UNIVERSITY OF ZIMBABWE

Assessment of impacts of socio-economic activities on water quality within Mulunguzi Catchment, Malawi

BY
Jacqueline Lekani Dias

A thesis submitted in partial fulfilment of the requirements for the Master of Science Degree in Integrated Water Resources Management (IWRM)

Department of Civil Engineering
Faculty of Engineering

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Supervisors

Eng. Z. Hoko (UZ)
Dr. S. Sajidu (UNIMA)

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DECLARATION

I hereby certify that the results, calculations and graphs presented in this report are essentially my own work

Name: **Jacqueline Lekani Dias**

Signed………………………………day of ……………………………………2008

DEDICATION

To PJ, my one and only. Thanks for taking care of Nicole when she was only ten months old. Celesta for sacrificing your time to take care of my angels Vitoh and Nicole

Dad for your prayers and my late Mama for interceding for me, brothers and sisters, I cherish you all.

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ABSTRACT

The main objective of this research was to assess the impact of socio-economic activities on water quality within Mulunguzi hydrological catchment. The rate of timber harvesting has not matched the rate of planting within the catchment which renders a large percentage of the catchment bare. The socio-economic activities within the catchment do not incorporate measures to safeguard the quality of water resources. Despite the fact that the mentioned activities are a threat to water quality, there is insufficient information on the impact of socio-economic activities on water quality within the catchment.

The study was conducted from January to March, 2008 and aimed at determining surface water quality in relation to socio-economic activities and to quantify the resultant pollutant loads. Socio-economic activities in the catchment were timber harvesting, animal and fish farming. Methods of study included water quality parameter analysis and documentation review. Water quality parameters studied included turbidity, pH, temperature, DO, faecal coliforms, nitrates, phosphates, sulphates, iron and manganese. Nitrates, phosphates and sulphates were analyzed using ion chromatography; iron and manganese through atomic absorption spectrophotometer. Turbidity, pH, temperature, dissolved oxygen and faecal coliforms were analyzed according to standard methods.

The results showed that nitrates concentrations ranged from 0.01 to 0.27 mg/L, phosphates 0.0 to 0.4 mg/L and sulphates 0.16 to 0.59 mg/L. Turbidity values ranged from 0.18 to 13.5 NTU, faecal coliforms ranged from 1 to 173 CFU/100. Iron and manganese concentration ranges were 0.0 to 10.6 mg/L and 0.0 to 0.68 mg/L respectively. Significant differences ($p<0.05$) were observed between upstream and downstream of timber harvesting activities in terms of turbidity and faecal coliforms; the Trout farm in terms of turbidity, faecal coliform, nitrates and phosphates; and for settlements in terms of turbidity, faecal coliform and sulphates; and finally for animal farming in terms of faecal coliform. Socio-economic activities were contributing more pollutant loads in terms of nitrates. The pollutant loads are accumulating at the bottom of the dam

The results suggest that water quality within the catchment is being affected by socio-economic activities under consideration. The activity affecting water quality most was trout fish farming and least was animal farming. There is need for awareness campaigns to promote behavior change among various stakeholders as well as good management and practices within the catchment on the importance of protecting water sources.

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CHAPTER 1

1.0 INTRODUCTION

1.1 General background

Safe adequate and sustainable water supplies for all, is one of the main social goals enunciated at global and regional levels (GWP, 2003). One of the Millennium Development Goals (MDG) target is to halve by 2015, the proportion of people without sustainable access to safe drinking water and sanitation (van der Zaag, 2007). Today 1.1 billion people lack access to safe drinking water and 2.4 billion people have inadequate access to sanitation according to the UN Development Program (Pottinger, 2001). The demand for fresh water is exacerbated by the fact that there are competing activities for the resource such as industry, agriculture, livestock and wildlife. Appropriate utilisation of water resources can help to alleviate poverty by bringing important benefits including improved health, increased agricultural and industrial productivity and increased human security.

The water resources in Malawi are continuously being threatened by a number of problems ranging from vagaries of weather to overexploitation, environmental degradation and pollution, which poise serious challenges to water resources management (Kankhulungo, 2003). The problem of water scarcity in Malawi is growing. The country is experiencing frequent occurrences of droughts resulting in dwindling river flow and reduced groundwater levels more especially during dry season. Malawi has been identified to be one of the countries in Southern Africa categorised under 'absolute water scarcity' by 2025 (Rothert *et al.*, 1999). Water resources degradation was identified as one of the very serious concerns that the country is facing. As a result of the effect of population pressure arising from high population growth and effects of deforestation, most of the water resources have been degraded. At the same time due to agricultural practices, there is considerable siltation in the rivers greatly affecting the water quality of the rivers (Chimwanza *et al.,* 2006). Increasing improper disposal of industrial waste products including human sewage into water courses as well as groundwater has led to serious pollution of water resources in the country especially in urban areas of Blantyre, Lilongwe, Zomba and Mzuzu (Sajidu *et al*., 2007). At the same time, increasing application of agro-chemicals such as fertilizers and pesticides in cultivated lands has also greatly contributed to the degradation of water resources in catchments which are heavily cultivated.

Urban areas in Malawi depend on water from perennial rivers whose discharge is sustained by base flows in the dry season. For example the City of Lilongwe, which is the Capital City of Malawi, depends on water from Lilongwe River, which originates from Dzalanyama hills to the South West of the City. Likewise, the City of Zomba together with Zomba South Rural Scheme in Southern Malawi is served by the Mulunguzi River, which originates from Mulunguzi catchment (Pike and Rimington, 1971).

Mulunguzi catchment covers an area of about 20 km^2 and is wholly situated in the Zomba forest reserve. The reserve itself covers some 8170 ha (RFO, 2001). The catchment is situated in the Zomba Mountain forest of which 2194 ha is under forest plantation, 506 ha is natural woodland and about 680 ha is land which cannot be planted (rock outcrops, roads, firebreaks, river belts and settlement). The plantation in the catchment is composed *of Pinus* and *Widdringtonia* species with small woodlots of *Eucalyptus* and minor hardwood species along the lower tributaries. *Brachstegia* woodland flanks the steeper slopes and some stream banks. The plantation was planted for commercial purposes and it's under the jurisdiction of Forestry Department (FD). Mulunguzi dam is located within the catchment.

Mulunguzi dam is the main source of water for Zomba Municipality which has a projected population of about 87,200 based on 1998 population census calculated at 2.5 % growth rate. The dam was commissioned in 2000 to ease water shortages in the area which rendered schools and colleges to close. The dam has a capacity of 3.4 Mm^3 and is the second largest in Malawi after Mpira Balaka Dam (ZWSP, 1998). The dam is a rock fill type and has a free overflow with a downstream rock cascade and a 180 meter long tunnel with an equivalent diameter of 4.0 meters. The tunnel harbors a penstock and delivery pipe. It is under the control of Southern Region Water Board (SRWB).

SRWB is a parastatal organization which was formed in 1995 through an act of parliament. There are five Water Boards in Malawi which are Blantyre Water Board (BWB), which is responsible for supplying potable water to Blantyre City and Lilongwe Water Board (LWB), supplying the Capital City of Malawi, Lilongwe. Three Regional Water Boards, which are Northern Region Water Board (NRWB), Central Region Water Board (CRWB) and Southern Region Water Board (SRWB), are responsible for supplying potable water to all small towns in the north, central and southern part of Malawi respectively except the mentioned Cities of Lilongwe and Blantyre. Ministry of Water Development and Irrigation is responsible for supplying rural areas through gravity piped schemes and boreholes (Ministry of Water Development, 1997)

1.2 Problem statement

Due to a number of factors such as successive forest fires that occurred between 1995 and 1998, cyclones, over harvesting and generally poor forestry management, the vegetation cover in Mulunguzi catchment has been destroyed (RFO, 2000). However replanting efforts have not matched the rate of tree harvesting because of lack of resources and inappropriate management plans by Forestry Department (Chilima, 2001). As a result, large areas of the catchment are bare or with inappropriate vegetation cover to protect the soil from high levels of soil erosion and increased risk of sedimentation. Poor sanitation, fish and animal keeping are some activities also suspected to contribute to degradation of water quality in the catchment (Interconsult, 2001).

Despite all the threats which might arise from the above activities, there is insufficient information in the area to determine the impact of the stated bad practices on water quality that might help to guide implementation of mitigation measures (Chilima, 2001).

1.3 Justification

The Municipality of Zomba used to experience regular acute water shortages in the early 1990s more particularly during the 1991/92 drought. Schools and colleges closed due to water shortages. Mulunguzi Dam, which is the second largest in Malawi was constructed and commissioned in 2000 to ease the situation.

Since its commissioning, the dam is experiencing a number of problems which include the development of algae (Mazibuko, 2007). The samples analysed for algae comprised 90% *Zygnema* and *Zygnemopsis, Anabaena* represented 4% occurrence while 6% comprises of *Mougeotia*, *Thamniochate*, *Spirogyra*, and *Euglena*. The presence of faecal coliforms in the dam which is indicative of human and animal contamination (Chapman, 1996) is a worrisome situation. Despite the findings, no thorough investigations have been conducted to establish the activities which could be contributing to the pollution.

Companies processing timber in the forest make temporary shacks within the catchment. Without proper sanitation provision, the workers consequently defecate within the catchment area. There is dumping of waste in the catchment and animals are let to graze in the buffer zones. Studies conducted at South Lunzu in the City of Blantyre found that poor sanitation and domestic solid waste were polluting water resources in the area (Palamuleni, 2002). In view of this it can be hypothesised that the aforesaid activities could also contaminate the water resources within the catchment. However the impacts of these activities on water quality have never been studied thoroughly. It was therefore imperative to undertake the study so that the managing authorities could consider designing mitigation measures before the problem becomes unmanageable.

Mulunguzi catchment is part of Lake Chilwa which is designated under the Ramsar Convention on wetlands which was signed in Iran, in 1971. Ramsar Convention is an intergovernmental treaty which provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources (Chavula, 1999). According to Chavula (1999), Lake Chilwa, which is downstream Mulunguzi Catchment has rare species of both fish and aquatic birds. Water is reusable downstream if quality is maintained upstream (GWP, 2000). Polluted surface water cannot sustain a balanced ecosystem; therefore it is necessary that sources of water be jealously guarded for the establishment of a stable, healthy community (Tebbutt, 1992).

1.4 General and specific objectives

The general objective of the study was to assess the effect of socio-economic activities on water quality within Mulunguzi Catchment.

Specifically the objectives were:

- To determine water quality in the dam and rivers in relation to socio-economic activities which are timber harvesting, settlements, animal and fish farming
- To quantify the pollutant load emanating from the stated socio-economic activities.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 General background

The world's land and water resources are critical for human survival (Penning et al., 2002). They provide goods such as food crops, fish, livestock, timber and other products. They also provide ecological services such as purification of air and water, maintenance of biological diversity, decomposition, and recycling of nutrients (World Resources Institute, 2000). Despite the emerging recognition of their central role in human survival, land and water ecosystems are being degraded at an alarming rate due to over usage and pollution (Miller, 1996). As a result they are under a threat, creating negative impacts on human livelihoods and recreation (GWP, 2000).

It is important to appreciate that all natural waters contain a variety of contaminants arising from erosion, leaching and weathering processes (Smol, 2003). According to Smol (2003), any body of water is capable of assimilating a certain amount of pollution without serious effects because of the dilution and self purification factors which are present. If additional pollution emanating from human activities occur, the nature of receiving water will be altered and its suitability for various uses may be impaired (Tebbutt, 1992). As is the case of Kafue River in Zambia, continuous discharge of pollutants into the river has led to eutrophic conditions, increased heavy metals resulting in decreased fish catch and fish size (Kambole, 2003). Water quality deterioration in Malawi results from increased suspended solids and turbidity, caused by deforestation and inappropriate land use (MWSWD, 1994). Inadequate sanitation and waste disposal arrangements in many settlements are also resulting in increased contamination of water sources, with potential risks to human health. Improper application of agricultural and hazardous chemicals in industrial wastes, also present risks of contamination of receiving waters (Kankhulungo, 2003). Essential parameters in relation to human activities are presented in section that follows.

2.2 Turbidity

Turbidity in water is caused by the presence of suspended matter such as clay, silt, colloidal organic particles, plankton, and other microscopic organisms (Chapman, 1996). Soil becomes susceptible to erosive agents when it is stripped of its protective vegetative cover; this in turn enhances the water/wind erosive force where atmospheric deposition and surface run-off are loaded with suspended sediments or dust (Machiwa, 2003). Suspended sediments in turn increase water turbidity especially in areas where timber harvesting are not properly planned (USEPA, 1992).

Sullivana (1985) examined a 10 km reach of Santiam River flowing through a managed forest land with an area of 8,000 ha. Continuous monitoring of suspended sediment and turbidity levels from 1972-80 indicated no deterioration of water quality through time. During this period, the watershed was subjected to harvesting of 3,400 ha of old growth and creation of additional 180 km roads. The author concluded that strong erosion control practices reduced turbidity to near background levels. Hornbeck and Reinhart (1964) examined water quality of five experimental watersheds which underwent a variety of harvest treatment. These treatments ranged from commercial clear-cut to a carefully planned and logged intensive selection cut. The commercial clear-cut exhibited a maximum turbidity of 56,000 NTU while the planned cut exhibited a maximum value of 25 NTU. The authors suggested that the result exemplified the value of good planning in controlling timber harvest impacts to water quality. In another study to examine the influence of strip cut covered with deciduous forest (Hornbeck et al., 1975), storm flow turbidity was measured before, during and after harvesting. The maximum turbidity taken prior to logging was 23 NTU. During and after logging, the drinking standard of 10 NTU was exceeded only six times. The author suggested that lack of impacts was due to careful logging.

Livestock grazing is related to run-off, erosion, and sediment (Packer, 1953; Platts and Meehan 1977; Van Haveren et al., 1985). A study by Rauzi and Hanson (1966) evaluated the influences of grazing levels and vegetation cover on water run-off in mixed prairie in South Dakota. They found that water intake rate decreased as grazing intensity increased and that annual run-off was greatest from heavily grazed watersheds and least from lightly grazed watersheds. Differences in soil bulk density and soil pore space between the grazing levels were significant. The authors concluded that heavy grazing can change soil properties including decreasing the pore spaces and increasing bulk density. Because of alteration of soil properties by cattle grazing, runoff levels and soil erosion are affected. In a study of different grazing levels in a Colorado pine-bunchgrass range, Dunford (1949) noted an increase of 210 and 325% in moderate and heavy grazing areas, respectively, compared to a control area. The amount of soil eroded from control areas was approximately half the amount yielded from the heavily grazed area, but no change from the control area was noted in the moderately grazed area. In the Badger Wash Basin of western Colorado, Lusby (1970) found that run-off was directly related to the amount of bare soil. Grazed watersheds were compared to watersheds where cattle and sheep were removed. After 2 years, the grazed watersheds averaged 30% more run-off than the ungrazed. Also the ungrazed watersheds yielded 45% less sediment. The greatest differences in sediment were noted after 3 yr of cattle exclusion, with the grazed watersheds averaging 51% more run-off than the ungrazed watersheds (Lusby et al. 1971). In a southwestern Wisconsin study, Sartz and Tolsted (1974) also reported reduced run-off levels following 3 years of cattle exclosure.

