Mapping of Provisioning Ecosystems Services in Likangala River Catchment, Zomba, Southern Malawi

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DECLARATION

I declare that this thesis is an original work generated from data collected myself towards a PhD degree at North West University. Wherever reference to other's work was done, they have been clearly attributed. All sources of help have been acknowledged.

Parts of the thesis have been presented at the following conferences:

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DEDICATION

I thank the Almighty God in helping me complete this work. I would like to dedicate this work to my parents; my father, Rajagopalan Pullanikkatil and my mother, Roopalekha Sukumaran, who are my pillars of support, they taught me never to give up, to keep persevering and to believe in myself.

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ABSTRACT

Ecosystem services are linked to the well-being of humans and therefore there is a need to conserve and ensure sustainability of these services for human survival. This is a study of a river catchment ecosystem in Malawi that focuses on provisioning ecosystem services, where they are located, what influences them and makes recommendations on a holistic ecosystem management approach where human and ecosystem needs are balanced. The Likangala River located in Southern Malawi is important for the provisioning ecosystem services of both food and non-food. However, the river system is affected by various land use changes and waste disposal in the catchment. Additionally, over extraction and poor land use practices are threatening provisioning ecosystem services.

Community members undertook participatory mapping to chart the provisioning ecosystem services that they derive from the catchment. They drew up an inventory and recorded ten important provisioning services which included wild animals, wild fruit, sand, stone, fish, medicinal plants, birds, ornamental flowers, wood and reeds. They reported that with increasing population and the influx of migrants into the catchment; there was increasing competition for provisioning services. Furthermore, they reported that these services were declining over the years due to deforestation which affected the habitats of wild animals and birds and reduced the abundance of wood, wild foods and medicinal plants.

Land use/land cover change detection between 1984 and 2013 revealed that woodlands have decline by 88.5%, shrublands have declined by 16.7%, agricultural areas have increased by 44.3% and urban areas increased by 143%. The declining woodlands, forests and shrublands have implications on the availability of provisioning services that communities derive from this ecosystem. River bank cultivation was affecting habitats of medicinal plants while water pollution affected abundance of fish in the river. The study established that water quality of the Likangala River is affected by pollution from urban areas in particular the sewage treatment plant, runoff from farms, waste disposal from households and by degrading land use activities all along the catchment including deforestation, sand mining and river bank cultivation. These activities makes the water unfit for drinking without treatment as revealed by the water quality index. Hence, diseases such as cholera and diarrhoea due to consumption of polluted water were also reported. The linkages between population, health and environment became apparent and thus the need for a holistic approach to manage this ecosystem became evident.

The Population Health Environment approach is an integrated method that addresses the elements of drivers, pressures, states and impacts of ecosystem change seen in this river catchment. The study noted that reducing deforestation, enforcement of buffers along river banks, waste management for improving water quality, improving sanitation, providing civic education to communities and employing an ecosystem approach in management of the catchment could assist in improving the state of the catchment. A practical explanation of how ecosystem conservation can be done using a bottom-up approach within the existing Malawian institutional setup is also provided. Using the Drivers-Pressures-State-Impacts-Responses model in combination with the Population, Health and Environment approach, the study made recommendations to achieve a balance between humans and ecosystem needs through a novel framework called the “Ecosystem Services Integrated Response Framework” (ESIRF). The ESIRF provides a structure for sustainably managing ecosystems and at the same time providing for human needs through integrated responses that address population, health and environment challenges. The study supports the philosophy of “environmentalism of the poor” where the poor are considered the solution rather than the problem, in order to achieve the outcome of an ecologically sustainable society.

