend of total dissolved solids in water samples from boreholes and dams in the area.

It is probable to conclude that irrigation water quality as a function of water quantity for conjunctive use in the area is not a constraint. Water is of good quality to be used for agricultural purposes and the worrying factor should be the actual quantities of water available in the reservoirs and what boreholes can yield. Photo 5.3 below shows a water sample number 19 collected at Mpapa village for laboratory tests:

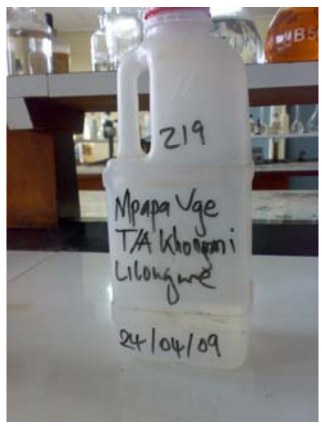

Photo 5.3: Water sample – Mpapa Village

5.8 Economic and environmental benefits of using small dams and groundwater for small scale irrigation as seen from users' welfare

A total of 220 households were sampled and 40 interviewed in detail regarding the availability and reliability of water resource (R), if citizens had access to it and if that access (A) was equitable, whether citizens had the capacity (C) to manage the water and its infrastructure. Wealth as proxied by ownership of durable materials, for example bicycles, was assessed in the area. 70% of the respondents in the study area reported that most small earth dams dry up during dry season, a period when they need it most for small scale irrigation. 65% of the respondents indicated that access to dam water for irrigation was confined to only those with their customary fields close to the dams. 60% of the households interviewed own bicycles, 85% of which were bought after selling produce. It was discovered that 30% of the respondents feel that selection of representatives to the Water User Associations (WUA), Village Development Committees

(VDCs) favours those with money and those related to the chiefs. 98% of the respondents at Mandala village indicated that deforestation has, for the past decade been rampant and that most of the rivers have been greatly silted. Lesser percentage (13%) of the respondents knew that water from boreholes and shallow wells could be used as reliable sources of water supply for small scale irrigation in times when small earth dams have dried up. General observations made during this research revealed that in about 17 villages of the study area, 80% of the citizens were not doing small scale irrigation during dry season. 'It was time to rest', said one respondent from Mweziwauma village in Traditional Authority Khongoni. Water Poverty Index (WPI) was then used to assess the overall effect of water availability (remedied by conjunctive use) or scarcity on households in the area.

Water Poverty Index (WPI) as developed by Sullivan et al., (2003) equation 4.7, yielded the following results (also see appendices 5.7a and b for calculations):

Table 5.8: Weights for crude WPI for study area

Weight for Water Resource, w_r	Weight for Access, w_a	Weight for Capacity, w_c	Weight for Use, w_u	Weight for Environmental Integrity, w_e
0.9	0.7	0.8	0.6	0.7

Results:

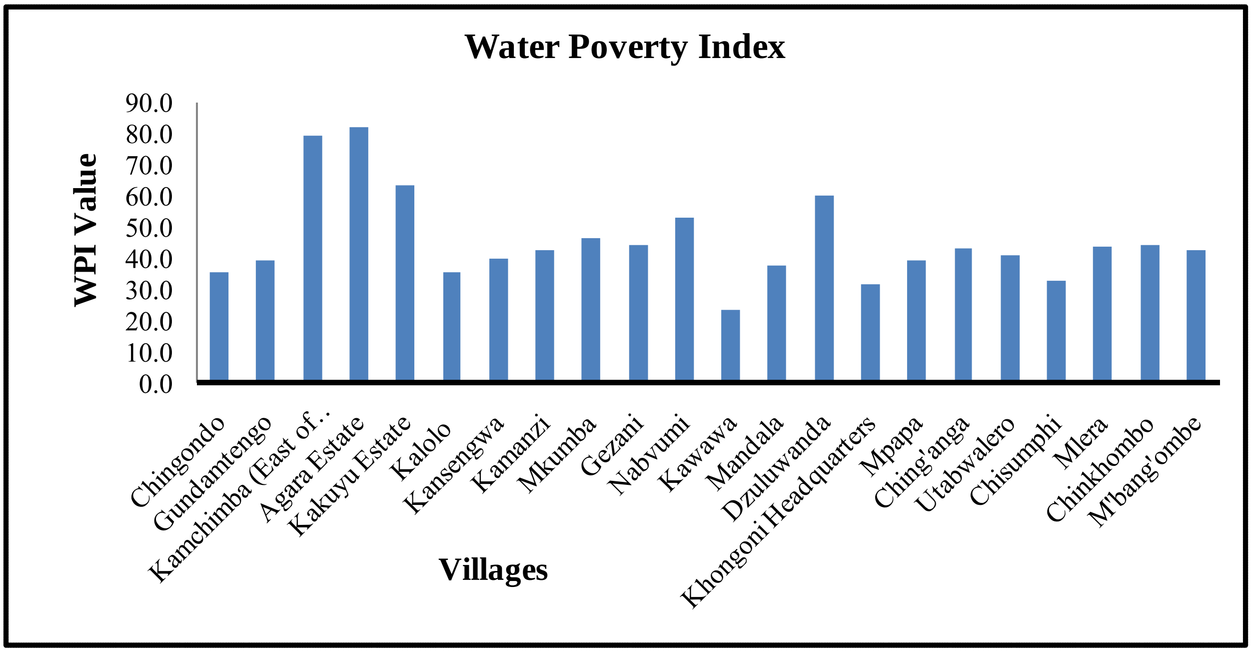

Fig: 5.21: Aggregate index of Water Poverty.