Turbidity has no health effects but can interfere with disinfection and provide a media for microbial organisms (Akoto and Adiyiah, 2007. Sanderson and Kelly (Clark , 1964) reported the presence of coliforms in water with turbidities ranging between 3.8 and 84 NTU. This was after treatment with chlorine producing free chlorine residues between 0.1 and 0.5 mg/L and a minimum contact time of 30 minutes. The presence in water of various clays and humid acid was shown to protect "*Klebsiella aerogenes*" from disinfection (Bitton, 1972). Suspended sediments can damage the gills of some fish species, causing them to suffocate, and can limit the ability of sight-feeding fish to find and obtain food (USEPA, 1992).

Careful logging and erosion control practices during harvesting, results in low measured turbidity values. Animal grazing is related to run-off, erosion and sediments. Livestock grazing within the watershed reduces water intake rate as grazing intensity increases. Heavy cattle grazing changes soil pore-spaces and increases soil bulk density. Run-off levels and soil erosion are in turn affected because of the alteration of these properties. Due to increased run-off and erosion, heavily grazed watersheds yield more sediments than lightly grazed areas.

2.3 pH

The pH is an important variable in water quality assessment as it influences many biological and chemical processes within a water body (Chapman, 1996). According to Chapman (1996), the most usual causes of acidity are free carbon dioxide in the water and organic acids. Another wide spread cause of acidity is decomposing organic matter of vegetable and especially peaty origin producing carbonic acid and organic acids in water (Twort *et al*. 1974). The presence of nutrients and industrial effluents into the aquatic environment leads to fluctuation of pH (Chapman, 1996).

In nearly all cases in Minnesota, pH does not change after timber harvesting (Chessman, 1986; Cornish and Binns, 1987; McClurkin et al., 1987; Davis, 1989). However, deposition of conifer bark increased soil pH slightly (Lumme and Laiho, 1988). Conifers grow in and produce acidic coils, reducing the pH of runoff. Afforestation of watershed which had previously been vegetated with gorse or other shrubs often has resulted in reduction of pH in their effluent streams (JPC, 1992).

Most acid waters are corrosive (Twort et al., 1974). Corrosion in water mains and water treatment plants can be a major economic burden (WHO, 1984). In addition to the corrosion problem there is a loss of distribution capacity and the concomitant increase in the pumping costs that result in cases of calcium carbonate composition (McClanahan and Mancy, 1974). Low pH is fatal to aquatic life (Chapman, 1996). A direct relationship between human health and the pH of drinking water is impossible to ascertain because pH is so closely associated with other aspects (WHO, 1984). Taylor (1966) was unable to establish any correlation between the incidence of viral hepatitis A and finished water pH. However, it is claimed that at high pH levels, drinking water acquires a bitter taste (US EPA, 1977).

Increased pH levels in a timber harvesting activities in watershed in associated with tree species. Timber harvesting activities per se in a watershed do not increase pH levels

2.4 Temperature

Stream water temperature rise is directly related to the amount of water surface exposed to direct sunlight after timber harvesting (Ensign and Mallin, 2001). Tree canopy removal can raise stream temperatures by 3-7 ^{o}C (Binkley and Brown, 1993). Levno and Rothacher (1967) found that logging increased water temperature after 55 percent of watershed was cleared and trees were felled along all major streams. However, Brown (1970) addressed the stream temperatures issue in a more precise way. He recognized that solar radiation falling on a stream was one of the significant variables associated with summertime stream heating and it was the removal of riparian vegetation, rather than timber harvesting in the watershed per se, which most directly affects stream temperatures. Use of buffer zones has proven to protect streams from temperature rise of more than 2 ^{o}C. This was demonstrated by Messina *et al.* (1997) who found temperature increase of stream water in a clear cut site compared to a control in Texas bottomland hardwood forest for streamside management zone (SMZ).

Cattle prefer riparian areas because of the topography, variety of forage, and availability of shade, water, and thermal cover (Ames 1977; Gillen et al. 1985). The combination of cattle preference for riparian areas and the importance of these areas for maintaining water quality accentuate the problems caused to water quality. Grazing may influence water temperature by the removal of vegetation that shades the stream (Wyoming Department of Environmental Quality, 1990).

In a study conducted in Alsea in the Oregon Cost Range, temperature increase (30 ^{o}C) in a clear-cut resulted in a significant decline in resident trout population to one third pre-harvest (JPC, 1992). These effects lasted for seven years after timber harvesting. In the patch cut and control basins, trout populations actually increased after harvest. The study demonstrated the need of riparian protection and the potential for serious long-term impacts without stream and riparian protection (Hicks et al., 1991). Temperature has no public health effect but cool drinking water is preferable to warm (WHO, 1984). Temperature affects every aspect of treatment and delivery of potable water (Chapman, 1996). The efficiency removal of colour and turbidity removal by coagulation, sedimentation and filtration may be less under winter temperature conditions than in summer (WHO, 1984). At low temperatures, viruses can survive considerably longer than bacteria and survival times of up to six months have been reported by poliovirus in tap at low temperatures (HWC, 1977).

The scientific literature strongly indicates that the removal of riparian vegetation increases the summertime temperatures of streams. It also indicates that these temperature increases should be minimal in streams where shading has been maintained by effective buffers. Grazing may influence increased water temperatures by removal of riparian vegetation that shades the streams.

2.5 Dissolved Oxygen

Oxygen levels in flowing streams are usually near saturation and are not often a cause of concern (JPC, 1992). Harvest operations have been shown to alter flow volumes and alter riparian zone characteristics (Hunter, 1990). According to Hunter (1990), low flows during late summer can be expected to produce higher water temperatures in streams, thus reducing the ability to hold oxygen. Dissolved oxygen levels may also be lowered by an increase in oxygen demand if large amounts of organic sediment or debris enter streams or reservoirs as a result of timber harvest (Chapman, 1996).

Binkley and Brown's (1993) review of timber harvest effects on water quality found that dissolved oxygen (DO) is frequently depressed downstream of harvested areas. Decreased in-stream DO was attributed to a biological oxygen demand (BOD) load of organic material released as a result of forest disturbance. The decrease in DO at Goshen

Swamp in Texas was attributed to logging debris and algal biomass coming from BOD loads (Ensign and Mallin, 2001).

Animal grazing is frequently accompanied by nutrient enrichment from dung and urine (Reeves and Champion, 2004). Manure from grazing animals contains organic matter, which can serve as oxygen-demanding materials (Hatfield et al., 1998). Nutrients can lead to a decrease in DO concentrations as a result of the increased microbial activity occurring during degradation of organic matter (Wyoming Department of Environmental Quality, 1990). If the rate of oxygen depletion exceeds the aeration rate of the stream, oxygen depletion occurs (Hubbard et al., 2004.

Significant difference in dissolved oxygen was observed upstream and downstream of trout fish farm in a study conducted in Karasu stream, Turkey (Pulatsu et al., 2004). Higher feeding rates increased the output of organic matter from farms either as uneaten food or faeces and resulted in marked elevations in the BOD of receiving waters. This in turn resulted in higher DO intake from the feeding water. The relatively high concentration of DO occurred downstream of the trout farm. This was accredited to mechanical aeration and oxygenation of receiving waters. Similar observations were also reported by Boaventura et al. (1997).

Depletion of DO in water bodies causes death of most aquatic species if exposed for longer than a few hours (Chapman, 1996). The critical range according to South African guidelines (1993) is between 0-1 mg/L. Chapman (1996) indicated that DO levels below 2 mg/L can lead to the death of many fish. DO has no health effects but depletion of dissolved oxygen concentration below 80 percent saturation leads to an increased incidence of consumer complaints especially regarding taste, odour, and discolored water (WHO, 1984).

Decreasing of in-stream dissolved oxygen demand in timber harvesting activities, results from increased oxygen demand from debris, organic sediment and algal biomass. Manure from grazing animals contains organic matter, which can serve as oxygen demanding materials. Nutrients from dung and urine exert high BOD due to increased microbial activities during degradation of organic matter. Oxygen depletion in fish farming is mainly due to fish feed and faeces, which result in higher DO intake from the feeding waters. Mechanical aeration and oxygenation of receiving water increase DO concentration downstream of receiving waters.

2.6 Faecal coliforms

Major water quality concern with grazing animals is pathogens, which may move from wastes into surface water bodies particularly when the animals are not fenced out from streams (Hubbard et al., 2004). Cattle have been shown to produce 5.4 billion faecal coliform and 31 billion faecal streptococcus bacteria in their faeces per day (Howard et al., 1983). According to Howard et al. (1983), cattle can contribute significant numbers of these organisms to surface waters since they spend a significant portion of their time in or near streams, lakes, and wetland areas and on average cattle defecate 12 times per day. Proximity of cattle to the stream determines the level of impacts to water quality. Cattle grazing adjacent to streams cause greater impacts to water quality (Buckhouse and Gifford 1976; Milne, 1976). Unless animals are defecating directly into the stream or adjacent to the streambed, faecal coliform contamination is unlikely (Buckhouse and Gifford, 1976). A study of a western Montana stream concluded that in a cattle winter grazing situation, little bacterial impact existed on stream sections that were inaccessible to the livestock (Milne, 1976). Run-off affects delivery of animal wastes to streams (Jawson et al., 1982). In a study by Saxton et al. (1983), faecal coliform and faecal streptococcal bacteria increased from cattle grazed area with run-off levels in the spring after animals were removed. In Big Creek, Utah, Duff (1977) noted that faecal coliform levels from grazed stream reaches were generally low except during a period of heavy rains which increased run-off levels.

The presence of excessive levels of pathogenic bacteria renders water unsuitable to human consumption or contact (Hammer and MacKichan, 1981). Such contamination brings a threat of infection for people who use the water for drinking, bathing, or watering fruits and vegetables. Human faeces can contain a variety of intestinal pathogens which cause diseases ranging from mild gastro-enteritis to serious and possibly fatal dysentery, cholera and typhoid (WHO, 1984). Twort et al. (1974) indicated that the presence of any faecal coliforms must be regarded as an advance warning that more serious pollution may follow especially after rain.

Animal grazing adjacent to the stream has the greater potential of impacting water quality through the faecal matter. Two main factors that exacerbate this impact include direct defecation in the stream but also through run-off which delivers animal waste to streams.

2.7 Nitrates

The nitrogen cycle in an undisturbed forest is relatively closed system of soil- plant-microorganisms interaction (Vitousek, 1983). Timber harvesting interrupts the nitrogen cycle by eliminating uptake of plants (JPC, 1992). At the same time, nitrate continues to be produced on site by nitrogen-fixing organisms and subsequently accumulates on the site. In fact, nitrogen fixation is often accelerated because canopy removal raises soil temperature and moisture by exposing the ground to sunlight and decreasing water losses from evapotransipiration thereby promoting increased microbiological activity (Likens et al., 1970). Excess nitrogen is removed from the site through erosion and nitrate leaching (JPC, 1992). The nitrate ion is relatively mobile and can be easily leached into streams (Vitousek, 1983). According to Vitousek (1983) erosive losses of nitrate are usually small in undisturbed areas, but soil exposed by logging can become dislodged and washed from site into nearby streams and waterways.

Studies by Hornebeck et al. (1975) reported that strip cutting increased stream nitrate concentrations from 7 to 25 mg/L. Martin and Pierce (1980) reported stream nitrate increased from baseline levels of 1.8 mg/L to a maximum levels of 25.1 mg/L following a clear-cut. In his studies, Likens et al. (1969) reported that nitrate concentrations increased 59-fold from 0.9 to 53 mg/L in a two year period after clear-cutting and vegetation removal. In another report one year later, Likens et al. (1970) reported that nitrate concentrations on a harvested watershed were 41-fold higher the first year after harvesting and 56-fold higher the second year following harvesting. Hornebeck and Kroeplin (1982) reported that nitrate concentrations increased two to three times over a one-to two- year period after cutting.

Increased nitrate levels also result from animal grazing (Chesters and Schierow, 1985; Crosson, 1987; Robinson, 1988). Nitrates from grazing are of short duration and do not seriously impact water quality, except in situations of obvious overgrazing by livestock (Van Haveren et al., 1985). Gary et al. (1983) noted that even when cattle spent more than 65 percent of the day adjacent to the stream, only small changes in nitrate concentrations occur. Duff (1977) found nitrate and phosphate levels associated with cattle grazing in the bottomlands to increase with run-off, but water quality remained acceptable.

The more significant impact of nutrient enrichment from grazing is the downstream cumulative impacts of eutrophication (Likens and Bormann, 1974; Cole et al., 1986). Nutrients (primarily phosphorous and nitrogen) from animal excreta entering the stream may pass through the stream system with little impact, but provide increased nutrients to downstream bodies of water. Excess nutrient loading provided to aquatic vegetation results in increased photosynthetic rates followed by diminishing light transmission through the water (JPC, 1992). Decreasing light decreases photosynthetic rates, causing plants to consume oxygen for respiration, leading to oxygen depletion of the water (U. S. EPA, 1979). Reduced DO levels leads to death of fish if DO levels drop to 1-3 mg/L (SA guidelines, 1993). High concentrations of nitrates cause methemoglobinemia (blue baby disease), whereas nitrites are considered to be potentially carcinogenic (Hubbard et al., 2004).

Timber harvesting disrupts the nitrogen cycle by eliminating uptake by plants. Canopy removal raises soil temperature and moisture by exposing the ground to sunlight and decreasing water losses from evapotransipiration thereby increasing denitrification of nitrogen to nitrates. Nitrate ion can be moved into streams through erosion and nitrate leaching. Animal grazing can introduce nutrients through excreta entering the streams. Nutrients loads from animal grazing are of short duration and impact is minimal except for areas which are overgrazed.

2.8 Phosphorous

Phosphorous behaves quite differently from nitrogen in forested areas (Vitousek, 1983). It does not ordinarily undergo oxidation-reduction reactions and is not significantly associated with organic decomposition (JPC, 1992). Phosphorous is relatively immobile in the soil, being taken up by microorganisms and precipitated with various cations. It is added to the soil through rock weathering, while losses occur through removal of forest products and soil erosion (Chapman, 1996).