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ACRONYMS

APHA:	American Public Health Association
BOD:	Biological Oxygen Demand
CBNRM:	Community Based Natural Resources Management
COD:	Chemical Oxygen Demand
CFU:	Colony Forming Units
DEC:	District Executive Committee
DDP:	District Development Plan
DEC:	District Executive Committee
DO:	Dissolved Oxygen
DPSIR:	Drivers, Pressures, State, Impacts, Responses
DWAF:	Department of Water Affairs and Forestry
EEA:	European Environment Agency
EPA:	Environmental Protection Agency
ES:	Ecosystem Services
FAO:	Food and Agriculture Organization
FAOSTAT:	The Food and Agriculture Organization Corporate Statistical Database
GDP:	Gross Domestic Product
GIS:	Geographic Information System
GPS:	Geographic Positioning System
HSA:	Health Surveillance Assistant
InVEST:	Integrated Valuation of Ecosystem Services and Trade-offs
IPBES:	Intergovernmental Panel on Biodiversity and Ecosystem Services
MBS:	Malawi Bureau of Standards
MEA:	Millennium Ecosystem Assessment
NDVI:	Normalised Difference Vegetation Index
NGO:	Non-Governmental Organization
NIR:	Near-Infrared Regions
NSF:	National Sanitation Foundation
NTU:	Nephelometric Turbidity Unit
OECD:	Organization for Economic Cooperation and Development
PES:	Payment for Ecosystem Services
PGIS:	Participatory Geographic Information System

PHE:	Population, Health and Environment
PPGIS:	Public Participation Geographic Information System
PRA:	Participatory Rural Appraisal
SEP:	Socio Economic Profile
SolVES:	Social Values for Ecosystem Services
SP:	Sampling Point
TEEB:	The Economics of Ecosystems and Biodiversity
TFR:	Total Fertility Rate
TA:	Traditional Authority
UNEP:	United Nations Environment Programme
UNESCO:	United Nations Education, Scientific and Cultural Organization
USA:	United States of America
UTM:	Universal Transverse Mercator
VAP:	Village Action Plans
VNRMC:	Village Natural Resources Management Committee
WHO:	World Health Organization
WQI:	Water Quality Index
WRI:	Water Resources Institute

DEFINITIONS

Biodiversity: The number and variety of organisms found within a specified geographic region. The variability among living organisms on the earth, including the variability within and between species, and within and between ecosystems.

Ecosystem Cultural services: are the environmental settings that give rise to the cultural goods and benefits that people obtain from ecosystems such as recreation from tourism, etc. .Ecosystem Services such as recreation from tourism, spiritual values (e.g. Sacred Rivers) and educational values (e.g. nature inspiring design of new products and technology).

Regulating Services: Ecosystem Services such as ecosystem control of natural processes which will benefit humans (e.g. Regulation of climate, maintaining air, soil and water quality, regulating water flow by wetlands, controlling erosion, etc.)

Supporting services: Ecosystems Services such as natural systems that maintain other ecosystem services (e.g. nutrient cycling, habitats that support species, water cycling).

Ecosystem well-being: A condition in which the ecosystem maintains its diversity and quality and thus its capacity to support people and the rest of life as well as its potential to adapt to change and provide a viable range of choices and opportunities for the future.

Ecosystem: A dynamic complex of plant, animal, and microorganism (living organism) communities and the non-living environment interacting as a functional unit.

Ecosystems Services: The conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life.

Indigenous knowledge: A body of knowledge that has been built up by people who have been living in close contact with nature and usually passed on from generation to generation through word of mouth.

Participatory Geographic Information Systems: Participatory approaches involving communities in planning, spatial information and communication management.

Payment for Ecosystem Services: A method of internalizing the positive externalities associated with a given ecosystem or a specific resource use.

Provisioning Services: Ecosystems Services such as goods or products obtained from ecosystems (e.g. crops, water, fish, and timber)

Red List Species: List of threatened or near extinct plants, animals and birds.

Total Fertility Rate: It is the number of children born to women of reproductive health age between 15-49 years.

Well-being: The satisfactory state that someone or something should be in, that involves such things as being happy, healthy, safe, meeting basic needs of clothing, shelter, food and livelihood.