Despite drying up of Mweziwauma dam in dry season, Ching'anga village had a better WPI (43) than most villages in the study area. This has been attributed to the use of borehole water and shallow wells for small scale irrigation during this time. Kamanzi village had a low use function of WPI (10) since most people were not benefiting from the small earth dam. However, it had an overall WPI of 42.4. Kawawa village had the lowest of WPI and this was linked to lack of access to clean water since the villagers still drink from unprotected sources (shallow wells). Dzuluwanda village (60 WPI) uses water from both shallow wells and a borehole to supplement reservoir supply in dry season. Agara and Kakuyu estates have a very good water management system as estates. Water resources management is run by central estate management. Their tenants use more than US$ 1 a day, better than most citizens in the study area who still use less than US$1 a day.

The main income generating activity in the study area is agriculture with maize and burley tobacco as the main crops. Maize is grown on an average farm piece of 0.5 ha for one family, giving average yield of 800 kg/ha and a monthly consumption of 70 kg per family. Half of the homes are usually in deficit diet for 6 months per year thus prompting small scale irrigation in dry season to supplement the normal yield. They harvest an average yield of 1200 kg/household of burley tobacco per year, all of which is grown during the ‘normal’ planting season. It is probably reflective of these results therefore that conjunctive use of surface water and groundwater can improve people’s welfare.

One of the challenges of using WPI was that it was relatively difficult to evaluate the accuracy of public data sets included in the calculation in this research which would in turn jeopardize the accuracy of WPI and overall results. However, familiarity of the study area by the researcher and information sourced from the Ministry of Irrigation and Water Development helped improve quality of data.

With the index values as above, WPI thus can be used as an instrument to start a discussion, as an overview of the water situation in an area, as well as for classifications of the water situation. The variety of uses can also be seen in the interdisciplinary concept of the WPI. Several sectors and aspects are included making it an interesting monitoring tool not only for the water sector.

5.8 Development of strategy pointers for Ministry of Irrigation and Water Development (MALAWI)

The study has come up with strategy pointers for the Ministry to consider overtly incorporating conjunctive use of surface and groundwater into her policies and strategies. The costing of these strategy pointers and the units scales used have been adopted from MoIWD reports.

As argued by Feter (1994), the need for management of groundwater and surface water as elements of an interrelated system is most critical when demand exceeds supply. The water supply and demand situation of Kamanzi and Mweziwauma small earth dams indicate that supply infrastructures present are not adequate enough to meet the demand. Water demand at Mandala dam for example surpasses supply by 12450 m^3. It was evident through this research that most institutions fail to appreciate the impact of the policies they have in place mainly due to lack of follow ups and assessments of the schemes instituted. In Malawi for instance, most small earth dams are in disrepair with siltation issues raging high (Kamtukule, 2008). Siltation and increases in demand due to changes in population make water supply for small scale irrigation inadequate most of the times.

Malawi water policies and strategies are not very particular on conjunctive use of surface and groundwater. For example, the Malawi Water Resources Management Policy and Strategy (2001) acknowledges lack of sustainable strategies for groundwater development, utilization and management (pp 4). Specific strategy 4.26 of the National Water Policy (2007) mentions the need to undertake appropriate integration between surface water and groundwater resources management. Strategy 5.5.4 of the Water Resources Act (1969) calls for promotion of development of small scale beneficiary-managed irrigation schemes with an emphasis on efficient water management while ensuring and maintaining environmental integrity.

Development of a strategy is a multi-tasking job which includes a lot of steps and volumes of data within the implementer's reach (Vazquez, 2003). This study therefore looked at strategy pointers that would in the long run help the Ministry of Irrigation and Water Development develop full blown strategies within their frameworks. They are believed to help the Ministry in quest of maximizing benefits of both surface and groundwater resources:

Strategy Pointer 1: Conjunctive Use of Surface and Groundwater as part of the Integrated River Basin Management

Hallowes et al. (2008) state that increasing acuteness of water scarcity problems, worldwide, requires the adoption of a double approach of water supply management and water demand management. Governments tend to consider river basins as water resources management units and as a spatial basis for the formulation of water management strategies integrating all cross-sectoral issues such as water resources conservation, environment, water resources allocation, and water demand management. The conjunctive use of surface and groundwater is one of the strategies of water supply management which has to be considered to optimize the water resources development, management and conservation within a basin and artificial recharge of aquifers is certainly one of the tools to be used for that purpose (Qureshi et al., 2004). Cook et al. (2007) argued that use of the river basin as the spatial unit for analyzing the interactions and interrelations between the various components of the water system, and for defining the water management policy, is well justified, and is increasingly becoming common practice. However, Malawi is yet to fully use river basins as a spatial unit of analyzing interactions and interrelations between the various water components.

This research work has found out that there is need to adopt water management policies that would allow preparation of spatial management plans and linkage of water and land use through river basin plans. This is because according to Cook et al. (2007), the adoption of an integrated river basin management approach for elaborating policies and strategies of water resources development, management and conservation would help consider the water resources as one system and would avoid a water resources development approach focused only on surface water. It would also facilitate the management of the resource itself, allowing a better understanding, by water users, of the hydrological issues involved.

Strategy Pointer 2: Promotion of Water Harvesting (WH) Techniques as a strategy for Conjunctive Use of surface water and groundwater.