The relative immobility and low leaching potential of phosphorous usually means that only a small amounts end up in streams following harvesting (JPC, 1992). Although some authors report that timber harvesting can increase stream phosphate (Vitousek, 1983) many researchers do not report phosphate contributions to stream water as being an important consequence of forest harvest. Post-harvest levels of phosphate in streams have not often been reported in literature; perhaps because of minor impact timber harvesting has on stream phosphate levels (JPC, 1992). It is well known that phosphate loading from agricultural run-off plays a major role in eutrophication of lakes and waterways, but studies indicate that only small changes occur during harvesting operations. Douglas and Swank (1975) reported stream concentrations of 0.001 to 0.020 mg/L on a 180-acre clear-cut site. Phosphate increases reported by Hornbeck et al. (1986a) were also minimal. In the western U.S., phosphate levels were reported to double after clear-cutting and burning at H.J. Andrews's experimental forest in Oregon (Fredriksen, 1971; Fredriksen et al., 1975). Although the levels doubled, concentrations were low, ranging from 0.016 to 0.039 mg/L. Phosphate levels in streams at the Alsea watershed in Oregon showed no increase after a 25 percent clear-cut (Fredriksen, 1971).

Effluents from fish farming are discharged to the environment with enhanced concentrations of nutrients and solids (Pulatsu et al., 2004). The sources are from fish excretion and uneaten food (Bartoli et al., 2007). Bartoli et al. (2007) found that 30 percent of nitrogen and phosphorous were retained in fish farm effluent despite the fact that all the pellets supplied were consumed. Their results confirmed the general findings that even if the small amounts of supplied food is completely eaten by fish, excreted and faecal materials are dispersed in the environment. Such effluents may have a serious negative impact on receiving waters when discharged untreated (Pulatsu et al., 2004).

In general, changes in stream phosphate following timber harvesting seemed to be more variable and about an order of smaller magnitude. Serious water quality impacts from phosphorous can occur from discharging untreated effluent into the receiving waters.

2.9 Iron and manganese

Metals found commonly in fish feed are contributed by the raw ingredients and a mineral pack added by the manufacturer (Maule et al., 2007). Iron and manganese concentrations from a Norwegian feed ranged from 68.7-353 ppm and 5-120 ppm respectively, and were slightly higher than iron and manganese concentrations ranges (15.0-622.0 µg/L and 3.6-196 µg/L, respectively) in fish feed found by Maule et al. (2007).

Most water contains some iron and manganese which naturally leaches from rocks and soils (HETL, 2004). The presence of iron and manganese in fresh waters can be attributed to the dissolution of rocks and minerals, acid mine drain, landfill leachates, sewage, or iron related industries (WHO, 1984).

Iron is an essential element in human nutrition (WHO, 1984). This metal is not harmful but can make water unpalatable when present in large amounts (Twort el. 1974). When water is exposed to air and takes up oxygen, the iron is likely to precipitate and the deposits cause brown stains upon sinks, baths, washbasins and laundry (WHO, 1984). The iron that settles out in the distribution system gradually reduces the flow of water. Manganese is regarded as one of the least toxic pollutants in water although in 1941; it was associated with a disease called encephalitis in Japan when the concentrations were above 14 mg/ (WHO, 1974). In another area in Japan, manganese concentrations of 0.75 mg/L in drinking water had no apparent adverse effects on the health of its consumers (Suzuki, 1970).

Iron and manganese found in fish feed are contributed by the raw ingredients and mineral pack added by the manufacturers. Concentrations of these metals were of smaller magnitude. Trace amounts of these metals are always present in fresh water from the weathering of rocks and soils.

2.10 Pollutant load

Human activities are usually the main sources of toxic pollutant in water sources (Tebbutt, 1992). These activities may be responsible for increasing the erosion rates thereby allowing concentrations to reach levels which may be a hazard to aquatic systems and to man (Chapman, 1996). Organisms react to concentrations and exposure time of a contaminant in a water body. The lake or reservoir concentration, either in water or sediment is as a result of the pollutant load which is mass per unit. Pollutant loadings in tonnes (P_L) are calculated using equation (1) while the total loading rate (P_{TL}) is calculated using equation 2 (Ntengwe, 2006).

1. $P_L = QC$ ………………………………… 1

2. $P_{TL} = Q\,(C_1+C_2+C_3 \,……..+Cn)$…………...2

Where

P_L is indicative pollutant load
Q is flow rate in m^3/d
C is concentration of the parameters in mg/L
C_1, C_2 ...C_n are concentrations of different pollutants passing through a point
IP_{TL} is indicative total loading at any point

The daily pollutant load from trout fish effluent for Karasu stream in Turkey was estimated to be 8.09 kg/day (Pulatsu, 2004). The phosphorous load obtained were considered high and exceeded loads reported for fish farms in Nordic and North American farms. Bartoli et al. (2007) measured a net daily load exported from Val Cedra fish farm in Italy of 2.20 kg N/day and 0.76 kg/day phosphorous. The results were influenced by fish feed. According to Bartoli et al. (2007) when higher amounts of fish feed are used the proportion of waste products probably remains the same. Nutrients loads from fish farms could be reduced by use of low pollution feed and better feed management (Pulatsu, 2004).

2.11 Mitigation measures on impacts of socio-economic activities on water quality

Riparian zones are considered one of the most important components of the aquatic/terrestrial landscape due to their influence on habitat within the aquatic system; transport of pollutants and erosion to a stream, wetland or lake; habitat of terrestrial species; and recreation opportunities for the public (JPC, 1992). According to JPC (1992), numerous authors have provided recommendations for best management practices (BMPs). Swift and Baker (1973) found that maintenance of riparian vegetation between a clear-cut and the stream bank prevented significant changes in stream temperature. Brazier and Brown (1973) also found that a properly managed buffer strip could prevent significant harvest induced changes to stream temperatures. Welch et al. (1977) observed significant reductions in stream benthos below abandoned logging roads which had contributed sediment to the stream channel. In addition, the authors noted that most small logging operations (<1000 ha) within their study area had been clear-cut up to the stream bank. The authors concluded that impacts to stream communities could be minimized by management of a buffer strip and proper construction and maintenance of abandoned roads.

Curtis et al. (1990) examined the effectiveness of BMPs in preventing changes in water quality and ecology within the Pickett State Forest, Tennessee. Buffer strips were designed adjacent to cut areas to minimize sedimentation, changes in stream temperature and changes in allochthonous litter inputs to the stream system. Although temperature ranges increased slightly, no real change in stream temperatures were observed after harvest with buffer strips. In addition, changes in suspended solids and invertebrate densities and biomass were minimized when harvest incorporated buffer strips.

Grazing best management practices are often implemented without considering integrated functions of the control system (Carmen et al., 2004). Recommendations regarding BMP implementation are based largely on general considerations such as proximity of grazing pastures to streams, grazing intensity in relation to vegetative cover, and livestock access to streams (Hubbard, 2004). Grazing animal systems should be managed to include adequate land area for animal numbers at the field and landscape scale, fencing animals out of streams and lakes and use of riparian buffer systems to assimilate sediment, nutrients and pathogens from grazing animals (Carmen et al., 2004).

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CHAPTER 3

3.0 STUDY AREA

3.1 Location of the area

The area under study is located in Zomba District, about 70km from the City of Blantyre in Southern Malawi at latitudes 15^0 90'S and longitude 35^0 19' E (Figure 1).

Figure 1 Map of Malawi showing Zomba District where the study area is located

The Municipality of Zomba was the capital of Malawi during the colonial era up to 1975. The capital was subsequently moved to Lilongwe. It was declared a City in April, 2008. The District is part of the Lake Chilwa catchment area, which occupies a depression of the East African Rift Valley System located to the east of the study area (Figure 2).

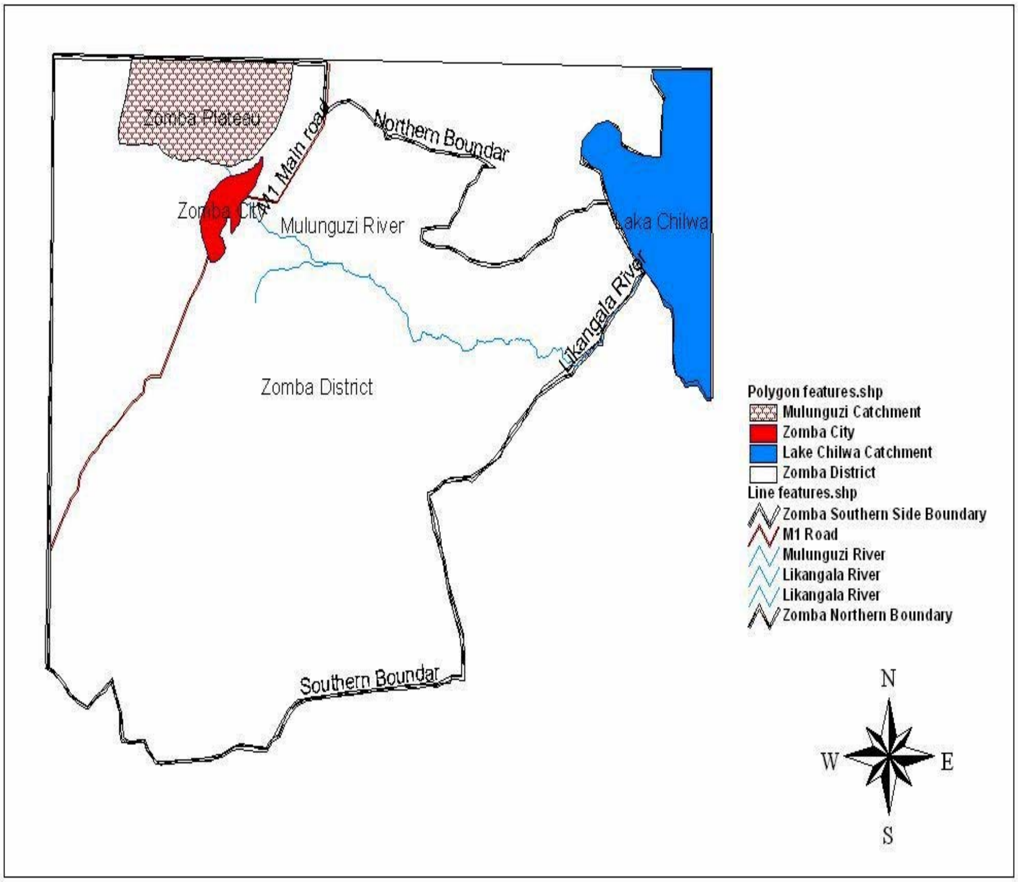

Figure 2 Map of Zomba City showing the study area as part of Lake Chilwa wetland which is a designated area under Ramsar Convention

The Lake Chilwa wetland area is also designated under the Ramsar Convention of 1971 for the protection of endangered species. Apart from supplying water to the City of Zomba, fishing, agricultural production and international research in water resources, biodiversity studies are some of the activities in the area (Chavula, 1999).
Areas of unique scientific and geographical significance in the Mulunguzi Catchment include:
1. The Zomba Mountain Forest Reserve which is protected area; and
2. Mulunguzi River and Mulunguzi Marshes that constitute the wetlands on the plateau.

3.2 Population and water demand

According to the 1998 population census, the City of Zomba had a total population of 65,915 (NSO, 1998). A growth rate of 2.5 percent was suggested for the next 10 years. The current calculated population basing on the background may be about 87,200.

Zomba city has an average per capita consumption that ranges from 50 to 80 l/c/d for high density areas and 200 l/c/d for the low density areas (GOM-UNDP, 1986). Mulunguzi Dam was constructed together with additional treatment works that enables Southern Region Water Board to treat 22,200 m3 of water daily.

3.3 Land use

The Mulunguzi catchment area covers an area of about 20 km2 of Zomba Plateau and is wholly situated in the Zomba Forest Reserve. For administrative purposes, the Zomba forest is divided into two sections, the Zomba Plateau and the Zomba outer slopes (Chilima, 2001). The catchment is situated in the Zomba Mountain forest of which about 2194 hectares is under plantation forest, 506 hectares in natural woodland and about 680 hectares in unplantable land. The Mountain pine plantations date back to 1920 when the first Pinus Patulla trees were introduced. The prescribed rotation age of the Zomba Mountain Pinus Pattula species is at 30 years. The plantation is important in maintaining the water balance but also in conserving both indigenous flora and fauna and contributes to biological diversity. Within the plantations, there are some patches of evergreen Montana vegetation, shrub and glass woodlands.

Apart from the establishment of the plantation, other major land use changes on the mountain over the years include silvipastoral and eco-tourism. From the mid 1980s, cattle began to be used in logging operations. This resulted in some areas being used for grazing of cattle and horses. The plateau is also a major tourist attraction, which has resulted in construction of a hotel, cottages and lodges. Horse rides are also common. Tourists' activities are suspected to have some impact on the status of the environment in the forest reserve (Chilima, 2001).Mulunguzi Dam further increased tourist activity in the catchment (Eneya, 2001). Another major land use is that of fish farming. The farm is about 500 square meters. It consists of approximately ten fish ponds arranged in series. Water is diverted from Mulunguzi River to the fish ponds through a concrete channel. The effluent is discharge to a small earth dam located downstream of the fish ponds, which drains into Mulunguzi River. The exact tonnes of fish sold in a year could not be established due to poor record keeping. Apart from fish farming, the farm is also used for raising tree seedlings which are supplied to Forestry Department. The farm employees about 100 personnel for both fish farming and tree nursery activities.

3.5 Climate

3.5.1 Rainfall

Mulunguzi Catchment, which is located in Zomba Plateau, is among areas in Malawi which normally receive extremely high rainfall with an annual mean of over 2000 mm. Other high rainfall areas include the Shire Highlands, Mulanje Mountain, Kirk Ranges and Nyika Highlands (GOM-UNDP, 1986). The area receives twice the amount experienced over low-lying areas between November and April with maximum recorded in January or February (Appendix B, Table 17). The main rain bearing system in the Mulunguzi River catchment area is the Inter-tropical Convergence Zone (ITCZ), which is mainly active between November and in April.

Average yearly rainfall on the plateau for the period 1954-2003 was 1,894 mm/year. Recorded minimum was 1,059 mm/year in 1991; a maximum was 3, 179 mm/year in 1978 (Source: Meteorological Department data).

3.5.2 Temperature

Average yearly temperature within the catchment for the period 1953-1990 is 16 oC. Recorded minimum mean temperature was 14.3 oC in 1965; the maximum mean was 17.8 in 1990. July recorded average mean temperatures of 12.6 oC. July falls within winter in Malawi. October has the highest mean temperature of 19.2 oC. This is during the summer period.

3.6 Geology of the area

3.6.1 Rock and Soil

TypesThe dominant bedrock across the dam area is porphritic quartz-microsyenite of the "Inner Ring" structure of the Zomba Mountain massif. This is a massive and compact rock-type which is resistant to weathering and gives rise to the ramparts of Zomba Mountain.

The dam basin and river alley upstream to dam inlet is mostly underlain by foliated charnockitic gneiss, which strikes north-north-east to north-east and is to represent a roof pendant intruded by and uplifted within the Zomba Mountain syenite, the mechanism of emplacement being taken to be that of sub volcanic cauldron subsidence. Gneiss blocks have been shown to persist as large xenoliths on the immediate right bank where they are deeply weathered.