CHAPTER 1

1 INTRODUCTION

1.1 BACKGROUND

Life on our planet is entirely dependent on the ecosystem services provided by Earth's natural systems. Ecosystem services are defined as the benefits derived from nature, such as food, clean water, flood control, climate regulation by forests and nutrient cycling (MEA, 2003). There is scientific evidence linking ecosystem services to human well-being (TEEB, 2009) most apparently by provision of food (Butler and Oluoch-Kosura, 2006) and so there is a need to conserve and ensure sustainability of ecosystem services for human survival (EPA, 2012; WRI, 2012). However, growing population pressure and the drive for economic growth make human beings themselves contributors to damaging ecosystems and their services thereby causing negative feedbacks (MEA, 2003; Ehrlich and Ehrlich, 2012; Saehoon and Peter, 2012). Consequently, there is need to balance ecosystem and human needs in order to attain sustainability. Finding this balance forces mankind to look at the complexities of nature and community lives and their interconnectivities; hence management paradigms must use an integrated systems approach, embracing many disciplines (Wainger and Mazotta, 2011).

Since the publication "How much are nature's services worth?" by Westman (1977), there has been extensive research and interest in the nature of ecosystem services. The Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) was established by the United Nations in 2010 and a new academic journal (Ecosystem Services) has been dedicated to the subject (Orenstein *et al.*, 2012). Irrespective of the widespread use and understanding of the concept of ecosystem services, research gaps still exist. In the first major study, the Millennium Ecosystems Assessment (commissioned by the United Nations), compiled by experts from 95 countries, highlighted the fact that ecosystem services cannot be taken for granted. About 60% of the world's major ecosystems are already degraded and this impacts negatively on human well-being (MEA, 2003). The MEA study concluded that worldwide, developmental activities are posing threats to the health of ecosystems and affecting the services they could provide. Studying ecosystem services, their impact on human welfare and the consequent effects of degradation of ecosystems on humans becomes an interesting scientific study and has the potential to provide information for community-based natural resources management which could aid conservation and lead to poverty reduction. This study fills the research gap identified by the MEA and researchers who concluded that there is need to understand how ecosystem services are benefitting people and how they are being managed in various landscapes especially at the micro scale (MEA, 2003; Carpenter *et al.*, 2006; Carpenter *et al.*, 2009).

Understanding what the provisioning ecosystems services are, where they are located, benefits accrued by the population within the catchment and appreciation of the changes in land use, land cover and water qualities which affect ecosystems services form part of this research. This study centres on the interdisciplinary field of ecosystem services science using the case study of a river catchment in Southern Malawi. The study involves multiple approaches including analysis of land use change, water quality assessment, ethno botany, mapping of provisioning ecosystem services and developing a framework for natural resource management using a systems approach.

1.2 THE CONTEXT OF ECOSYSTEM SERVICES

The concept of "Ecosystem" was coined by Arthur Tansley in 1938 who defined the term "ecosystem" as an interactive system of living and non-living things which brought attention to the fact that the environment is a system which has biological, chemical, physical and other components which interact and interplay (Heath, 2013). Odum published "Fundamentals of Ecology" in 1953 where ecosystem was defined as the basic functional unit of ecology (Heath, 2013).

Ecosystem services were defined by Daily (1997) as "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life", while. Harrington *et al.* (2010) defined it as "benefits that humans recognize as obtained from ecosystems that support, directly or indirectly, their survival and quality of life". TEEB (2009) defined Ecosystem services as "the direct and indirect contributions of ecosystems to human well-being". Jenkins *et al.* (2010) defines it as "a collective term for the goods and services produced by ecosystems that benefit humankind". De Groot *et al.* (2002) defined it as "the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly". Costanza *et al.* (1997) defined it as "the benefits human populations derive, directly or indirectly, from ecosystem functions". The MEA (2005) defined it as "the benefits people obtain from ecosystems". Boyd and Banzhaf (2007) said ecosystems services are "components of nature, directly enjoyed, consumed, or used to yield human well-being”. Fisher *et al.* (2009) defined it as “the aspects of ecosystems utilized (actively or passively) to produce human well-being”. Nelson *et al.* (2009) stated that ecosystems services are “a range of goods and services generated by ecosystems that are important for human well-being”. All these definitions either link ecosystem services to the benefits humans derive or state that ecosystem services are equal to the benefits humans derive from nature. As such, there is one commonality in all these definitions; the fact that humans benefit either directly or indirectly from ecosystems services.