Water Harvesting (WH) as the process of collecting and concentrating water from runoff into a run-on area is considered good approach to improve crop irrigation, groundwater recharge and water storage for future use in drought prone areas (Rutherford, 2007). Due to limited land and financial resources available and ecological considerations, small dams are the most advocated for surface water harvesting methods in semi-arid region (Richter et al., 2007). However, most of the small earth dams assessed under this study are under heavy siltation, which is tremendously reducing their storage capacities.

Strategy Pointer 3: Sustainable development and management of Groundwater resource for Conjunctive Use with surface water.

Foster et al., (2006) have argued that affordable innovations in water-lifting technologies, for example, treadle pumps and motor pump technology have been potentially critical in improving people's access to groundwater. Research results show that small scale farmers, for example at Mandala, rely much on shallow wells for small scale irrigation just because there is no equitable access to dam water. With improved technologies, there is potential to transform these rural communities from low productivity subsistence agriculture to more intensive forms of production. However, Gale, (2005) warns of over-reliance on single groundwater resource since from his studies, groundwater-based rural economies have shown signs of vulnerability when aquifers deplete. Therefore, sustainable development of groundwater resource for conjunctive use is in this research work deemed a good strategy pointer.

Consideration of all these strategy pointers would therefore make sure that farmers realize maximum benefits from both surface and groundwater resources. The following section presents analysis of the selected strategy pointers.

5.8.1 Strategy analysis

An analysis of the presented strategies in order to rank them was carried out using Multi-criteria Decision Analysis (MCDA) as devised by Vazquez, J.F. (2003).

Table 5.9: With and without strategy scenarios

Criteria	Year: 2009							
	Pessimistic Scenario (No overt Strategy Pointer)				**Optimistic Scenario (With overt Strategy Pointer)**			
	Indicator	**S1**	**S2**	**S3**	***Indicator***	**S1**	**S2**	**S3**
Implementation Cost	Low (US$ 000)	0	0	0	Low (US$ 000)	200	310	110
Political Vulnerability	Low(Unit)	0.6	0.8	0.5	Low(Unit)	0.4	0.2	0.5
Socio-economic benefit	High (Unit)	0.3	0.1	0.4	High(Unit)	0.7	0.9	0.6
Financial Benefit	High (US$ 000) Per Annum	30	18	47	High (US$ 000) Per Annum	100	215	145

Adapted from: Vazquez, J.F., 2003

Table 5.10: Strategy Pointer Ranking

Criteria	**Strategy Pointer Ranking for Optimistic scenario.**		
	S1	**S2**	**S3**
Implementation Cost	2	3	1
Political Vulnerability	2	1	3
Socio-economic Benefits	2	1	3
Financial Benefits (per annum)	2	1	3
Total Score	**8**	**6**	**10**
Final Strategy Ranking	**2**	**1**	**3**

Where *SI* = Conjunctive Use of surface and groundwater as part of the Integrated River Basin Management

S2= Promotion of Water Harvesting techniques as strategy for conjunctive use

S3= Sustainable development and management of surface and groundwater

Strategy pointer 2 (S2) had the best score of the three followed by strategy 1 (S1) and (S3) respectively.

Table 5.11: Effect of Time on Strategy Pointers

Criteria	Period (Years)							
	2009				2039			
	Indicator	**S1**	**S2**	**S3**	***Indicator***	**S1**	**S2**	**S3**
Implementation Cost	*Low(US$ 000)*	200	310	110	*Low(US$ 000)*	550	875	405
Political Vulnerability	*Low(Unit)*	0.4	0.2	0.5	*Low(Unit)*	0.5	0.4	0.6
Socio-economic benefit	*High(Unit)*	0.7	0.9	0.6	*High(Unit)*	0.6	0.8	0.5
Financial Benefit	*High(US$ 000)* *Per Annum*	100	215	145	*High(US$ 000)* *Per Annum*	310	795	385

From the data presented as above, it is evident that cost of implementation of strategy pointers will be more in the future (2039) than now (2009). It is also clear that these strategy pointers will be more politically vulnerable in the future than now since citizens would have felt the wrath of resource depletion. There seems to be more socio-economic benefits if adopted now, than in the future since once citizens are empowered, they would diversify into some equally important economic activities for example commercial farming and/or property investment.

5.8.5 Strategy Prioritization

With analysis as done above, the strategy pointers are presented in accord to priority of implementation and thus promotion of water harvesting techniques (WHT) as conjunctive use strategy pointer is most favoured. The prioritization of these strategy pointers is as given below;

SI = Conjunctive Use of surface and groundwater as part of the Integrated River Basin Management **(2)**

S2= Promotion of Water Harvesting techniques as strategy for conjunctive use **(1)**

S3= Sustainable development and management of surface and groundwater **(3)**

In its strategy development, the Ministry should therefore consider promoting water harvesting techniques as a priority area for conjunctive use of surface and groundwater resources.

Photo 5.3: Need to promote conjunctive use of these: Dam at Mandala and Borehole at Khongoni.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

From the observations made during the period of this research work and analysis of collected data made, it is probable to say that;

- It is optimal to conjunctively use surface and groundwater in dry season because both sources showed vulnerability in this season of study area. However, to maximize on benefits, more groundwater could be tapped against highly vulnerable surface water resource in dry season while more surface water would be used in rainy season when it is relatively abundant. For example, water available in Kamanzi and Mweziwauma dams in dry season is not sufficient to meet present ($0.7Mm^3$ and $0.6Mm^3$ respectively) and future (2039) demands ($2.2Mm^3$ and $2.0Mm^3$ respectively). Results from the WAFLEX Simulation Model indicate that the villages around Kamanzi experience water shortage 93% of the time in dry season with water supply meeting only 26% of demand. With inclusion of water from boreholes and shallow wells, the system is meeting about 31% of demand. At Mweziwauma dam, inclusion of water from boreholes improves reliability by 2% (meets 32% of demand against 30% without boreholes). In the future (2039), Kamanzi dam (with boreholes included) will experience shortages 100% of the time and meet 11% of the time. According to Smathkin (2001), supply which fails to meet demand about 50% of the time is not reliable. This situation therefore brings in water insecurity among the citizens.