The main structural feature crossing the dam structure and the controlling the Mulunguzi gorge is the east-south-east trending Mulunguzi Fault, which may have displaced the gneiss block and enclosing syenite but which is now filled by white microsyenite dyke material followed by a narrow, closely jointed lamprophyre dyke.

Due to rainfall and aggressive weathering in the area, the syenites, which are effective quartz-free, give rise to deep red-brown silty clay soil underline by yellow-red-brown residual silty clay enclosing soft silty to gravely decomposed syenite. This gives way to soft and hard completely weathered syenite with grey sphedroidal cores, and then usually sharply into highly weathered, closely jointed syenite and what is invariably sound rock. The humid top soil cover does not usually exceed 0.5m in thickness, and the soil profile on steeper slopes above the Mulunguzi valley is often telescoped, containing rounded boulders screed and highly weathered syneite blocks often transported as a gravity flow debris deposit.

The gneisses by contrast are foliated quartz –feldspathic rock banded with hornblende and biotite. They also give rise to deep red-brown soils, and on the far left bank of the dam, they decompose to white-grey more sandy silt with gritty quartz content. Completely weathered soft material reach a depth of 16 to 26 metres on the far bank.

3.6.2 Weathering

Rock weathering on Zomba Mountain is aggressive due to high and more equitable rainfall experienced. Soils tend to be consistently moist, deep, residual and highly leached. They contain a concentration of iron and aluminous sesquioxides in the process of bauxitisation and kaolinization, and they contain soft, completely weathered and decomposed rock material, which increases proportionately with depth. As the syenite is a massive and compact igneous rock, weathering below the zone of decomposition is concentrated along joint lines which tend to be orthogonal planes inclined at steep or near horizontal attitudes. This ensures that spheroidal weathering processes are the most active, giving rise to blocks and rounded boulder outcrops. This intimates that fresh rock outcrop cores will be surrounded by soft zones of high to complete weathering, and thick zones of decomposition, clay seams and stained joints planes enclose or disrupt the rock cores. These dislocations may or may not be open and their frequency tends to become more prominent with depth, the staining of joint faces being less apparent below the phreatic surface.

The gneiss exhibit a strong mineral foliation at moderate to steep inclination and are also jointed, but are susceptible to more uniform weathering decomposition. Thus on the far left bank of the dam they appear to be more deeply weathered than the syenites.

The lamprophyre dyke has been eroded down to bedrock along Mulunguzi River. The close jointing in this situation appears to be more open, the effects of weathering perhaps being only slight. (Source Lahmyer International and Stewart Scot Design Report)

CHAPTER 4

4.0 MATERIALS AND METHODS

4.1 Study design

4.1.1 Selection of sampling sites

Water quality sampling was done on fourteen sampling stations taking into consideration the socio-economic activities taking place within the catchment. The socio-economic activities considered were timber harvesting, trout fish farming, animal farming and settlements. Sampling sites were located upstream and downstream of each activity to assess if there is any significant variation between the sites (Figure 3). If the variation was significant ($p<0.05$), it meant the activity was affecting water quality. The sampling stations were denoted J for easy identification. Detailed descriptions of sampling stations are presented in Table 1.

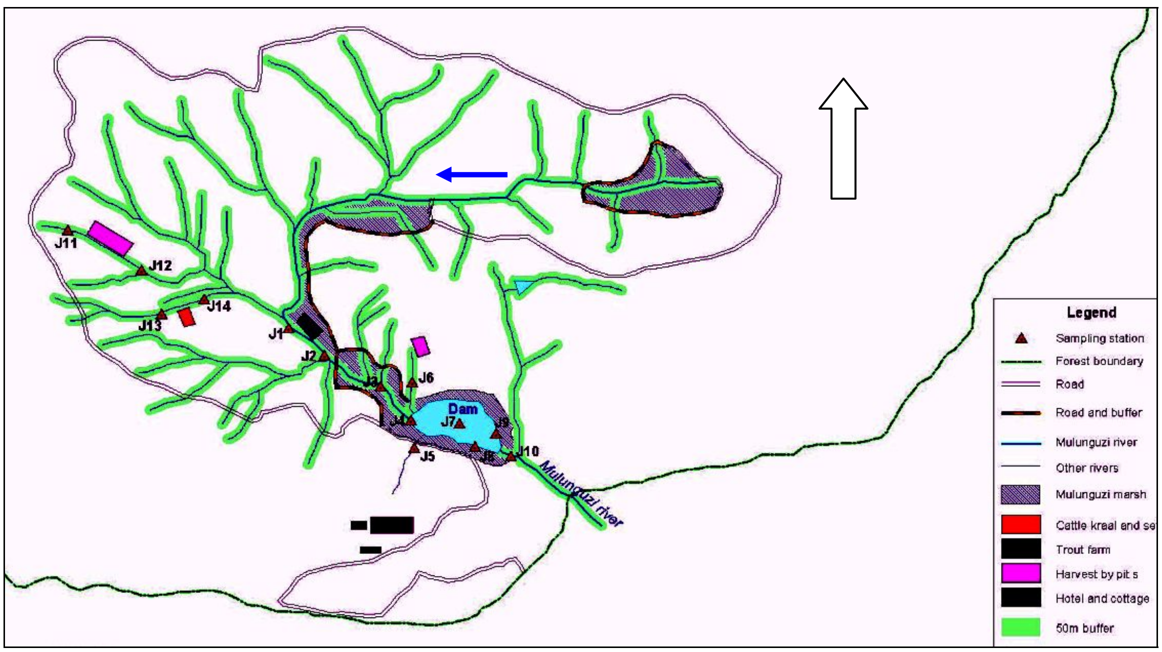

Figure 3 Sampling stations indicating socio-economic activities under consideration within Mulunguzi catchment area in a study which was conducted from January to March, 2008.

4.1.2 Sampling methods and frequency

Grab sampling technique was used for sampling collection. This technique was used because the character of the waste in the catchment is constant (Clarke et al., 1977). Samples were collected monthly from January to March, 2008.

4.2.3 Selection of sampling parameters

Parameters to be analysed were selected based on the activities taking place within the catchment which are a threat to water quality. Poor sanitation facilities and practices were indicated by faecal coliforms; iron and manganese were indicators for TFF; nitrates, phosphates and sulphates were indicators of agricultural activities within settlements. Indicators for timber harvesting activities were turbidity and pH. Finally temperature was considered as a general parameter, which affects physical, chemical and biological processes (Chapman, 1996).

Table 1 Characteristics of sampling stations located along Mulunguzi River, stream and Mulunguzi Dam

Sampling station	Characteristics
J1	Located upstream of trout fish farming.
J2	Located downstream of trout fish farming at a receiving point of effluent from the farm
J3	Located at the dam weir where a storm water drain from settlements within the catchment
J4	Located at the dam inlet called Mandala falls.
J5	Located at the discharging point of south stream into the dam. A hotel, cottages are located upstream of this point
J6	Located at the discharging point of north stream into the dam. Timber harvesting activities by pit sawyers were taking place upstream of this point
J7	Located at dam centre.
J8	Located at the dam spillway. The spillway, which is of a fan type, discharges into Mulunguzi River
J9	Located at the dam embankment, which is of rock fill type.
J10	Located at the first abstraction point of the intake tower. The tower is vertical, and has five intake points. The bottom intake is taken as first point.
J11	Located upstream of timber harvesting area along Chitinji road.
J12	Located downstream of timber harvesting area along Chitinji road
J13	Located upstream of Forestry Department staff compound and animal farm (cattle kraal)
J4	Located downstream of Forestry Department staff compound and animal farming (cattle kraal)

4.2 Analytical methods

4.2.1 pH and temperature

The pH and temperature were measured immediately after sample collection using a microprocessor pH meter, Jenway 3310 as recommended by APHA, 1995.

4.2.2 Turbidity

A microprocessor turbidity meter, H1 93703 was used to measure turbidity immediately after sample collection. The instrument was calibrated with standard solution 10 NTU, 200 NTU and 999 NTU. After calibration, a cell containing distilled water was used as blank to ascertain the measurement accuracy if the reading was zero.

4.2.3 Dissolved oxygen

Dissolved oxygen determination was done using dissolved oxygen analysing kit model number 5946-75 9Cole Palmer under 29 ^{0}C and a pressure of 7.4mmHg as recommended by APHA (1995).

4.2.4 Iron and manganese

Dissolved iron and manganese concentrations were determined using atomic absorption spectrophotometer (Bulk Scientific Model, 200A) by aspiration of the solutions into air acetylene flame. The analyses of iron and manganese were performed at 248.3 and 279.5 nm respectively as recommended by APHA (1995).

4.2.5 Nitrates, phosphates and sulphates

Water samples were filtered through a 0.45µm cellulose nitrate membrane to remove large particles. Nitrates, phosphates and sulphates concentrations were measured using ion chromatography (APHA, 1995).

4.2.6 Microbiological analyses

Faecal coliforms were determined using the membrane filtration method (MF) and the standard plate count (WHO, 1987). Each 50 ml sample was filtered on a Millipore filter paper and placed on a pad nourished with Slanazt and Bartely. The petri dishes were closed and incubated in Paqua lab incubator at 44 ºC for 16 hours. The results were obtained by counting yellow colonies developed on filter paper and were reported in number of colony forming units per 100 ml of water.

4.3 Data analysis

Statistical calculations (mean, standard deviation and 2-tailed Student's t-test at 95 percent confidence level) were performed using Microsoft Excel statistical package. Through out the text, significant difference means that $p<0.05$.

4.4 Data quality control

All samples were collected in triplicate in order to identify outliers. All samples were analysed within 24 hours after collection according to APHA (1995).

4.5Pollutant loadings

Indicative pollutant loads (IP_L) in kg/day were calculated using equation 1 while total indicative pollutant load per station was calculated using equation 2. The flow rate Q (m^3/d) was calculated by finding mean discharge values for the wet season from January to March, 2004 which was available at Meteorological Department in Blantyre. The data is already corrected for errors as such no analysis was necessary. The data is for the period 1979-2004, and is presented in appendix B (Table 18). Pollutant loads were calculated for J2 because there is only one gauging station in the catchment and is located upstream of this point on Mulunguzi River.

1. $IP_L = QC$……………..1

2. $IP_{TL} = Q (C_1 + C_2 + C_3 \ldots\ldots + C_n)$ ……………..2

Where

IP_L is indicative pollutant load

Q is flow rate in m^3/d

C is concentration of the parameters in mg/L

C_1, C_2 ...C_n are concentrations of different pollutants passing through a point

IP_{TL} is indicative total loading at any point

CHAPTER 5

5.0 RESULTS AND DISCUSSIONS

5.1 Water quality analysis

Average values of turbidity, pH, temperature, faecal coliforms and dissolved oxygen are presented in table 2. Significant differences at 95 % confidence level to assess the impact of socio-economic activities are presented in table 3 while average values of nitrates, phosphates, sulphates, iron and manganese are presented in table 4.

Table 2: Mean values for turbidity, pH, Temperature and faecal coliforms from January to March, 2008

Sampling Stations	Parameters (Mean ± SD)				
	Turbidity (NTU)	pH	Temperature (^{0}C)	Faecal Coliforms (No/ 100 ml)	Dissolved Oxygen
J1	2.23±1.34	7.07±0.05	21.82±1.72	63±47	7.93±0.24
J2	3.48±1.13	7.09±0.05	21.89±2.06	173±78	7.87±0.19
J3	2.46±0.57	7.13±0.03	22.42±0.30	99±64	7.82±0.12
J4	3.26±1.30	7.09±0.12	21.65±1.18	37±27	7.83±0.09
J5	2.02±1.10	6.97±0.15	22.10±0.67	57±57	7.88±0.02
J6	2.41±1.20	6.95±0.10	22.34±1.13	16±7	7.85±0.07
J7	0.56±0.47	6.97±0.16	22.36±0.77	31±30	7.93±0.05
J8	1.89±2.24	6.98±0.19	23.06±1.98	39±43	7.83±0.05
J9	0.58±0.65	7.03±0.15	22.88±1.51	15±12	7.90±0.14
J10	1.99±2.27	6.95±0.11	22.77±1.46	1±2	7.62±0.02
J11	0.18±0.26	7.07±0.04	20.98±1.66	128±174	
J12	13.15±16.05	7.07±0.04	21.02±1.53	164±227	
J13	6.45±3.67	7.05±0.06	20.63±0.73	98±102	
J14	6.03±6.57	7.05±0.07	21.36±0.98	117±26	
WHO guidelines	0.1-1 NTU[a]	6.5-8.5	20-25 ^{o}C[b]	0/100 ml	>5 mg/L

Number of samples (n) = 9; SD= Standard Deviation; [a] Malawi Bureau of Standards; [b] European Community Standards

Table 3: p values for before and after socio-economic activities

Parameter	Socio-economic activities				
	TFF (J1/J2)	Settlement (J1/J5)	Timber harvesting (J1/J6)	Timber harvesting (J11/J12)	Animal farming & FDC
Turbidity	**0.030**	**0.012**	**0.011**	**0.007**	0.199
pH	0.085	0.183	0.304	0.057	0.423
Temperature	0.129	0.649	0.622	0.228	0.171
FC	**0.007**	**0.008**	**0.004**	**0.025**	**0.004**
NO_3^-	**0.029**	0.744	0.572		
SO_4^{2-}	**0.002**	**0.013**	0.320		

p values in bold ($p<0.05$) indicate that there is a significant difference between the two points at 95 % level of confidence

Table 4 Mean concentrations of nitrates, phosphates, sulphates, iron and manganese

Sampling Stations	Parameter (Mean ± SD)				
	NO_3^- (mg/L)	PO_4^{3-} (mg/L)	SO_4^{2-} (mg/L)	Fe (mg/L)	Mn (mg/L)
J1	0.18±0.05	n.d.	0.24±0.16	n.d.	n.d.
J2	0.20±0.03	n.d.	0.16±0.00	n.d.	n.d.
J3	0.27±0.03	n.d.	0.59±0.54	n.d.	n.d.
J4	0.19±0.02	n.d.	0.23±0.01	n.d.	n.d.
J5	0.16±0.01	n.d.	0.17±0.00	n.d.	n.d.
J6	0.12±0.07	n.d.	0.38±0.02	n.d.	0.11±0.16
J7	0.10±0.04	n.d.	0.30±0.17	n.d.	n.d.
J8	0.13±0.06	0.04±0.06	0.32±0.16	n.d.	n.d.
J9	0.13±0.01	n.d.	0.25±0.14	n.d.	n.d.
J10	0.01±0.02	n.d.	0.35±0.12	10.61±0.59	0.68±0.97
WHO guidelines	50 mg/L	0.5 mg/L	250 mg/L	1 - 3 mg/L[a]	0.4 mg/L

Number of samples (n) = 9; SD= Standard Deviation; [a] Malawi Bureau of Standards; [b] European Community Standards

5.1.1 Turbidity

Average turbidity values ranged from 0.18 NTU to 13.15 NTU (Table 2). The minimum and maximum values were recorded at J11 (0.0 NTU) and J12 (24.5 NTU) which stand for before and after timber harvesting area respectively as illustrated in figure 4. The high value obtained at J12 could be due to erosion as a result of removal of vegetation cover (Machiwa, 2003). According to Machiwa (2003), when the soil is stripped of its vegetative cover it becomes susceptible to agents of erosion which are wind and water. Surface runoff becomes loaded with sediments which are in turn deposited in water sources.