Tracing the history of studies on ecosystem services, it has been documented that in the 1970s, ecosystem functions were connected to services that humans benefit from and thereby generating interest in biodiversity conservation (Westman, 1977; Ehrlich and Ehrlich, 1981; de Groot, 1987). In the 1990s, scientists began using the term “ecosystems services” in literature (Costanza and Daily, 1992; Perrings *et al.*, 1992; Daily, 1997), which led to scientists working with economists and estimating economic value of ecosystems services (Costanza *et al.*, 1997). The Millennium Ecosystem Assessment (MEA, 2003), which gave a comprehensive assessment of the world’s ecosystems, to achieve policy level attention and since then, there have been many studies on ecosystems services (Fisher *et al.*, 2009; Power, 2010; Bateman *et al.*, 2011; Garbach *et al.*, 2012; and Johnson *et al.*, 2012) . The journal *Nature* has stated that term Ecosystem Service has gained such popularity that it has now entered mainstream scientific and political thinking (Nature Editorial Board, 2009).

Ecosystem services have been classified into four categories based on the reports of the Millennium Ecosystem Assessment (MEA, 2005); The Cost of Policy Inaction (Braat and ten Brink, 2008); and The Corporate Ecosystem Services Review (Hanson *et al.*, 2012). The four categories of ecosystem services are provisioning services, regulating services, cultural services, and supporting services. Provisioning services include goods or products obtained from ecosystems (e.g. crops, water, fish, timber), while regulating services include services such as ecosystems control of natural processes which will benefit humans such as regulation of climate; maintaining air, soil and water quality; regulating water flow by wetlands; and controlling erosion. Cultural services involve recreation from tourism; spiritual values derived from nature (e.g. sacred rivers), educational values such as nature inspiring design of new products and technology and supporting services include natural systems that maintain other ecosystem services for example, nutrient cycling, water cycling and habitats that support species. All the four services are important for natural resource management and affect human life in one way or another. The services classification has recently been reduced to only three categories namely, provisioning, regulating and supporting. This has been due to confusion between cultural and supporting services which overlapped in some areas (Lele *et al.*, 2013). This study looks at provisioning ecosystem services in a river catchment (the Likangala) in Southern Malawi as they are the ones which are directly affecting livelihoods. The supporting, cultural and regulating services are not covered in this study and may be areas of further study. Here we underscore how human activities affect ecosystem services and highlight the need for a holistic approach for ecosystem management.

1.3 ANTHROPOGENIC ACTIVITIES AND IMPACTS ON ECOSYSTEMS

The effect of anthropogenic activities such as land use and land cover change comprising agricultural expansion, urbanization and deforestation affect ecosystems services. Land use and land cover change due to urbanization has affected ecosystem services globally as studies in China (Tianhong *et al.*, 2010; Feng *et al.*, 2012), United States (Kreuter *et al.*, 2001) and Iran (Monavari *et al.*, 2010) indicate. Tianhong *et al.* (2010) derived ecosystem service value using the method of multiplying the area of land use and land cover category and ecosystem value coefficient and reported that due to the decreasing areas of woodland and wetland, there was a net decline in ecosystem service value of ¥231.3million from 1996 to 2004 in Shenzhen (0.19 million hectares), China. Feng *et al.* (2012) stated that the total ecosystem service value of Manas River, China, declined at the rate of 0.1 % per year over 32 years (1976 to 2008) due to a decreasing area of grassland and water supply, waste treatment, soil formation and retention, and biodiversity protection being the main ecological functions to be affected. Kreuter *et al.* (2001) used different methods (remote sensing, economic valuation and sensitivity analysis) to quantify urban spread (sprawl's) has negative effects on ecosystem services in Texas, USA. Monavari *et al.* (2010) conducted a Biodiversity Impact Assessment in Iran to estimate the impact of the Dasht Arjan – Pol Abgineh road on the vegetation and wildlife. The findings of the assessment showed that ecosystems would be negatively affected by the construction of the planned new road in that area. In a special analysis in Flanders, Belgium, the biodiversity score (number of Red List plant species per grid cell) and ecosystem services showed a clear decline with an increase in land use intensity (Schneiders *et al.*, 2012). The study found that as human use of land increased, the biodiversity score declined. Globally, conversion of natural ecosystems by humans for agriculture and settlements has affected wildlife habitats, advancing extinction of what

(Hoekstra *et al.*, 2005). Schneiders *et al.* (2012) advocated the need for the conservation and restoration of biodiversity hotspots. Interestingly, increasing plant diversity was found to have had a positive effect on provisioning services such as food, fodder, timber and firewood as well as other services such as erosion control and soil quality improvement (Quijas *et al.*, 2010). Such studies indicate the result of development on ecosystem services and highlight the need for managing development in such a manner so as to avoid negative impacts to ecosystems. The above mentioned authors also suggest that biodiversity conservation and ecosystem services management are complementary approaches for ecosystem management.