- Water allocation process as a function of conjunctive use in the area is predominated by customs and traditions which compromise equitable water allocation. Seven (7) out of 10 dams under study, apply prior appropriation principle where only citizens with their customary land very close to the small earth dams and boreholes have access to the water for small scale irrigation. Village Development Committees (VDCs) and Water User Associations (WUAs) that have been mandated to oversee water allocation process in some villages for example Kamanzi have no powers to reverse this trend.

- Conjunctive use of small earth dams and boreholes is not practiced on a larger scale in the study area despite evidence that it maximizes benefits from both sources for the betterment of small-scale farmers. Only 11% of the boreholes under study are used for small scale irrigation despite borehole water being readily available when reservoirs dry up in dry season for example at Mweziwauma dam.

- Water from both dams and boreholes in the area was of good quality for irrigation. Out of 32 samples collected, only Mpapa borehole registered highest salinity values of about 0.61mhos/cm with minimal seasonal variations. Kamchimba (0.31mhos/cm in April to 0.41mhos/cm in August), Gezani (0.22-0.3), Dzuluwanda (0.28-0.32) and Mweziwauma (0.11-0.28) had notable seasonal variations. However, all samples had their salinity and TDS test values less than the UCCC (1974) limit of 3mhos/cm and 2000mg/L respectively. The worrying factor was therefore the actual quantities of water available in the reservoirs and what boreholes can yield.

- Water Poverty Indices (WPI) for the area showed 'resource' and 'use' functions dependability. 77% of the villages had less than WPI value of 50. Since most rivers are ephemeral, aggregate environmental integrity function of WPI is notably low (about 10). These low WPI are also reflected in socio-economy of the area whereby most small scale farmers live on less than US$1 a day. There is need therefore to promote water resource development and use in order to improve people's livelihoods in the area.

- Malawi water policies and strategies are not very particular on conjunctive use of surface and groundwater. The Malawi Water Resources Management Policy and Strategy (2001) (pp 4), Specific strategy 4.26 of the National Water Policy (2007) and Strategy 5.5.4 of the Water Resources Act (1969) all mention conjunctive use of surface and groundwater on in a specific and elaborate manner. After analysis of the strategy pointers, it was evident that promotion of Water Harvesting techniques as strategy for conjunctive use was favoured over conjunctive use of surface and groundwater as part of the Integrated River Basin Management and sustainable development and management of surface and groundwater respectively.

6.2 Recommendations

The study therefore recommends that:

- Since most of the small earth dams in the area dry up because their storage capacities have been tremendously reduced due to siltation, there is need to consider dry excavation so that storage capacity would be restored to a considerable degree for effectual conjunctive use,
- Ministry of Irrigation and Water Development should train Community Based Management (CBM) and/or Village Development Committees (VDC) in the study area on Integrated Water Resources Management (IWRM) principles to help them manage the catchment and the water resources. This could help reduce cases of reservoir siltation and would help promote equitable water allocation,
- In the mean time, Local Government should help do land consolidation in the riparian areas of these small earth dams so that customary land is made public for access by all in an equitable manner. This is to improve water allocation process in the area and then promote conjunctive use,
- A study should be carried out to determine the surface water – aquifer recharge rates relation so that it becomes clear as to what percentage of surface water is made available for tapping again from the aquifers.

CHAPTER SEVEN

7.0 REFERENCE

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APPENDICES

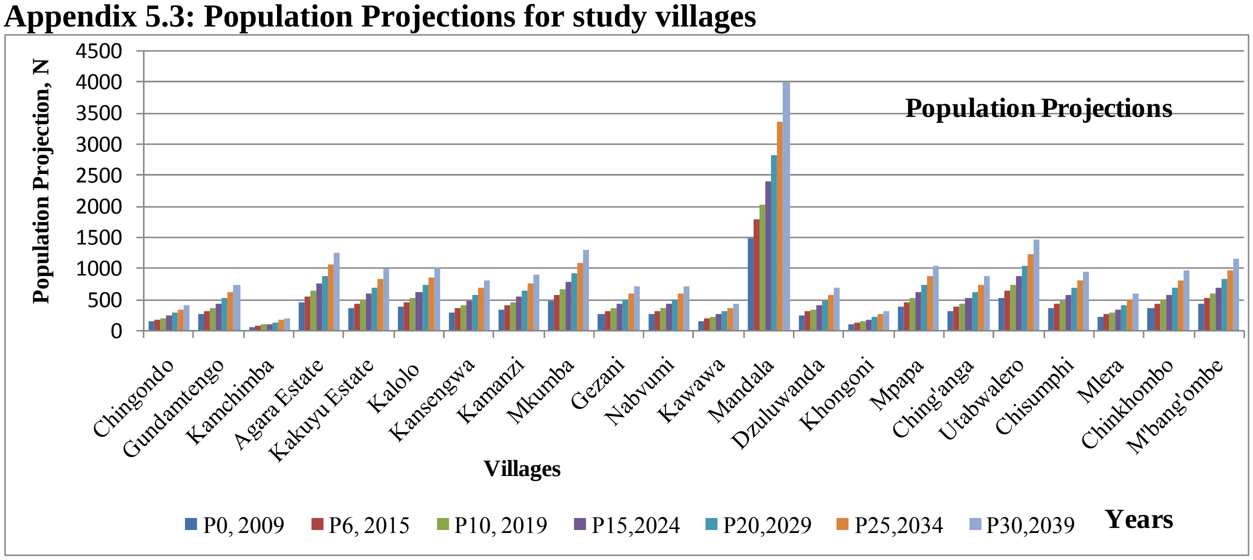
Appendix 5.1: Average Annual Rainfall Data (1968-2008)