Most of the values recorded were above MBS for drinking water which is 0.1-1 NTU except for dam centre (J7), dam embankment (J9) and upstream of timber harvesting area (J11). The results are compared to standards and guidelines for drinking water because Zomba rural south abstracts raw water without treatment. Communities downstream, who are outside Zomba city boundary uses the water for domestic purposes. Low turbidity values at J7 and J9 could be due to settling effects of sediment due to low velocities at these sites. As water flows to the dam, velocity in the dam reduces and allows sediments to settle because of low energy levels (Twort *et al.*, 1974). According to Twort et al. (1974) sediments settle out at a velocity of not more than 0.3 m per second.

Significant differences ($p<0.05$) were observed between upstream and downstream of Trout Fish Farm (J1/J2), settlements (J1/J5), both timber harvesting areas at J1/J6 and at J11/J12. This indicates that the downstream points (J2, J5, J6 and J12) are more turbid than the upstream points. The observed significant difference at TFF could be due to effluent which contains remains of fish feed and is discharged direct into the main

Mulunguzi River. The other contributing factor could be the cleaning process of fish ponds which is done almost daily. Chapman (1996) indicates that turbidity levels can be increased by the presence of effluents. The differences observed upstream and downstream of the settlements could be due to domestic solid wastes that are deposited into the south stream which is used for both cleaning utensils and washing clothes. Domestic solid waste causes the water to be turbid (Palamuleni, 2002). The observed differences between J1 and J6 and between J11 and J12 could be attributed to clear cutting of timber. This is consistent with the findings of Hornbeck et al., (1975) where turbidity increased with commercial clear-cut.

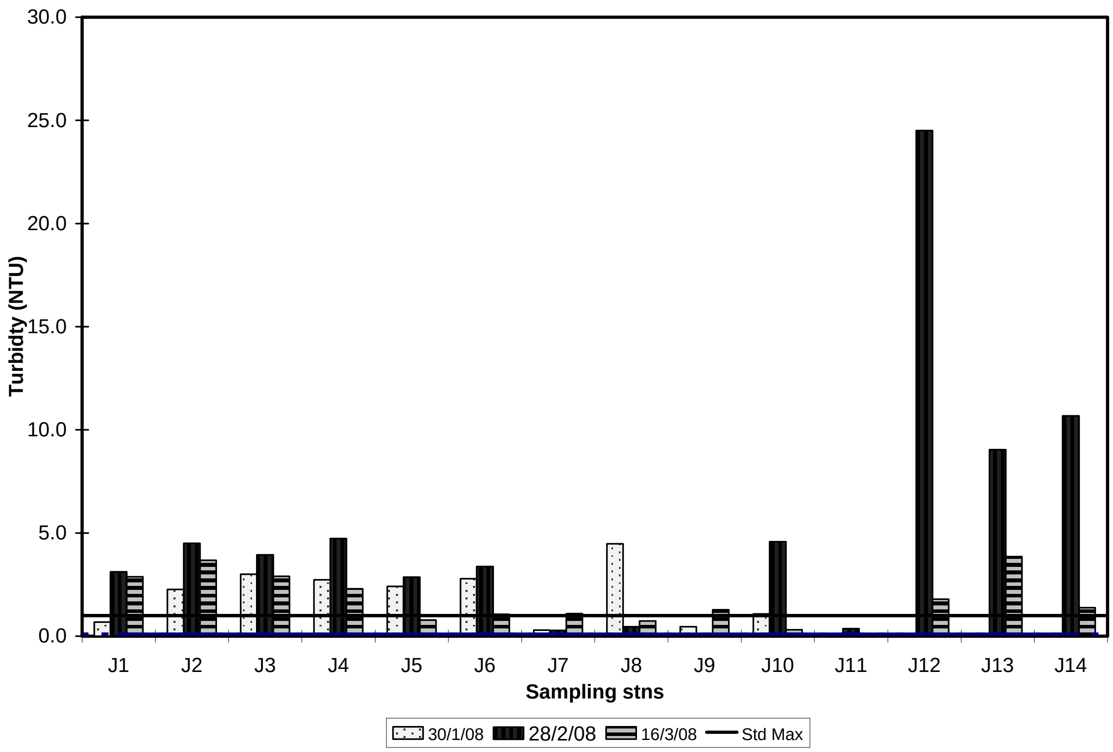

Figure 4 Turbidity values for all sampling stations within Mulunguzi Catchment for the period from January to March 2008 in comparison with Malawi Bureau of Standards (MBS) for drinking water

The results based on $p<0.05$ suggest that TFF, settlements and timber harvesting within the catchment are contributing to water quality deterioration in terms of turbidity. Turbidity has no health effects; however it can interfere with disinfection during water treatment and provide a medium for microbial growth (Akoto and Adiyiah, 2007). Turbidity may also indicate the presence of disease causing organisms. These organisms include bacteria, viruses, and parasites can cause symptoms such as nausea, cramps, diarrhoea, and associated headaches (WHO, 1984) hence such water is not suitable for drinking without treatment.

5.1.2 pH

Table 2 indicates that pH ranged from 6.95 to 7.13. The lowest values as shown in figure 5 were obtained at J10 (6.83) and J6 (6.83), while the highest value was at J3 (7.20). The lowest values obtained at J10 and J6 could be due to the presence of iron and manganese respectively which are high at these points as compared to the WHO guidelines for drinking water. The occurrence of iron and manganese in aqueous solution is dependent on environmental conditions, especially oxidation and reduction. Since pH is actually measured as the concentration of hydrogen ions, as iron and manganese are oxidized, water is weakly ionized to hydrogen ions and hydroxide ions (Chapman, 1996). This could result into the lower values of pH obtained. At the dam weir (J3), there is a storm water drain for surface water from settlements upstream of this point, which contains detergents. Detergents contain carbonates which may raise pH (Tebbutt, 1992).

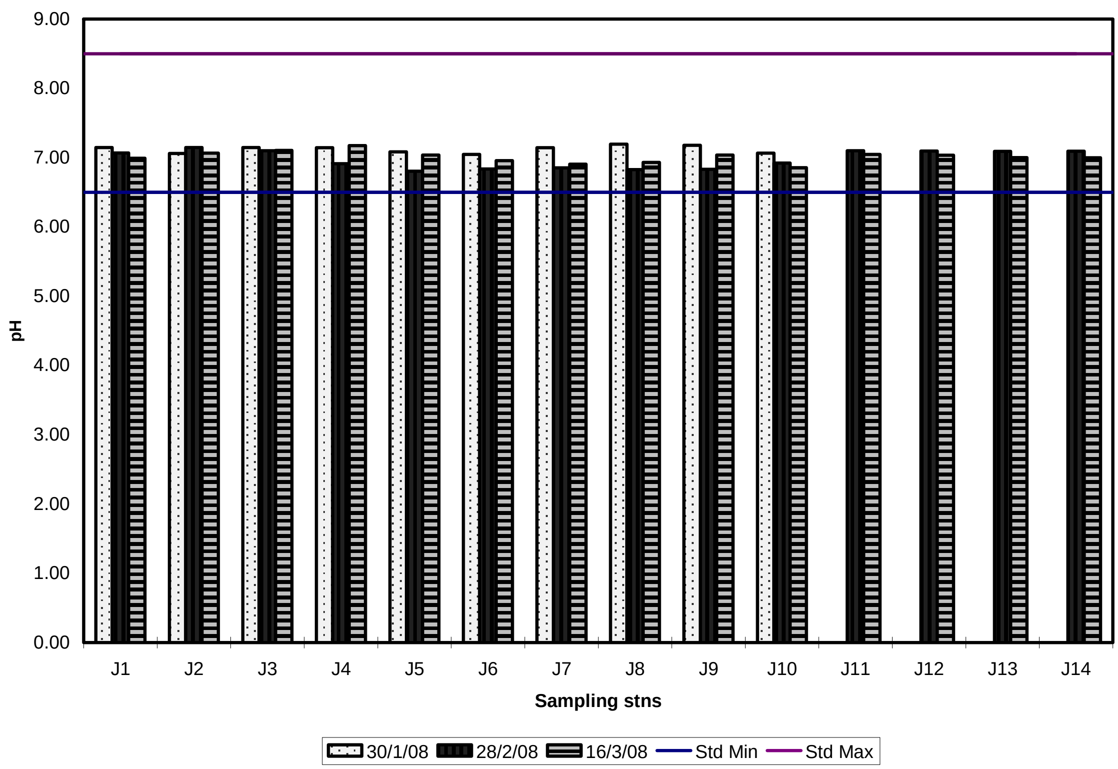

Figure 5 pH values for all sampling stations within Mulunguzi Catchment for the period from January to March 2008 in comparison with WHO guidelines for drinking water

The average pH values for all sampling stations were falling within allowable WHO guidelines for drinking water. The results are consistent with a study conducted by Palamuleni (2002) in South Lunzu streams in Malawi, where pH values were falling within the allowable range by WHO guidelines when the effects of sanitation, domestic solid waste and hygiene practices on stream water quality were assessed. This however contrasts the findings by Sajidu et al. (2007) from a study in Blantyre streams, assessing water quality of the streams and waste water treatment. The pH found by Sajidu et al. (2007) ranged from 6.63-9.38.

There were no significant differences ($p>0.05$) for pH between upstream and downstream of each socio-economic activity under consideration. The results suggest that TFF, settlements, timber harvesting and animal farming are not impacting on water quality as far as pH is concerned. Twort *et al*. (1974) observes that decomposing organic matter of vegetable and especially peaty origin producing carbonic acid and organic acids in water is wide spread cause of acidity. The results therefore could indicate that the socio economic activities did not produce adequate decomposing material to warrant changes in pH. Timber harvesting could be a potential source of decomposed material. However since the harvesting was done during the research period the off-cuts would not have adequately decomposed to contribute to pH change.

5.1.3 Temperature

The average temperature range within the catchment was 20.63 to 22.88 ^{0}C, and the minimum temperatures were recorded at J2, J11, J12 and J13 with 20^{0}C each while the maximum temperature was recorded at J8 (25^{0}C) as illustrated by Figure 6.

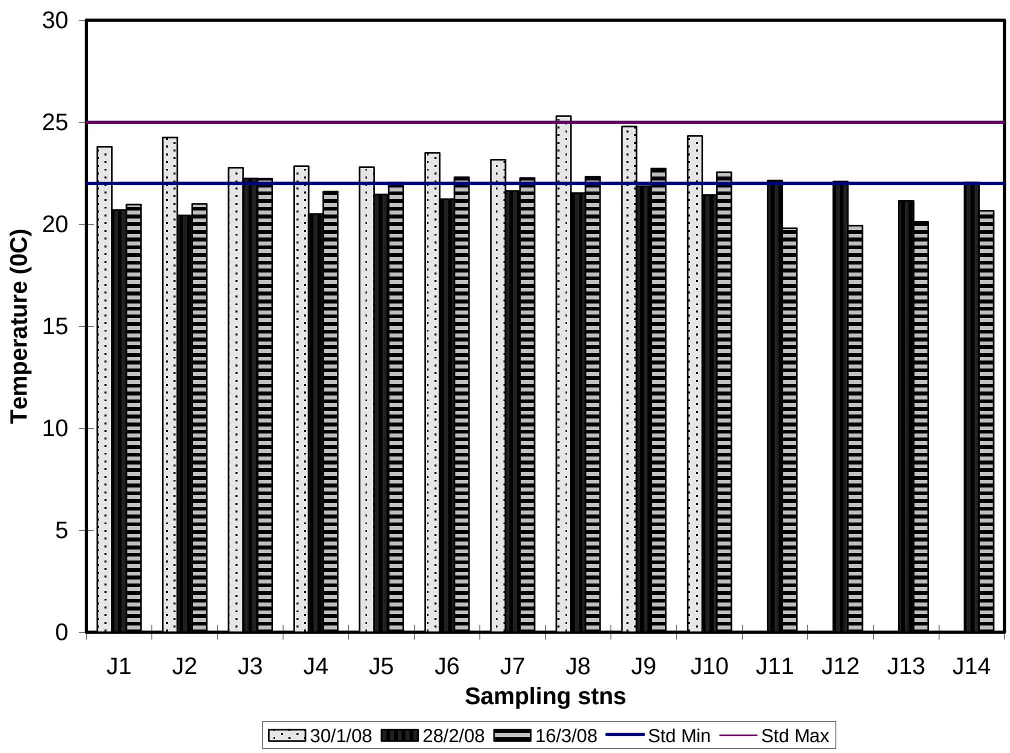

Figure 6 Temperature values for all sampling stations within Mulunguzi Catchment for the period from January to March 2008 in comparison with European Community Standards

The temperature of surface waters is influenced by latitude, altitude, season, time of day, air circulation, cloud cover and flow and depth of water body (Chapman, 1996). The low value obtained at J2, J11, J12 and J13 could be influenced by depth especially during rainy season when temperatures are usually low. On the other hand the high temperature value could be attributed to the nature of water abstraction in the reservoir during the rainy season. Water is abstracted at lower depths due to the presence of suspended solids at the surface. This could result in the withdrawal of cold hypolimnion leaving out a thermocline where there is well mixing with warm surface water (Nhiwatiwa, 2007), resulting in high temperatures.

Average temperature values obtained were within recommended European Community Standards (ECS) for drinking water which ranges between 22-25 ^{o}C (Tebbutt, 1992). ECS has been used because temperature is generally not specified in most drinking water standards and guidelines, including WHO (Hoko, 2005). Hoko (2005) conducted a study to assess water quality in some rural districts of Zimbabwe where one of the parameters measured was temperature. In his results, temperature ranged from 19.1 to 31.8 ^{o}C. The difference in temperature was attributed to climatic differences, geographical location, and depth of water points and different times of the day when samples were collected and analyzed. In a similar study by Olajire and Imeokparia (2000) carried out in Osu in Nigeria found a temperature range from 27.5 to 29.0 ^{o}C which is above the range found from the study (20.63 to 22.88 ^{0}C). Nigeria is hot and this explains the difference.

No significant differences ($p>0.05$) were observed in TFF, timber harvesting areas, settlements and animal farming and FD compound. Timber harvesting and animal grazing would be expected to affect temperature. Clear cutting of timber increases stream temperatures (Messina *et al.*, 1997) while animal grazing removes vegetation that shades the stream (Wyoming Department of Environmental Quality, 1990). However the results could be due to the geographical location of Mulunguzi catchment which is within a plateau area but also could be due to the fact that temperatures during the rainy season are usually cool. Animal grazing within the catchment may not have affected the temperatures due to low stocking rates. It can therefore be said that the aforesaid activities are not affecting water quality within the catchment in terms of temperature.