In addition to urbanization and development, another human activity that affects ecosystem services both positively and negatively, is agriculture (Zhang, 2007; Braat and ten Brink, 2008). The Millennium Ecosystem Assessment (MEA, 2005) stated that 35% of the Earth's land surface is used for growing crops or rearing livestock. Agricultural production and the pursuit of food security have brought about changes in land use and are key drivers of landscape change (UNEP, 2011). Agricultural ecosystems are important for human well-being, as food, forage, bioenergy and pharmaceuticals are derived from these. Some of the benefits to regulating ecosystems services from agriculture include pest control; regulation of water quality; carbon sequestration (for example in agroforestry); genetic diversity for agricultural use in future; soil retention; nutrient cycling and pollination (Power, 2010). However, negative effects from agriculture on ecosystem services include loss of soil protection, reduced biodiversity and pollution from fertilizers and pesticides. In spite of agriculture being an important economic sector in many countries including Malawi, the value of ecosystems services to agriculture is most often underappreciated (Power, 2010). In some countries such as Australia (Sandhu *et al.*, 2012) and China (Feng *et al.*, 2010), studies have indicated that ecosystem services were negatively impacted due to agricultural expansion. Power (2010) argues that maximizing provisioning services from agriculture may result in negative impacts on other ecosystem services such as loss of wildlife habitat, loss of species diversity, nutrient runoff, sedimentation of waterways, greenhouse gas emissions and pesticide poisoning of humans and non-target species. Some of the disservices from agriculture include loss of habitats for biodiversity due to land being used as cropland for mono-cropping. Thus, it is essential to manage land for agriculture so as to avoid trade-offs to ecosystem services and minimize disservices.

1.4 TRADE-OFFS AND MANAGEMENT OF ECOSYSTEMS SERVICES

1.4.1 Agriculture and Ecosystem Services

Humans value ecosystem services mainly for their provisioning services and when land is used for agriculture as is the main land use globally (Power, 2010); there are instances when trade-offs are made. In agriculture, provisioning services such as production of crops for food, collection of timber and firewood may be increased most often by trade-off with regulating services such as soil conservation, carbon sequestration or water purification, (MEA, 2005). Trade-offs informed by the identification of ecosystem services, their values and who benefits from them will help natural resource management. Schneiders *et al.* (2012) state that trade-offs between biodiversity and ecosystem services most likely happen when provisioning services based on food production are involved. Trade-offs among ecosystem services needs to be managed well so that other services do not suffer when provisioning services are increased for feeding the human population. This was confirmed by a study by Power (2010) where the author also talks about the trade-offs that may occur between provisioning services and other ecosystem services. Power (2010) identifies using appropriate agricultural management practises that can help realize the benefits accrued from ecosystem services and at the same time reduce the disservices. A number of tools are available that model trade-offs, such as the Integrated valuation of ecosystem services and trade-offs developed (InVEST) (Tallis and Polasky, 2009). Scenarios which benefit both humans and the ecosystem need to be explored to prevent trade-offs, so that human well-being is not affected. In this regard, it is important to understand the link between poverty and ecosystems.