Year	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	
Average Annual Rainfall (mm)	799.2	987.1	1009.25	945.4	910.25	993.64	1127.4	1205.1	899.34	976.2	
Year	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	
Average Annual Rainfall (mm)	955.23	1001.7	943.5	723.2	895.5	1055.4	1115	986.5	1003.5	1211.5	
Year	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	
Average Annual Rainfall (mm)	921.2	1193.25	988.2	701.2	653.2	1000.5	1020.3	897.23	1175.8	1002.4	
Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Average Annual Rainfall (mm)	994.7	1110.3	1034.22	786.2	1201.58	947.2	1141.3	618.8	928.8	1028.9	1123.2

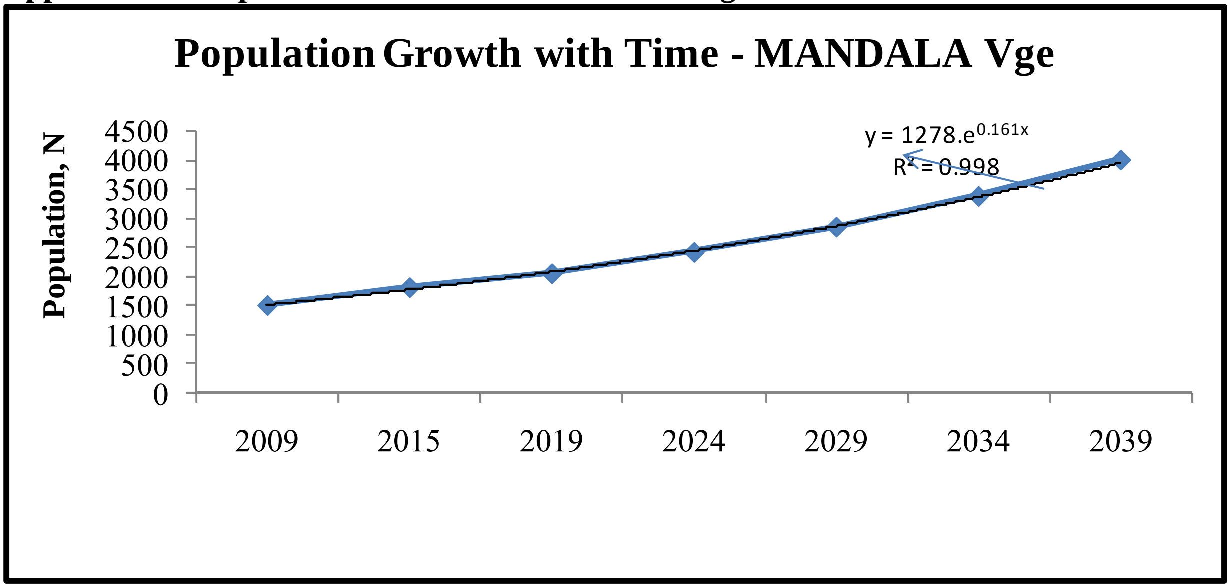
Appendix 5.2: Evaporation (mm) for Kamanzi and Mweziwauma Dams

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
79.9	115.5	127.3	115.3	122.1	101.6	119	137.7	175.3	211.9	167.7	104.4

Appendix 5.3: Population Projections for study villages



Appendix 5.4: Population Growth for Mandala Village



Appendix 5.5: Unprotected water source for domestic use – Mandala Village

Appendix 5.6: Guidelines for Interpretation of Water Quality for Irrigation.

GUIDELINES FOR INTERPRETATIONS OF WATER QUALITY FOR IRRIGATION

Potential Irrigation Problem		**Units**	**Degree of Restriction on Use**		
			None	**Slight to Moderate**	**Severe**
Salinity *(affects crop water availability)*					
	EC_w	dS/m	< 0.7	0.7 – 3.0	> 3.0
	(or)				
	TDS	mg/l	< 450	450 – 2000	> 2000
Infiltration *(affects infiltration rate of water into the soil. Evaluate using EC_w and SAR together)*					
SAR	= 0 – 3 **and EC_w** =		> 0.7	0.7 – 0.2	< 0.2
	= 3 – 6 =		> 1.2	1.2 – 0.3	< 0.3
	= 6 – 12 =		> 1.9	1.9 – 0.5	< 0.5
	= 12 – 20 =		> 2.9	2.9 – 1.3	< 1.3
	= 20 – 40 =		> 5.0	5.0 – 2.9	< 2.9
Specific Ion Toxicity *(affects sensitive crops)*					
	Sodium (Na)				
	surface irrigation	SAR	< 3	3 – 9	> 9
	sprinkler irrigation	me/l	< 3	> 3	
	Chloride (Cl)				
	surface irrigation	me/l	< 4	4 – 10	> 10
	sprinkler irrigation	me/l	< 3	> 3	
	Boron (B)	mg/l	< 0.7	0.7 – 3.0	> 3.0
	Trace Elements (see Table 21)				
Miscellaneous Effects *(affects susceptible crops)*					
	Nitrogen (NO_3 - N)	mg/l	< 5	5 – 30	> 30
	Bicarbonate (HCO_3)				
	(overhead sprinkling only)	me/l	< 1.5	1.5 – 8.5	> 8.5
	pH		**Normal Range 6.5 – 8.4**		