5.1.4 Faecal coliforms

Faecal coliforms as presented in table 2, ranged from 1 to 173 CFU/100 ml. The minimum value was recorded at J10 (0 CFU/100 ml) while the maximum was recorded downstream of the timber harvesting area (J12 with 324 CFU/100 ml) as illustrated in figure 7. The survival of microbiological pathogens, once discharged into a water body, is highly variable depending on the quality of receiving waters, particularly turbidity, oxygen levels, nutrients and temperature (Chapman, 1996). The lower value obtained at J10 could be due low temperatures (22^{o}C) at the bottom of the dam since faecal bacteria show optimal growth at 37^{o}C (Chapman, 1996). On the other hand the higher value for faecal coliforms at J12 could be due to the activities occurring around the timber harvesting area. The activities include camping and cattle logging. Buckhouse and Gifford (1976) observed that animals grazing adjacent to streams could pollute water sources through direct defecation into the water bodies.

WHO guidelines for drinking water quality stipulate zero coliforms per 100 ml to be safe limit if water is used for drinking. The range from 1 to 173 coliforms/100 ml is above the stipulated guidelines. The results obtained are consistent with the finding by Alam *et al*. (2006), where faecal coliform value obtained ranged from 22 to 51 FCU/100 ml, when assessing water quality parameters along rivers in Bangladesh. Mvungi *et al*. (2003) in a similar study found faecal coliforms ranging from 890-1000 CFU/100 ml in their study carried in Harare when assessing water quality in a tributary of Marimba River.

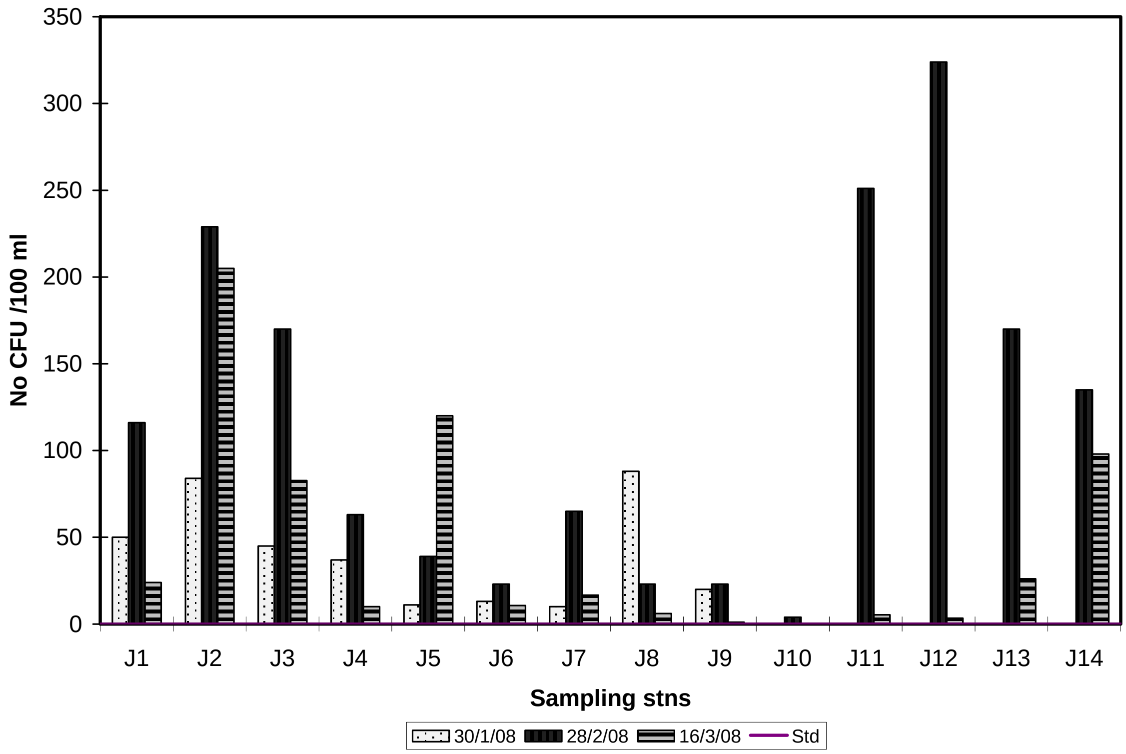

Figure 7 Faecal coliform values for all sampling stations within Mulunguzi Catchment for the period from January to March 2008 in comparison with WHO guidelines for drinking water.

Significant differences ($p<0.05$) were observed at both timber harvesting areas, TFF, settlements, animal farming and Forestry Department (FD) compound. This indicates that the water quality in terms of faecal coliforms was lower downstream of each of the activities. The observed difference at timber harvesting areas could be due to temporary dwellings by timber processing companies operating within the catchment. These companies have no provision for sanitation as a result the forest is used for defecation. Significant difference at animal farming could be due to faecal matter from animals which graze within the protected buffer zones (50 m for rivers and 100 meters for dam). According to Howard et al. (1983), cattle can contribute significant numbers of faecal coliforms to surface waters since they spend a significant portion of their time in or near streams and on average cattle defecate 12 times per day. Within the FD compound, there is no provision for dumping of waste leading to the improper disposal of solid wastes into the streams. Most of the septic tanks around the forestry offices and forest compounds are overflowing; this could contribute to the significant difference in faecal coliforms observed at the stated activities.

The results suggest that the considered activities are polluting surface water within the catchment in terms of faecal coliforms. Contamination brings a threat of infection for people who use the water for drinking, bathing, or watering fruits and vegetables. For Southern Region Water Board, this implies increased treatment costs and possible cholera outbreaks for downstream communities that abstract water without treatment. Human faeces can contain a variety of intestinal pathogens which cause diseases ranging from mild gastro-enteritis to serious and possibly fatal dysentery, cholera and typhoid (WHO, 1984). The results therefore show that the water is not suitable for direct use without treatment.

5.1.5 Dissolved oxygen

Average dissolved oxygen results ranged from 7.63 to 7.93 mg/L with minimum value at J10 (7.6 mg/L) and maximum values at both J7 and J1 registering 8.1 mg/L (Figure 8) at temperatures of 22.77 ^{o}C, 22.36 ^{o}C and 21.86 ^{o}C respectively.

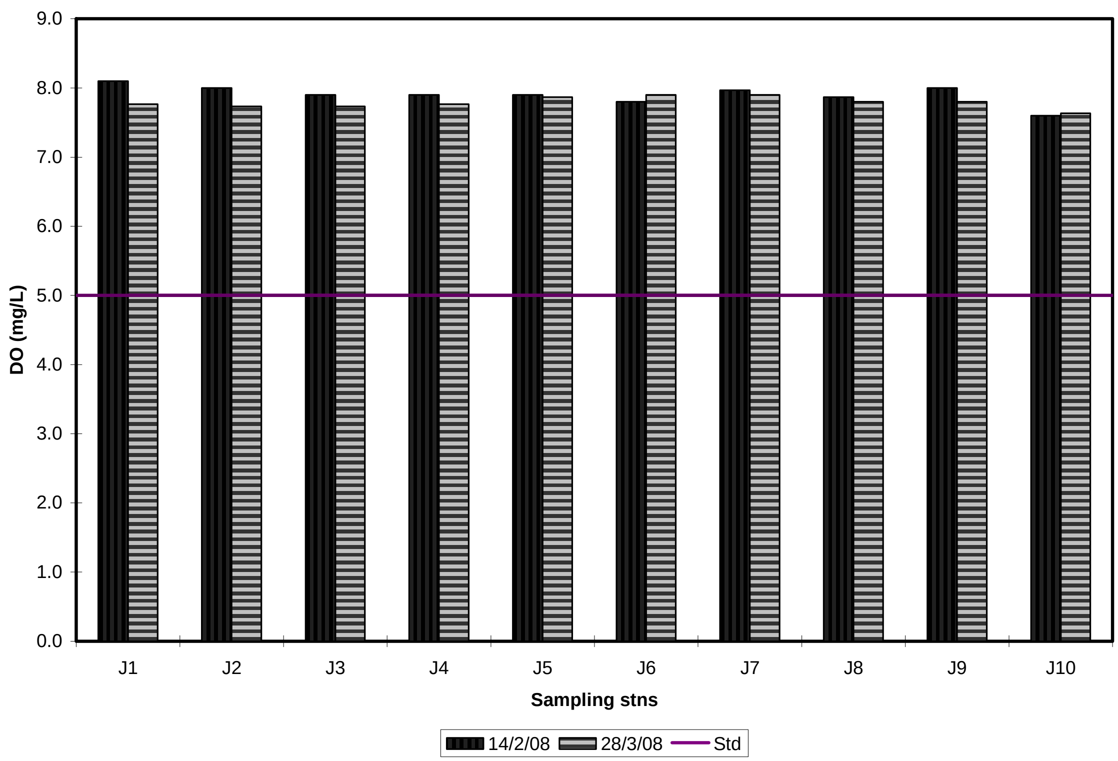

Figure 8 DO concentrations for all sampling stations within Mulunguzi Catchment for the period from February to March 2008 in comparison with WHO guidelines for drinking water.

The oxygen content of natural waters varies with temperature, salinity, turbulence, the photosynthetic activity of algae and plants and atmospheric pressure (Chapman, 1996). According to Chapman (1996), solubility decreases as temperature and salinity increases.

At the temperature range obtained the saturation DO for clean water ranges from 8.61 mg/L to 8.75 mg/L. Due to impurities the DO for polluted waters is generally lower than the saturation value (Tebbutt, 1992). However dissolved oxygen has no direct impact on health (WHO, 1996).

DO values obtained (7.63 to 7.93) in the study were within the recommended WHO guidelines for drinking water which is above 5 mg/L. This is supported by the findings by Alam *et al*. (2007) where average DO value obtained was 5.72 mg/L. In contrast Mumba *et al*. (2005) obtained a range from 0.44 to 2.9 mg/L in his studies on water quality of receiving rivers in urban areas of Blantyre, Malawi. The contributing factor was attributed to organic load from sewage which was partially treated. Organic pollutants tend to exert a heavy oxygen demand which results in reduced DO levels in the water body (Chapman, 1996).

There were no significant differences ($p>0.05$) observed for DO upstream and downstream of each of the activities which include timber harvesting areas, TFF, animal farming and FD compound. This indicates that the activities are not affecting water quality in terms of DO. On the other hand the results could be attributed to re-aeration due to the hydraulic flow regime or the presence of vegetation which may affect the oxygen balance through photosynthesis. This would be supported by a study by Pulatsu et al., (2004) where downstream DO levels were higher than upstream levels and the difference was attributed to mechanical aeration and oxygenation of receiving waters.

5.1.6 Nitrates

Table 4, shows average nitrates concentrations which ranged from 0.01 to 0.27 mg/L. The minimum and maximum values were obtained at J10 (0.0 mg/L) and J3 (0.29 mg/L) respectively (Figure 9). The low value obtained at J10 could be due to uptake by aquatic plants because nitrates are essential nutrients for aquatic plants (Tebbutt, 1992; Smol, 2003). The maximum concentration recorded at J3 could be attributed to inorganic fertilizers used for small scale agriculture within the catchment. Since almost the whole catchment is under forest reserve, small scale agriculture is practiced within settlements. The storm water drain responsible for draining surface run-off from settlement discharges at the dam weir (J3). This therefore could contribute to the high nitrate levels at J3.

The recorded nitrate concentrations for all sampling stations were within allowable WHO guidelines for drinking water which is 50 mg/L. The concentration values obtained are consistent with the results obtained by Chimwanza *et al* (2005) on a study carried out on Likangala River in Zomba City (Malawi) where concentration values ranged from 0.16 to 0.39 mg/L. Results recorded by Fatoki *et al*. (2001) on Umtati River, South Africa ranged from 0-12.5 mg/L.

Significant differences ($p<0.05$) were observed at TFF. This indicates that there were high levels of nitrates downstream of TFF. Apart from fish farming, the farm also raises tree seedlings for commercial purposes. The observed differences could be due to fertilizer application at the tree nursery or due to fish droppings in the effluent. High concentrations of nitrates cause methemoglobinemia (blue baby disease), whereas nitrites are considered to be potentially carcinogenic (Hubbard et al., 2004). Excess nitrate loading provided to aquatic vegetation results in increased photosynthetic rates followed by diminishing light transmission through the water (JPC, 1992). Decreasing light decreases photosynthetic rates, causing plants to consume oxygen for respiration, leading to oxygen depletion of the water (USEPA, 1979). Reduced DO levels leads to death of fish if DO levels drop to 1-3 mg/L (SA guidelines, 1993).

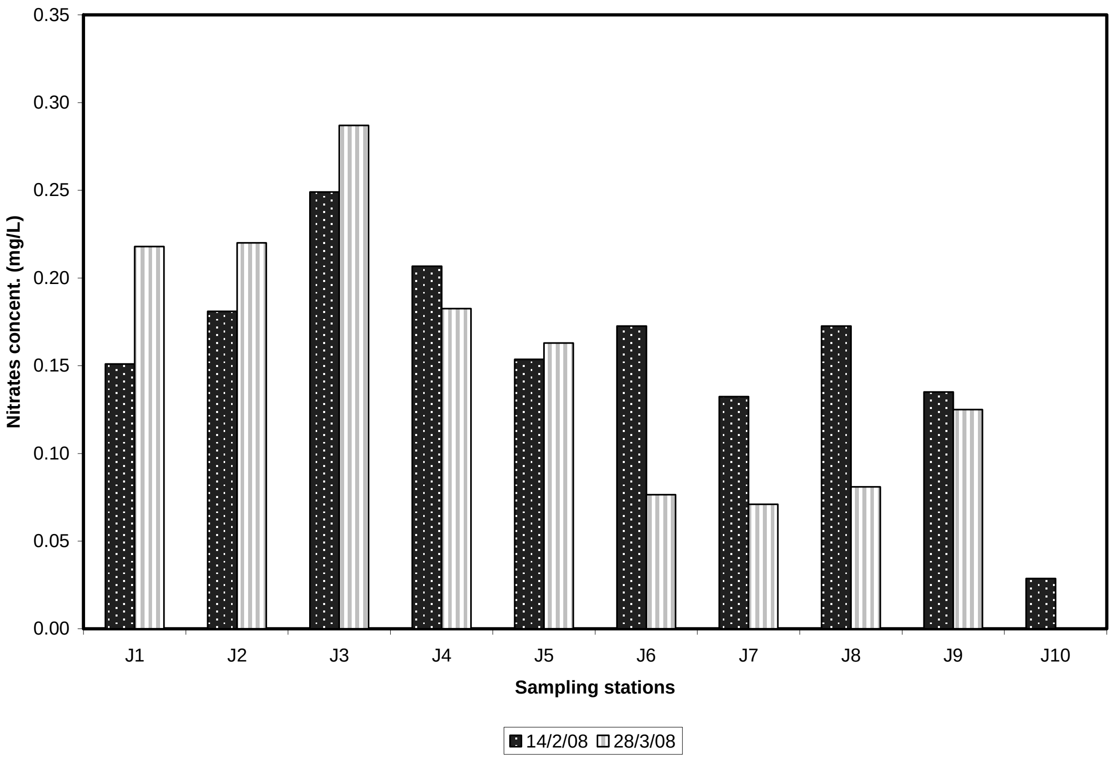

Figure 9 Nitrates concentrations for all sampling stations within the Catchment for the period from February to March 2008 in comparison with WHO guidelines for drinking water

5.1.7 Phosphates

Phosphates concentrations were below detectable limits for all sampling stations except at the J8 (0.081 mg/L). Phosphates in natural waters originate principally from sewage effluents including their detergent content; they may also come from concentrated farmyard manures or from industrial effluents (Holtzclaw *et al*., 1991). Further more, many fertilizers contain phosphates. A number of phosphates compounds that are present in certain rocks are partially dissolved and reach streams through natural runoff (White, 1995). Runoff water drainage from cottages and a hotel in the catchment is through a storm water drain that discharges near the spillway. The registered concentration of phosphate could be due to detergents from washing powder but also from fertilizers originating from small home gardens.