1.4.2 Poverty and Ecosystems

If ecosystems are degraded, services derived from ecosystems are affected and thereby impacting on humans in many ways including increasing poverty. For poorer countries, livelihoods depend on provisioning ecosystem services that humans derive from nature (MEA, 2005; TEEB 2009). Poverty and ecosystems have a symbiotic relationship in such natural resources-dependent countries. Ecosystems can be subjected to shock from anthropogenic activities such as developments that clear forests or pollution that renders water bodies unfit for human consumption. In addition, natural disasters such as landslides or earthquakes and climate change which cause erratic rainfall patterns and extreme weather events can contribute to these shocks. Such shocks may exacerbate poverty as ecosystems services will decline, thereby affecting livelihoods. This is true in Malawi as the country has been experiencing climate change induced extreme weather events which have affected agriculture and natural resource dependent livelihoods (Government of Malawi, 2011). Hence, it may be inferred that poverty and ecosystem services are linked. This makes it important to study where and what ecosystem services exist, in order to protect them better for future generations. In this regard, mapping of ecosystems services is a useful tool as it provides a special inventory of ecosystem services, which makes it easier to manage. In this context, mapping of provisioning ecosystem services in Likangala River catchment becomes important.

1.4.3 Mapping of Ecosystem Services

Mapping of ecosystem services using chronological and spatial scales is important. Provisioning ecosystem services and interactions are not static and do not only include biophysical, but socio-economic factors, which play a role in how the services change. To understand how the services change in space, spatial information is used and therefore mapping is suitable. Mapping of ecosystem services has emerged as a valuable method for studying these services and researchers have increasingly used Geographic Information System (GIS). GIS has been used to map social values of ecosystem services in the United States (Sherrouse *et al.*, 2011) where the authors used a GIS application called Social Values for Ecosystem Services (SolVES). This method integrates attitude and preference survey results with data of the physical environment. The authors however, did not look at the health of ecosystems over the years, for example, water quality and quantity of lakes which were part of the study area. Another study by Rozenstein and Karnieli (2011) used remote sensing and GIS to study Israel's land use changes over the years. This study was limited to land use changes and did not study ecosystem services. Hessel *et al.* (2009) used Participatory GIS (PGIS) method which involved the local community, researchers and government officials who came together for integrated land use planning in Burkina Faso, focussing on land use and not ecosystem services.

PGIS has been used to develop scenarios describing the effects on livelihoods and water resources in different management configurations and has been helpful for improved water management decision making in Tanzania (Cinderby *et al.*, 2012). However, the study did not look at provisioning ecosystem services. Brown and Weber (2012) undertook an internet based Public Participation GIS (PPGIS) in Australia, which is similar to PGIS, and was used to measure changes in the importance in spatial distribution of landscape values. Brown *et al.* (2012) undertook a similar study in Colorado, USA. Using internet based PPGIS method is limiting as it can only target those who are literate and have access to the internet and may not be suitable for Malawi.

While mapping provides much needed spatial information on ecosystem services, putting economic value to ecosystem services provides another level of information for decision making. Giving economic value to ecosystem services is helpful to conservation efforts, and more recently, Payments for Ecosystem Services schemes are gaining popularity as a method of helping conserve ecosystems while at the same time reducing poverty (Pagiola, 2008; Garbach *et al.*, 2012).

1.4.4 Payment for Ecosystems Services

Unsustainable use of ecosystems will cause environmental degradation. The Millennium Ecosystems Assessment report (2005) stated that ecosystems were being degraded due to habitat loss, pollution, overexploitation, invasive species and climate change. Putting an economic value to ecosystem services was thought to help humans understand the extent of loss from ecosystems degradation. Ecosystem valuation is an emerging field and a number of methods are used in economics to estimate these values (Barbier, 2009; Hanley and Barbier, 2009; Holland *et al.*, 2010; Bateman *et al.*, 2011). Accounting for benefits such as supporting services have been found to be a challenge and double counting of "intermediate service" (a service that helps generate other services) and "final service" (service which is directly valued by people) has also been found to affect policy decisions (Johnston and Russell, 2011 Making the economic values explicit should influence policy decisions and reduce erosion of ecosystem services (Gret-Regameya and Kytzia, 2007; Gómez-Baggethun *et al.*, 2010; Niu *et al.*, 2012). This led to development of Payment for Ecosystem Services (PES) which uses economic incentives to protect ecosystems (Gómez-Baggethun *et al.*, 2010; Garbach *et al.*, 2012).