Appendix 5.7a: Water Demand Projection per Village

Villages	L per capita/day (Average) Dometsic Water Needs	Total Daily Domestic Water Demand/ Village (m^3)	Total daily green water requirement (m^3)	Total Annual Domestic Water Demand (m^3)	Total annual green water demand (m^3)	Total bi-annual water demand, $W_{t=dry\ season}$	Total annual water demand, $W_{t=0}$ (m^3)	Annual water demand growth rate, r	Water demand (m^3) 2015, t = 6yrs, $W_{t=6}$	Water demand 2019, t=10yrs, $W_{t=10}$	Annual Water Demand Growth Rate, r	Water demand 2019, t=0yrs, $W_{t=0}$
Chingondo	27	4.2	361	1,528	131,750	66,639	133,278	3.10%	160,522	181,714	3.30%	181,714
Gundamtengo	26	7.3	652	2,657	238,000	120,329	240,657	3.10%	289,853	328,118	3.30%	328,118
Kamchimba (East of Mc Pherson)	33	2.6	186	964	68,000	34,482	68,964	3.10%	83,061	94,027	3.30%	94,027
Agara Estate	38	18.1	1,106	6,588	403,750	205,169	410,338	3.10%	494,221	559,465	3.30%	559,465
Kakuyu Estate	37	13.9	873	5,064	318,750	161,907	323,814	3.10%	390,009	441,497	3.30%	441,497
Kalolo	28	10.9	908	3,986	331,500	167,743	335,486	3.10%	404,067	457,410	3.30%	457,410
Kansengwa	28	8.7	722	3,168	263,500	133,334	266,668	3.10%	321,181	363,582	3.30%	363,582
Kamanzi	33	11.4	803	4,156	293,250	148,703	297,406	3.10%	358,202	405,490	3.30%	405,490
Mkumba	35	17.3	1,153	6,324	420,750	213,537	427,074	3.10%	514,377	582,283	3.30%	582,283
Gezani	32	8.6	629	3,154	229,500	116,327	232,654	3.10%	280,213	317,206	3.30%	317,206
Nabvumi	31	8.5	640	3,112	233,750	118,431	236,862	3.10%	285,281	322,943	3.30%	322,943
Kawawa	26	4.4	396	1,613	144,500	73,057	146,113	3.10%	175,982	199,215	3.30%	199,215
Mandala	26	39.0	3,493	14,235	1,275,000	644,618	1,289,235	3.10%	1,552,783	1,757,775	3.30%	1,757,775
Dzuluwanda	41	10.9	617	3,966	225,250	114,608	229,216	3.10%	276,073	312,518	3.30%	312,518
Khongoni Headquarters	31	3.7	279	1,358	102,000	51,679	103,358	3.10%	124,486	140,921	3.30%	140,921
Mpapa	30	11.9	920	4,325	335,750	170,038	340,075	3.10%	409,594	463,667	3.30%	463,667
Ching'anga	29	9.6	768	3,493	280,500	141,997	283,993	3.10%	342,048	387,203	3.30%	387,203
Utabwalero	29.5	16.2	1,281	5,922	467,500	236,711	473,422	3.10%	570,200	645,476	3.30%	645,476
Chisumphi	28	10.2	850	3,730	310,250	156,990	313,980	3.10%	378,165	428,089	3.30%	428,089
Mlera	36	8.1	524	2,957	191,250	97,103	194,207	3.10%	233,907	264,786	3.30%	264,786
Chinkhombo	35	13.0	862	4,727	314,500	159,613	319,227	3.10%	384,484	435,242	3.30%	435,242
Mbang'ombe	32	14.1	1,025	5,139	374,000	189,570	379,139	3.10%	456,644	516,928	3.30%	516,928