The concentration recorded at the spillway (J8) is below the allowable limit of 0.5 mg/L by WHO guidelines for drinking water. The obtained concentration value is consistent with Mumba's (2005) results on a study conducted in the city of Zomba on Likangala River. Concentrations values recorded ranged from 0.01 to 0.45 mg/L. However, Sajidu (2007) in a study in Blantyre streams, phosphate concentrations ranged from 0.63 to 5.50 mg/L which is higher than the study findings. This was due to leaching of agricultural wastes including fertilizers into the streams. In addition there were additives in detergent formulations which leached into the streams through wastewater generated industrially, domestically or from cloth dyeing and garment industries operating within the city.

No significant differences ($p>0.05$) were observed for phosphates for all activities. This implies that timber harvesting, TFF, settlements and animal farming are not affecting water quality within the catchment in terms of phosphates. Phosphorous is relatively immobile in the soil. This relative immobility means that only small amounts end up in streams (JPC, 1992). The study findings are consistent with the findings by Fredriksen (1975) in streams at Alsea Oregon where phosphate levels showed no increase after a 25 percent clear-cut. The results suggest that there is no threat of phosphates from the activities under consideration.

5.1.8 Sulphates

Average sulphates concentrations ranged from 0.16 and 0.59 mg/L. The minimum and maximum concentrations recorded for sulphates J1 (0.13 mg/L) and J3 (0.97 mg/L) are presented in figure 10. Sulphates originate from the atmospheric deposition of oceanic aerosols and leaching of sulphur compounds, which are either sulphates minerals such as gypsum or sulphide minerals such as pyrite, from sedimentary rocks (Twort et al., 1974). For the dam weir (J3) as previously discussed, the sulphates could have been transported through the storm water drain, which discharges surface run-off from settlements.

Sulphate values for all sampling stations were falling within recommended WHO guidelines for drinking water of 250 mg/L. Akoto and Adiyiah (2007) in their study in Brong Ahafo region, obtained concentrations ranging from 3.33-8.02 mg/L, which are far above the values obtained under this study. Sajidu et al. (2007) also found values for sulphates ranging from 14.90 to 109.72 mg/L in a study conducted in Blantyre, and fertilizer application was highlighted as the attributing factor.

Significant differences ($p<0.05$) were observed for TFF and settlements upstream of J5. The contribution to sulphate concentrations by TFF could be due to fertilizer application at the tree nursery while that observed at J5 could be due to fertilizer application in the small home gardens. Sulphate doses of 1.0-2.0 g in public drinking water have a cathartic effect on humans resulting in the purgation of the alimentary canal (WHO, 1984). Noteworthy sulphate is not removed from water by conventional water treatment methods (WHO, 1984). However the results of this study indicate that though TFF and settlements are contributing to sulphates concentrations in the stream their impact on water quality within the catchment may not be significant. Nevertheless the results show that the activities have potential to impact on water quality.

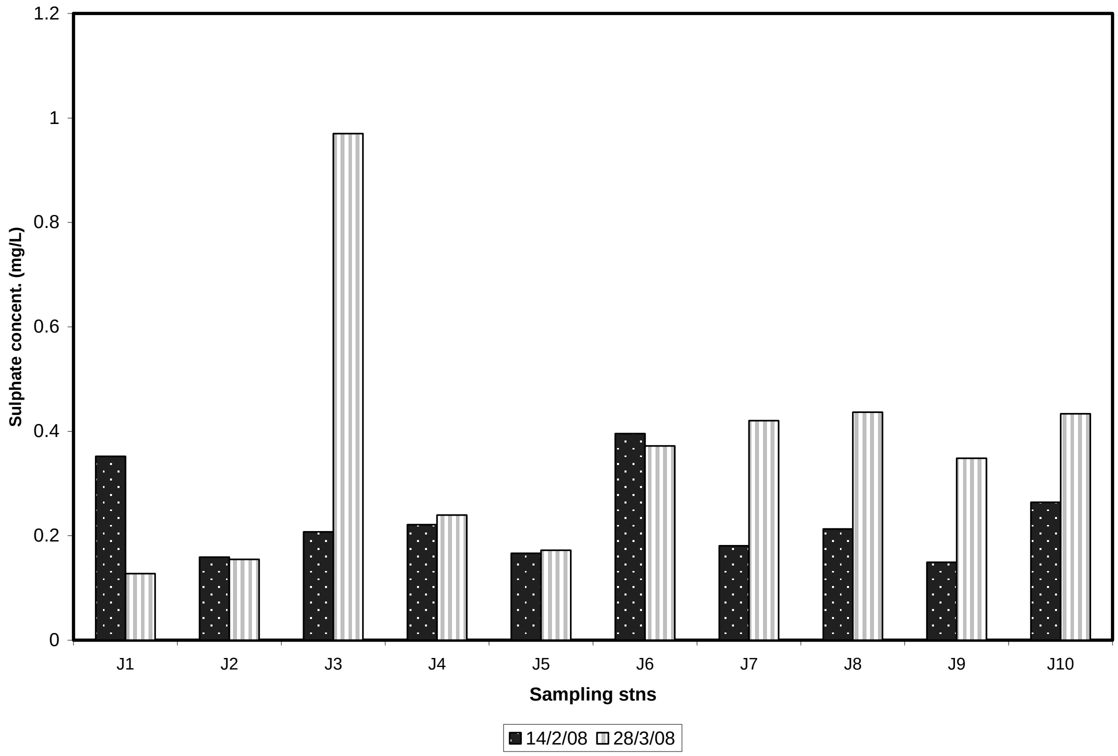

Figure 10 Sulphates concentration for sampling stations within the Catchment for the period from February to March 2008 in comparison with WHO guidelines for drinking

5.1.9 Iron and manganese

Iron concentrations were below detectable limits for all sampling stations except for the J10 (10.61 mg/L). High concentrations of dissolved iron at J10 could be due to accumulation of sediments at the bottom of the reservoir since the energy levels are low to transport material out once it has settled at the bottom (Smol, 2003). Sediment acts as a carrier of nutrients and metals that affect water quality in the rivers, reservoirs and lakes (Funk *et al.*, 1975). Noteworthy, soils within the catchment contain iron. This could contribute to the high concentrations at J10.

Iron concentration at J10 was above WHO guidelines for drinking water which is 0.3 mg/L. High concentrations at J10 could be due to the geological nature of the soil transported to the dam through erosion as evidenced by high turbidity values recorded during the research. Since iron is heavy, as sediments settle it is deposited at the bottom of the dam. Dissolution state is pH dependent. At certain pH ranges including the pH range found in this study, forms hydroxides precipitate which are stable and tend to settle down (Peavy et. al., 1985; Viessman and Hammer, 2000). Iron concentrations above the recommended guidelines can cause staining to plumbing fixtures, dish ware, and clothes. The standard is not federally enforceable, since it is not considered a health risk.

Manganese concentrations were below detectable limits for all sampling stations except for J10 (0.68 mg/L) and J6 (0.11). Manganese concentrations at J10 were above WHO guidelines for drinking water of 0.4 mg/L. High values at J10 could be due to natural leaching from rocks (HETL, 2004). The presence of iron and manganese in fresh waters can be attributed to the dissolution of rocks and minerals, acid mine drain, landfill leachates, sewage, or iron related industries (WHO, 1984). Manganese is regarded as one of the least toxic pollutants in water although in 1941 it was associated with a disease called encephalitis in Japan when the concentrations were above 14 mg/ (WHO, 1974). In another area in Japan, manganese concentrations of 0.75 mg/L in drinking water had no apparent adverse effects on the health of its consumers (Suzuki, 1970).

5.2 Indicative pollutant loadings

Table 5 presents indicative pollutant loads for sampling stations from J1 to J10. These are points along the main Mulunguzi River. These points were selected based on availability of flow rate data as there is only one gauging station within the catchment which is on Mulunguzi River.

Table 5: Pollution loads in kg/ day in Mulunguzi Catchment

Parameter	Sampling stations										
	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	MCL
NO_3^-	**17.1**	**19**	**25.6**	**18**	**15.2**	**11.4**	**9.5**	**12.3**	**12.3**	**0.9**	**0.0062**
PO_4^{3-}	0	0	0	0	0	0	0	**3.8**	0	0	**0.0662**
SO_4^{2-}	22.6	15.2	56	21.8	16.1	36.1	28.5	30.4	23.7	33.2	**93.3**
Fe	0	0	0	0	0	0	0	0	0	1000.7	-
Mn	0	0	0	0	0	10.4	0	0	0	64.5	-
PTL	39.9	34.2	81.6	39.9	31.3	57.9	38	46.5	36.1	1105.9	

Pollutant loads in bold for the sampling stations are above acceptable maximum contaminant level

Indicative pollutant loads for nitrates ranged from 0.9 to 25.6 kg/day. The minimum value was calculated for J10 while the maximum was for J3. The values obtained were above the recommended nitrate pollutant loads of 0.0062 kg/day (Chapman, 1996). Based on the results it can be said that timber harvesting, TFF, settlements and animal farming are contributing pollutant load than stipulated.

All sampling stations registered zero pollutant phosphate load except for spillway (J8) of which could be due to surface run-off emanating from hotel, lodges and settlements upstream of this sampling station. The calculated value (3.8 kg/day) was above the recommended load of 0.0662 kg/ day. In this case, it can be said that settlements upstream of J8 are contributing more contaminant load than acceptable.

Pollutant contaminant load from sulphates ranged from 15.2 to 56.0 kg/ day. Minimum and maximum values were calculated at downstream of TFF (J2) and dam weir respectively (J3). All sampling points are within acceptable pollutant loads.

Contaminants loads for iron were zero for all sampling stations except for the last intake point for the dam (J10) which was 1000.7 kg/day. There is no maximum acceptable pollutant loads specified. Manganese loads ranged from zero to 64.5 kg/day with the maximum at the last intake point of the dam (J10). Manganese is generally a troublesome element in water even when present in small quantities (Twort *et al*., 1974). It tends to deposit out from water in the presence of oxygen when chlorine is added, and will then coat the interior of pipes with a black slime. Manganese is often associated with iron in water, and has a behavior which is similar, except that the deposits are cumulative. If the deposits are cumulative, it can be deduced that 64.5 kg/day would translate to 23,542.5 kg/year. From the results it can be concluded that timber harvesting activities are contributing high pollutant loads than acceptable.

Total pollutant load (P_{TL}) ranged from 31.3 to 1105.9 kg/day. The lowest load was at upstream of settlements (J5) while the highest was for the last dam intake point (J10). The concentration of iron in well aerated air water is seldom high. It can be concluded that there are high pollutant loads accumulating at the bottom of the dam that any other sampling point.

CHAPTER 6

6.0 CONCLUSIONS AND RECOMMENDATIOS

6.1 Conclusions

- Timber harvesting activities are contributing to water quality deterioration through turbidity and faecal coliform; Trout Fish Farm in terms of turbidity, faecal coliform, nitrates and phosphates while settlements are affecting water quality through turbidity, faecal coliform and phosphates and finally animal farming through faecal coliforms hence water is not suitable for drinking without treatment.

- High dissolved iron and manganese accumulating at the bottom of the dam is attributed to the geological nature of the soil within the catchment.

- Timber harvesting, TFF, settlements and animal farming were contributing high pollutant loads compared to acceptable loads while settlements are depositing more phosphates load than acceptable. Total pollutant load was obtained at the last intake point in the dam.

- Overally socio-economic activities are impacting on water quality within the Mulunguzi Catchment.

6.2 Recommendations

- Best management practices in timber harvesting may need to be encouraged to improve water quality within the catchment.

- Grazing of animals within the protected buffer zone areas may need to be barred because efficiently protected riparian zones reduce transport of pollutants and erosion into streams.

- A proper institutional set-up with reliable financial base will be essential to coordinate the activities within the catchment to ensure sustainability of the water resources for present and future generation since currently there is lack of coordination between Southern Region Water Board (SRWB) and Forestry Department

- There is need to carry out the study during the dry season to assess seasonal variations.