Johnston *et al.* (2012) argues that there is much uncertainty in ecosystem services valuations arising from significant ambiguity about the biophysical production of ecosystem services and additional vagueness about the value of services. Valuation of ecosystems can be done using market and non-market principles (Power, 2010). Provisioning ecosystem services such as food, fibre and fuel as well as cultural services of naturally-provided avenues for recreation may be more easily valued. However, it is more difficult to put a value for regulating and sustaining services such as climate regulation, flood protection, air and water purification, nutrient cycling and soil formation, as these are more difficult to value

Researchers argue that the poor have not really benefitted from PES schemes as indicated by studies in Brazil (Ludivine *et al.*, 2012) and in Vietnam (To *et al.*, 2012). Ludivine *et al.* (2012) discussed a PES scheme in Brazil, where agricultural intensification through fire-free practises was encouraged to foster reforestation. However, the author argues that this scheme only targeted long-established settlements where farmers were wealthier. Therefore, there is a need to specifically target poor communities and design schemes that can benefit them. Similarly in Vietnam, To *et al.* (2012) argue that PES schemes were benefitting rich people due to their access to forest land. Impediments for poorer communities from benefitting from such schemes include insecure land tenure, high transaction costs and high opportunity cost. Furthermore, political and economic constraints as well as existing state forestry management practices or principles were identified as hindrances for poor communities. Land ownership also remains a challenge as those who need to manage the land for ensuring provisioning ecosystem services may not be the ones who benefit from the services (Power, 2010). Ecosystem management plans frequently result in some sections of society benefitting, while others lose out (Thompson *et al.*, 2011). As an example, from the forestry sector, when forest conservation strategies are designed to maximize carbon sequestration, this may cause communities in the areas to lose out as they will no longer have access to forest goods and services. Forests are important and are found in most river catchments where they play an important role in filtering water thereby maintaining and improving water quality. Water is important for sustaining life and thus river ecosystems become important.

1.4.5 Rivers and Ecosystems Services

Water is an ecosystem service and people's survival depends on it thereby making river ecosystems one of the most worthy systems to study. Rivers are vital to communities as they provide freshwater, carbon storage, fisheries, recreation, transportation and habitats for biodiversity. Surface water and ground water sources provide irrigation for agro-ecosystems which in turn help in food production. Water provisioning is linked to the health of vegetation in a catchment. Vegetation in natural ecosystems such as forests plays an important role in water infiltration, retention and flow across the landscape (Power, 2010). The dynamics of ecosystem service value caused by land use changes in a river in China were studied and it was stated that land use planning should emphasize protection of water body, woodland and grassland as they were considered to have the highest ecosystem service value (Feng *et al.*, 2012). In China in the Xinjiang River, it was also found that land development has changed the ecosystem through changes in biogeochemical cycling, the ecosystem structure, and ecosystem service value (Feng *et al.*2012). The study advocated for environmental protection and nature conservation in this river ecosystem. Land use change is a significant factor for change in ecosystems services. Therefore, this study looks at land use and land cover changes in Likangala catchment, as this has ramifications for ecosystems services.

1.5 ENVIRONMENTALISM OF THE POOR

Malawi's rural population depends on rain-fed agriculture for food. This population also depends on provisioning ecosystem services such as medicinal plants, construction materials, ornamental products, forest products and wild foods. This dependence on gathering natural resources leads to environmental degradation when competition for these resources is driven by population growth. With the population having trebled over the past forty years and 85% of it living in rural areas, it is not surprising that deforestation and land degradation has increased in the country (Government of Malawi, 2011). In Malawi, 50.7% of the people live below the poverty datum line (<$2/day) (World Bank, 2014). Economic activities and employment opportunities are low for those in rural areas, making them heavily dependent on natural resources. Communities therefore are driven to cutting down trees, cultivate along river banks, wetlands and hill slopes, in their effort to produce food. Poverty is thus intricately entwined with environmental degradation in poor societies such as those in rural Malawi.