Villages	Annual Water Demand Growth Rate, r	Water demand 2019, t=0yrs, $W_{t=0}$	Water demand (m^3) 2024, t=5yrs, $W_{t=5}$	Water demand 2029, t=10yrs, $W_{t=10}$	Annual Water Demand Growth Rate, r	Water demand 2029, t=0yrs, $W_{t=0}$	Water demand (m^3) 2034, t=5yrs, $W_{t=5}$	Water demand (m^3) 2039, t=10yrs, $W_{t=10}$
Chingondo	3.30%	181,714	214,312	252,758	3.40%	304,428	360,840	427,705
Gundamtengo	3.30%	328,118	386,980	456,402	3.40%	549,700	651,563	772,300
Kamchimba (East of Mc Pherson)	3.30%	94,027	110,894	130,788	3.40%	157,524	186,714	221,313
Agara Estate	3.30%	559,465	659,830	778,199	3.40%	937,280	1,110,962	1,316,829
Kakuyu Estate	3.30%	441,497	520,698	614,108	3.40%	739,645	876,705	1,039,163
Kalolo	3.30%	457,410	539,466	636,242	3.40%	766,305	908,304	1,076,618
Kansengwa	3.30%	363,582	428,806	505,731	3.40%	609,114	721,986	855,773
Kamanzi	3.30%	405,490	478,232	564,024	3.40%	679,323	805,205	954,413
Mkumba	3.30%	582,283	686,740	809,937	3.40%	975,506	1,156,272	1,370,535
Gezani	3.30%	317,206	374,110	441,223	3.40%	531,419	629,893	746,616
Nabvumi	3.30%	322,943	380,877	449,204	3.40%	541,031	641,286	760,120
Kawawa	3.30%	199,215	234,952	277,101	3.40%	333,747	395,592	468,897
Mandala	3.30%	1,757,775	2,073,108	2,445,010	3.40%	2,944,824	3,490,514	4,137,323
Dzuluwanda	3.30%	312,518	368,582	434,703	3.40%	523,566	620,586	735,583
Khongoni Headquarters	3.30%	140,921	166,201	196,016	3.40%	236,086	279,834	331,689
Mpapa	3.30%	463,667	546,846	644,946	3.40%	776,788	920,730	1,091,346
Ching'anga	3.30%	387,203	456,665	538,587	3.40%	648,687	768,891	911,371
Utabwalero	3.30%	645,476	761,269	897,836	3.40%	1,081,374	1,281,757	1,519,273
Chisumphi	3.30%	428,089	504,885	595,458	3.40%	717,182	850,080	1,007,604
Mlera	3.30%	264,786	312,287	368,309	3.40%	443,599	525,801	623,234
Chinkhombo	3.30%	435,242	513,321	605,407	3.40%	729,166	864,284	1,024,440
M'bang'ombe	3.30%	516,928	609,661	719,030	3.40%	866,016	1,026,493	1,216,707

Appendix 5.7b: Water Demand Projections for each village

Appendix 5.8a: WPI Work sheet

Villages	Households within 0.5km radius (5 people/household) (NSO, 2008)	Population 2009, (Po)	Sample Size (No. of households/village)	Resource (R) -Is water available & reliable?		Access (A) -Is it equitable?		Capacity (C) -Own bicycle & Member to WUA or VDC?		Use (U) -Is there Conjunctive Use for small scale irrigation?		Environmental Integrity (E) -Is there too much deforestation? Many ephemeral rivers?	
				Y	N	Y	N	Y	N	Y	N	Y	N
Chingondo	31	155	10	4	6	3	7	6	4	1	9	7	3
Gundamtengo	56	280	10	4	6	3	7	7	3	3	7	8	2
Kamchimba (East of Mc Pherson)	16	80	10	10	0	10	0	8	2	1	9	1	9
Agara Estate	95	475	10	10	0	10	0	9	1	0	10	0	10
Kakuyu Estate	75	375	10	2	8	10	0	9	1	3	7	2	8
Kalolo	78	390	10	3	7	3	7	4	6	4	6	6	4
Kansengwa	62	310	10	4	6	4	6	4	6	4	6	6	4
Kamanzi	69	345	10	6	4	4	6	6	4	1	9	7	3
Mkumba	99	495	10	7	3	3	7	5	5	2	8	5	5
Gezani	54	270	10	6	4	4	6	6	4	1	9	6	4
Nabvumi	55	275	10	8	2	5	5	6	4	2	8	6	4
Kawawa	34	170	10	1	9	3	7	3	7	3	7	8	2
Mandala	300	1500	10	3	7	4	6	5	5	4	6	7	3
Dzuluwanda	53	265	10	8	2	6	4	6	4	3	7	4	6
Khongoni Headquarters	24	120	10	1	9	3	7	4	6	1	9	3	7
Mpapa	79	395	10	5	5	1	9	4	6	2	8	3	7
Ching'anga	66	330	10	3	7	4	6	4	6	5	5	4	6
Utabwalero	110	550	10	2	8	3	7	4	6	4	6	2	8
Chisumphi	73	365	10	1	9	2	8	4	6	3	7	3	7
Mlera	45	225	10	3	7	4	6	5	5	4	6	4	6
Chinkhombo	74	370	10	4	6	4	6	6	4	4	6	6	4
M'bang'ombe	88	440	10	4	6	5	5	6	4	3	7	7	3

Appendix 5.8b: WPI Calculations

Village	Components Score (%)					Weights (w)					Weighted Score				
	Resource (R)	Access (A)	Capacity (C)	Use (U)	Environmental Integrity (E)	w_r	w_a	w_c	w_u	w_e	Resource, (R)	Access, (A)	Capacity, (C)	Use, (U)	Environmental Integrity, (E)
Chingondo	40	30	60	10	30	0.9	0.7	0.8	0.6	0.7	36	21	48	6	21
Gundamtengo	40	30	70	30	20	0.9	0.7	0.8	0.6	0.7	36	21	56	18	14
Kamchimba (East of Mc Pherson)	100	100	80	10	90	0.9	0.7	0.8	0.6	0.7	90	70	64	6	63
Agara Estate	100	100	90	0	100	0.9	0.7	0.8	0.6	0.7	90	70	72	0	70
Kakuyu Estate	20	100	90	30	80	0.9	0.7	0.8	0.6	0.7	18	70	72	18	56
Kalolo	30	30	40	40	40	0.9	0.7	0.8	0.6	0.7	27	21	32	24	28
Kansengwa	40	40	40	40	40	0.9	0.7	0.8	0.6	0.7	36	28	32	24	28
Kamanzi	60	40	60	10	30	0.9	0.7	0.8	0.6	0.7	54	28	48	6	21
Mkumba	70	30	50	20	50	0.9	0.7	0.8	0.6	0.7	63	21	40	12	35
Gezani	60	40	60	10	40	0.9	0.7	0.8	0.6	0.7	54	28	48	6	28
Nabvumi	80	50	60	20	40	0.9	0.7	0.8	0.6	0.7	72	35	48	12	28
Kawawa	10	30	30	30	20	0.9	0.7	0.8	0.6	0.7	9	21	24	18	14
Mandala	30	40	50	40	30	0.9	0.7	0.8	0.6	0.7	27	28	40	24	21
Dzuluwanda	80	60	60	30	60	0.9	0.7	0.8	0.6	0.7	72	42	48	18	42
Khongoni Headquarters	10	30	40	10	70	0.9	0.7	0.8	0.6	0.7	9	21	32	6	49
Mpapa	50	10	40	20	70	0.9	0.7	0.8	0.6	0.7	45	7	32	12	49
Ching'anga	30	40	40	50	60	0.9	0.7	0.8	0.6	0.7	27	28	32	30	42
Utabwalero	20	30	40	40	80	0.9	0.7	0.8	0.6	0.7	18	21	32	24	56
Chisumphi	10	20	40	30	70	0.9	0.7	0.8	0.6	0.7	9	14	32	18	49
Mlera	30	40	50	40	60	0.9	0.7	0.8	0.6	0.7	27	28	40	24	42
Chinkhombo	40	40	60	40	40	0.9	0.7	0.8	0.6	0.7	36	28	48	24	28
M'bang'ombe	40	50	60	30	30	0.9	0.7	0.8	0.6	0.7	36	35	48	18	21