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APPENDICES

Appendix A: Results for water quality analysis within Mulunguzi Catchment

Table 6Turbidity results (NTU)

	Sampling Stations													
Date	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J11	J12	J13	J14
30/1/08	0.69	2.27	3.01	2.73	2.42	2.79	0.30	4.48	0.46	1.08				
28/2/08	3.13	4.50	3.94	4.74	2.87	3.38	0.28	0.46	0.00	4.58	0.37	24.50	9.04	10.68
16/3/08	2.88	3.68	2.91	2.30	0.78	1.07	1.10	0.74	1.28	0.31	0.00	1.80	3.86	1.38
20/2/08			42.04	43.77					3.53					
Avg	2.23	3.48	2.46	3.26	2.02	2.41	0.56	1.89	0.58	1.99	0.18	13.15	6.45	6.03
STD	1.34	1.13	0.57	1.30	1.10	1.20	0.47	2.24	0.65	2.27	0.26	16.05	3.67	6.57
P value at 95% c		**0.030**	0.153	0.121	0.075	0.074	**0.004**	**0.001**	**0.000**	0.241				

Table 7 pH results

	Sampling Stations													
Date	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J11	J12	J13	J14
30/1/08	7.15	7.06	7.15	7.14	7.08	7.05	7.14	7.20	7.18	7.06				
28/2/08	7.07	7.15	7.10	6.91	6.80	6.84	6.85	6.83	6.83	6.92	7.10	7.10	7.09	7.09
16/3/08	6.99	7.06	7.10	7.17	7.04	6.96	6.91	6.93	7.04	6.86	7.05	7.03	7.00	7.00
20/2/08			7.2	7.1					7.1					
Avg	7.07	7.09	7.13	7.09	6.97	6.95	6.97	6.98	7.03	6.95	7.07	7.07	7.05	7.05
STD	0.08	0.05	0.03	0.12	0.15	0.10	0.16	0.19	0.15	0.11	0.04	0.04	0.06	0.07
P value at 95% c		0.085	0.052	0.364	**0.012**	1.000	0.240	0.271	0.364	0.143		0.86		1.00

Table 8 Temperature results (^{o}C)

	Sampling Stations													
Date	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J11	J12	J13	J14
30/1/08	24	24	23	23	23	24	23	25	25	24				
28/2/08	21	20	22	21	21	21	22	22	22	21	22	22	21	22
16/3/08	21	21	22	22	22	22	22	22	23	23	20	20	20	21
20/2/08			**22**	**22**					**22**					
Avg	21.82	21.89	22.42	21.65	22.10	22.34	22.36	23.06	22.88	22.77	20.98	21.02	20.63	21.36
STD	1.72	2.06	0.30	1.18	0.67	1.13	0.77	1.98	1.51	1.46	1.66	1.53	0.73	0.98
P value at 95% c		0.129	**0.006**	0.317	0.338	**0.006**	0.249	**0.011**	0.657	0.049		0.98		0.49

Table 9 Faecal coliform results FCU/100 ml

	Sampling Stations													
Date	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J11	J12	J13	J14
30/1/08	50	84	45	37	11	13	10	88	20	0				
28/2/08	116	229	170	63	39	23	65	23	23	4	251	324	170	135
16/3/08	24	205	83	10	120	11	17	6	1	0	5	3	26	98
Avg	63	173	99	37	57	16	31	39	15	1	128	164	98	117
STD	47.43	77.72	64.12	26.50	56.61	6.55	30.02	43.28	11.93	2.31	173.71	226.75	101.82	26.16
P value at 95% c		**0.007**	**0.019**	0.518	0.111	0.592	0.543	**0.008**	**0.015**	0.079				

Table 10 Nitrate concentrations results (mg/L)

Date	Sampling stations									
	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10
14/2/08	0.15	0.18	0.25	0.21	0.15	0.17	0.13	0.17	0.14	0.03
28/3/08	0.22	0.22	0.29	0.18	0.16	0.08	0.07	0.08	0.13	0.00
Avg	0.18	0.20	0.27	0.19	0.16	0.12	0.10	0.13	0.13	0.01
STD	0.05	0.03	0.03	0.02	0.01	0.07	0.04	0.06	0.01	0.02
P value at 95% c		**0.029**	**0.001**	**0.001**	**0.003**	0.623	0.316	**0.003**	**0.004**	**0.021**

Table 11 Sulphate concentrations for results (mg/L)

Date	Sampling stations									
	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10
14/2/08	0.35	0.16	0.21	0.22	0.17	0.40	0.18	0.21	0.15	0.26
28/3/08	0.13	0.16	0.97	0.24	0.17	0.37	0.42	0.44	0.35	0.43
Avg	0.24	0.16	0.59	0.23	0.17	0.38	0.30	0.32	0.25	0.35
STD	0.16	0.00	0.54	0.01	0.00	0.02	0.17	0.16	0.14	0.12
P value at 95% c		**0.002**	**0.005**	0.159	**0.006**	**0.012**	**0.002**	**0.040**	**0.030**	**0.003**

Table 12 Phosphate concentrations results (mg/L)

Date	Sampling stations									
	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10
14/2/08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28/3/08	0	0	0	0	0	0	0	0.081	0	0
Avg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00
STD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00

Table 13 Iron concentrations results (mg/L)

Date	Sampling stations									
	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10
14/2/08	0	0	0	0	0	0	0	0	0	11.03
28/3/08	0	0	0	0	0	0	0	0	0	10.19
Avg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.61
STD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.59

Table 14 Manganese concentrations results (mg/L)

Date	Sampling stations									
	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10
14/2/08	0	0	0	0	0	0.22	0	0	0	0
28/3/08	0	0	0	0	0	0	0	0	0	1.37
Avg	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.68
STD	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.97

Table 15 DO results (mg/L)

Date	Sampling stations									
	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10
14/2/08	8.1	8.0	7.9	7.9	7.9	7.8	8.0	7.9	8.0	7.6
28/3/08	7.8	7.7	7.7	7.8	7.9	7.9	7.9	7.8	7.8	7.6
Avg	7.93	7.87	7.82	7.83	7.88	7.85	7.93	7.83	7.90	7.62
STD	0.24	0.19	0.12	0.09	0.02	0.07	0.05	0.05	0.14	0.02
P value at 95% confidence				0.370	1.000	1.000	**0.000**	**0.010**	0.100	**0.020**

Appendix B: Discharge and rainfall data for Mulunguzi River

Table 16 Discharge values for Mulunguzi River in m3/s

1979-2004	DISCHAR(	Q-RANKED	RANK (n)	m	P=(1+n)/m	P%	1/P
Jan	0.974	1.01	51	300	0.17	17.33	5.77
	0.416	1	52	300	0.18	17.67	5.66
	0.77	0.996	53	300	0.18	18.00	5.56
	0.898	0.991	54	300	0.18	18.33	5.45
	0.845	0.985	55	300	0.19	18.67	5.36
	0.263	0.981	56	300	0.19	19.00	5.26
	0.753	0.974	57	300	0.19	19.33	5.17
	1.26	0.96	58	300	0.20	19.67	5.08
	1.27	0.954	59	300	0.20	20.00	5.00
	1.16	0.946	60	300	0.20	20.33	4.92
	0.96	0.92	61	300	0.21	20.67	4.84
	0.317	0.919	62	300	0.21	21.00	4.76
	0.227	0.912	63	300	0.21	21.33	4.69
	0.3	0.909	64	300	0.22	21.67	4.62
	1.01	0.906	65	300	0.22	22.00	4.55
	0.881	0.901	66	300	0.22	22.33	4.48
	2.02	0.898	67	300	0.23	22.67	4.41
	0.919	0.898	68	300	0.23	23.00	4.35
	0.634	0.895	69	300	0.23	23.33	4.29
	0.454	0.886	70	300	0.24	23.67	4.23
	0.3	0.883	71	300	0.24	24.00	4.17
	0.782	0.881	72	300	0.24	24.33	4.11
	1.03	0.864	73	300	0.25	24.67	4.05
	0.504	0.861	74	300	0.25	25.00	4.00
	0.753	0.845	75	300	0.25	25.33	3.95
Feb	1.73	0.838	76	300	0.26	25.67	3.90
	0.838	0.83	77	300	0.26	26.00	3.85
	1.32	0.81	78	300	0.26	26.33	3.80
	1.37	0.797	79	300	0.27	26.67	3.75
	1.55	0.784	80	300	0.27	27.00	3.70
	0.47	0.782	81	300	0.27	27.33	3.66
	0.92	0.77	82	300	0.28	27.67	3.61
	1.02	0.753	83	300	0.28	28.00	3.57
	2.1	0.753	84	300	0.28	28.33	3.53
	1.39	0.748	85	300	0.29	28.67	3.49
	1.47	0.739	86	300	0.29	29.00	3.45
	0.739	0.738	87	300	0.29	29.33	3.41
	0.343	0.737	88	300	0.30	29.67	3.37
	0.405	0.736	89	300	0.30	30.00	3.33
	1.4	0.723	90	300	0.30	30.33	3.30
	2.33	0.719	91	300	0.31	30.67	3.26
	1.28	0.711	92	300	0.31	31.00	3.23
	1.11	0.711	93	300	0.31	31.33	3.19
March	2.71	0.592	101	300	0.34	34.00	2.94
	0.946	0.584	102	300	0.34	34.33	2.91
	1.24	0.582	103	300	0.35	34.67	2.88
	0.996	0.572	104	300	0.35	35.00	2.86
	0.985	0.555	105	300	0.35	35.33	2.83
	1.01	0.549	106	300	0.36	35.67	2.80
	1.8	0.547	107	300	0.36	36.00	2.78
	0.954	0.542	108	300	0.36	36.33	2.75
	1.7	0.541	109	300	0.37	36.67	2.73
	0.83	0.521	110	300	0.37	37.00	2.70
	1.72	0.518	111	300	0.37	37.33	2.68
	2.08	0.513	112	300	0.38	37.67	2.65
	0.861	0.513	113	300	0.38	38.00	2.63
	1.01	0.504	114	300	0.38	38.33	2.61
	1.11	0.504	115	300	0.39	38.67	2.59
	0.748	0.501	116	300	0.39	39.00	2.56
	0.784	0.49	117	300	0.39	39.33	2.54
	0.981	0.485	118	300	0.40	39.67	2.52
	1.09	0.484	119	300	0.40	40.00	2.50
	2.32	0.473	120	300	0.40	40.33	2.48
	0.864	0.47	121	300	0.41	40.67	2.46
	2.13	0.467	122	300	0.41	41.00	2.44
	0.901	0.466	123	300	0.41	41.33	2.42
	3	0.466	124	300	0.42	41.67	2.40

Table 17 Rainfall data for 1953 to 1998

MONTHLY RAINFALL DATA FOR 1953 TO 1998												
Mean (1953-1998)	145.8	365.1	411.1	349.6	340.2	149.1	53.9	26.9	15.8	9.7	14.1	35.7
Mean (1953-1980)	167.0	386.0	408.0	374.0	370.0	190.0	41.0	30.0	20.0	14.0	12.0	32.0
	Nov.	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
1953/54	13	335.8	63.5	194.8	227.5	14.7	9.1	1.5	0.5	8.4	4.5	3.2
1954/55	264.9	285.8	406.7	397.3	262.9	128.3	19.6	4.3	7.9	0	3.8	3.3
1955/56	124	284	228.9	174.2	273.4	259.8	6.3	30.5	3	15.7	11.9	45.5
1956/57	171.2	395.5	430.3	289.8	173.2	167.4	39.9	5.6	0	0.3	4.1	2
1957/58	41.7	380	318	298.7	20.8	40.1	16.6	10.2	4.1	7.4	108	9.7
1958/59	160.5	240.8	252.7	308.4	59.2	4.8	34.8	9.9	9.7	3.8	14	36.6
1959/60	51.3	153.9	89.7	267.7	196.1	37.6	13	53.3	15.2	0	15.2	0
1960/61	56.4	286	375.4	237.2	303.5	137.7	41.9	4.1	8.4	11.4	16.5	32.8
1961/62	232.9	422.1	359.4	99.3	480.8	154.7	22.6	5.3	16.8	2.5	0.5	7.9
1962/63	168.7	177.3	359.4	367.8	236.7	78.2	6.9	2	16.5	0	1.5	91.9
1963/64	74.2	356.4	261.4	227.6	90.9	10.2	18.8	0	19.1	1.8	0	5.3
1964/65	167	605.5	471.2	454.4	543.3	208.3	74.2	18.8	0	12.5	37.3	50.2
1965/66	203.5	103.4	363.5	593.3	335.3	93.2	103.5	131.9	47.2	0	37	10.9
1966/67	57.2	269.7	233.9	306.1	389	170.9	51.3	98	41.7	34.8	23.4	14
1967/68	68.3	243.1	258.3	457.4	232.7	172.7	10.4	61.2	0	20.1	2.5	4.1
1968/69	415.5	320	440.9	375.9	382	209.8	27.7	27.9	38.4	24.4	12.7	72.4
1969/70	48	644	602.3	334.1	90.9	118.1	23.5	51.6	29	1.5	0	41.9
1970/71	304.3	467.6	741.4	198.4	129.9	62.7	47.8	6.6	11.2	0	0	15.5
1971/72	176	470	613.5	248.4	243.3	232.4	144.3	32.8	26.4	18	1.3	27.7
1972/73	174.8	380	403.4	328.9	501.4	194.8	4.1	54.1	13	5.1	2.5	4
1973/74	127.3	123.4	493	509	664.7	216.9	95.6	28.2	50.8	13.5	1	0
1974/75	98	338.1	185.4	385.3	263.7	194	129.8	41.7	12.2	7.4	3.3	101.6
1975/76	154.9	520.4	403.9	492.5	263.7	194	34.3	28.4	21.1	0	0	91.9
1976/77	99.1	388.1	484.4	436.9	335	87.6	0	12.7	3.4	0.1	1.3	0
1977/78	209.3	387	420.3	500.5	1104.9	398	43.9	37.1	17	0	42.4	44.2
1978/79	140.5	804.2	471.4	532.6	436.9	95	0	38.6	31.8	0	3	154.2
1979/80	419.9	396	225.3	405	756.9	484.8	14.3	50.1	21	23	0	56.3
1980/81	28.4	389.8	153.7	353.8	183.5	70.8	5.4	1.8	22.1	0	45.7	34
1981/82	234.9	243.6	464.3	366.4	156.3	173.2	11.9	25.3	17.2	7.3	2.2	90.3
1982/83	100.8	431	552.5	427.8	337.1	121.2	86.6	7.1	48.8	0	0	6.7
1983/84	37.5	112.4	80.9	233.4	303.1	57.6	35.3	52.3	25.4	1.5	103	6.2
1984/85	166	836.5	310.8	193.3	647.6	275.2	0	72	6.7	20.1	16.3	0
1985/86	269.3	428.5	686.7	567	468.5	322.2	2.3	39.7	7.8	0	3.9	48.5
1986/87	289.7	539.1	369.3	424.8	171.1	72.2	68	15.5	0	6.5	1.7	163.7
1987/88	75.6	150.4	478.3	465.2	289.8	207.6	38.7	9.4	3.4	23.2	4.8	57.4

Appendix C Historical water quality data (1999-2006)

Table 18 Historical yearly water quality data from 1999 to 2006

Year and Parameter	**SAMPLE SOURCES**	
	Dam Intake tower(Point 5)	**Mulunguzi River(Point 2)**
2006		
Iron	21.21mg/l	0.62mg/l
Manganese	2.09 mg/l	0.01 mg/l
Nitrate	0.54 mg/l	0.34 mg/l
Phosphate	0.05 mg/l	0.04 mg/l
FS	0	12/100ml
FC	0	45/100ml
2005		
Iron	18.19 mg/l	0.5 mg/l
Manganese	1.85mg/l	0.41 mg/l
Nitrate	0.39 mg/l	0.27 mg/l
Phosphate	0.05 mg/l	0.04 mg/l
FS	0	3/100ml
FC	0	12/100ml
2003		
Iron	14.33 mg/l	0.06 mg/l
Manganese	0.06 mg/l	0.04 mg/l
Nitrate	0.28mg/l	0.1 mg/l
Phosphate	0.04 mg/l	0.03 mg/l
FS	6/100ml	40/100ml
FC	30/100ml	80/100ml
2000		
Iron	11.49 mg/l	0.03 mg/l
Manganese	0.04mg/l	0.05 mg/l
Nitrate	19.00mg/l	0.12 mg/l
Phosphate	0.03 mg/l	0.02
FS	12/100ml	34/100ml
FC	96/100ml	144/100ml
1999		
Iron	0.01	0.01
Manganese	0.05	0.04
Nitrate	0.1	0.1
Phosphate	0.1	0.1
FC	0	5
FS	0	1

(Source: SRWB Water Quality Department)