Appendix 5.9: Questionnaire

Questionnaire for ***assessment of conjunctive use of small dams and groundwater for sustainable rural livelihoods in a semi-arid area: Case of Lilongwe West Rural Groundwater Supply Project area – Malawi*** study conducted in partial fulfilment for an award of Master of Science in Integrated Water Resources Management (MSc IWRM) tenable at The University of Zimbabwe. D.D. KAMBUKU

SECTION A: Household Water Use Log

1.0 T/A……………………………………………………………………………………………………

2.0 Village name…………………………….. ………………………………………………………………….

3.0 Family Name…………………………………………………………………………………………………

4.0 Father/Mother/Child headed (Cancel out inapplicable)

5.0 Number of household members…………………………………………………………………………….

6.0 Total number of households in this village…………………………………………………………………….

7.0 Name of the one recording water quantities……………………………………………..............................

8.0 Day and date of records………………………………………………………………...............................

9.0 State your primary source of water

……..
.

10.0 How far is it from your homestead, say how many football pitches? ....

11.0 How many buckets (20L pails) of water do you use for each of the outlined uses (add yours too) per day? Enter number of buckets (pails) on each day alongside its use!

Use	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Drinking							
Cooking							
Laundry							
Cleaning							
Piggery							
Dairy							
Poultry							
Fish Farm							
Fruits							
Gardening							
Others (Specify)							

SECTION B: CONJUNCTIVE USE AND FARMERS' WELFARE

Tick the applicable answer and fill the blank space.

1.0 Would you say there has been joint use of water from small dams and boreholes or shallow wells for irrigation in this area in general since 2005?

A: Yes. But on a very small scale
B: Yes. And on a pronounced scale
C: No. Only water from small dams has been used for irrigation. Borehole water is for human drinking and livestock production.
D: No. Small dams are not well distributed. Boreholes do not yield enough water for irrigation.
E: I don't know.

2.0 Has your family ever practised conjunctive use of water from earth dams and that from boreholes or shallow wells for small scale irrigation? If yes, state since when.

……..

3.0 What type of irrigation is commonly practised in this village?

……..

4.0 Would you say there is a positive change in terms of family welfare for those practising conjunctive use of small dams/ponds and groundwater from wells and/or boreholes?...

5.0

A: Yes. They have surplus yields which they, most of the times, sell. B: No. They just plant enough for their families. C: No difference at all. D: I don't know.

6.0 How much per yield (in monetary terms – Malawi Kwacha) does your family get from farm sales per yield? What percentage of this comes from Irrigation farming produce?

……

……

7.0 What assets do you have? How much did you pay for them?

1…………………………………………………………MK…………………………………………………………

2…………………………………………………………MK…………………………………………………………

3…………………………………………………………MK…………………………………………………………

4…………………………………………………………MK…………………………………………………………

5…………………………………………………………MK…………………………………………………………

8.0 What other expenditures do you make? How often?

……

……

……

……

……

……..

9.0 What is your other source of income?

…….

…….

SECTION C: WATER ALLOCATION PROCESS

10.0 Would you say small scale farmers have benefitted from small earth dams in an equitable way as commercial farmers?

A: Yes. Most of the earth dams are controlled by village committees
B: No. Well established farmers control water allocation either directly or indirectly.
C: No. Small scale farmers lack inputs like fertilizer for their small scale irrigation
D: I don't know.

11.0 What is the water allocation process like in your area?

……

……

……

……

……..

12.0 Any problems encountered with water allocation issues between or among farmers that you can remember? How were they resolved?

……
……
……

SECTION D: RELIABILITY

13.0 Do earth dams and boreholes near your homestead have had enough water/yield for all farmers during the four (4) past dry seasons?

A: No. The earth dam dries to minimum levels in dry season. The boreholes' yields are not adequate for irrigation

B: No. Earth dam dries up to minimum levels. Boreholes' yields are good enough to support small scale irrigation.

C: Yes. Earth dams alone are enough to support small scale agriculture.

14.0 Is quality of water from either earth dams or boreholes/shallow wells good for people and livestock? If no, what is the problem?

……
……
……
……
……
……
……

END.

Thank you for answering these questions!