Malawians depend on natural resources for their survival and therefore they are intrinsically motivated to manage the environment. Co-management and community based natural resources management (CBNRM) have been found to be successful in Malawi. CBNRM helps reduce poverty, empowers communities and aids in sustainable natural resource management (COMPASS, 2002). Malawi approved a Strategic Plan for CBNRM in November 2001, which triggered CBNRM implementation in forestry and artisanal fisheries (Njaya, 2002). Participatory fisheries management in Malawi were initiated on Lakes Malombe, Chilwa, and Chiuta between 1993 and 1995, where communities participate in resource management and monitoring and enforcing fisheries regulations (Bell and Donda, 1993; Njaya, 2002). Challenges to CBNRM mainly on monitoring the outcomes have been described (Piers, 2006). Other challenges were with regard to the authority and power influences of traditional leaders in Malawi. Nonetheless, co-management has been successful (Njaya, 2002; Government of Malawi, 2011). Several instances of successful implementation of CBNRM in Malawi have been reported (COMPASS, 2002).

Many studies have been carried out on the role of resource users in community-level participation (Njaya, 2002). However, not much has been done at a higher scale such as at district or catchment level. Community based natural resources management needs to be applied for all natural resources and this will help promote greater participation and accountability within the community members (Njaya, 2002). This will further support the decentralisation process of Malawi and devolving of authority to grassroots level, in so doing the poor will have more to lose by failing to manage and conserve their environment.

"Environmentalism of the poor" was a thinking motivated by social issues and survival for poor people. It is a movement supporting the poor whose livelihoods are entwined with nature and are threatened by changes in the environment, such as pollution, land cover change and industrialization. The argument is that "Environmentalism of the poor" has the prospect to become the main driving force to achieve an ecologically sustainable society (Davey, 2009). Thus, "Environmentalism of the poor" recognizes that social justice and environmental issues are inseparable. By striving for sustainability in environmental management, there will be a balance between ecological and social justice goals (Basole, 2006). This study supports this line of thinking and has proposed a management framework accordingly.

1.6 KNOWLEDGE GAPS IDENTIFIED

Several studies indicate the need for in-depth understanding of ecosystem services and its management because of our dependence on these services (Becker, 1999; Ricketts *et al.,* 2004; Russ *et al.,* 2004; Carpenter *et al.,* 2006; Naidoo *et al.,* 2008). The Millennium Ecosystems Assessment (2005) helped to build an understanding of ecosystem management by creating scenarios of future possibilities. The report showed that changes in ecosystems affect human welfare. The understanding of the consequences of anthropogenic activities influencing ecosystems is still vague (Carpenter *et al.,* 2006). The Millennium Ecosystems Assessment reported on socio-ecological interactions and uncertainties of how the future will unfold. The way ecosystem services are managed will affect the developmental processes of a country. Research around the world has shown that since ecosystem services concept covers both environmental and human elements; trans-disciplinary approaches are necessary in ecosystem service research (Carpenter *et al.,* 2009; Niu *et al.,* 2012; Nahlik *et al.,* 2012; Siew and Doll, 2012).

Although the concept of ecosystem services is gaining popularity amongst scientists, it remains mostly at a theoretical level and the practical application in land use planning and decision making at local level has been slow (Naidoo *et al.,* 2008, Daily *et al.,* 2009, Elmqvist *et al.,* 2011). Furthermore, inconsistent terms, definitions, and classifications deter progression of the study and use of ecosystem services (Nahlik *et al.,* 2012). Therefore, there is a need for moving from theory to practise and when that happens, many disciplines such as urban planning, engineering, social sciences, economics, physical science and ecology will all be involved. Moreover, the need for community engagement in ecosystem identification and validation is crucial (Nahlik *et al.,* 2012). The connection between the ecosystem and human well-being has been identified as important, which will drive the decisions in development (MEA, 2005). Since ecosystem services and its management cuts across many sectors such as land, water, agriculture and biodiversity; there is a need for interdisciplinary research (Carpenter *et al.,* 2009). This study used an integrated approach which includes land use and land cover change assessment, water quality and ecosystems services mapping. This study engaged communities in a participatory process to identify provisioning ecosystem services which have direct relation to their well-being.

1.7 STUDY AREA AND RESEARCH GAP FILLED

The study area is Likangala River catchment within the Lake Chilwa basin. The Lake is important in terms of fisheries production and this has been affected by fluctuating water levels (Njaya *et al.,* 2011). Lake Chilwa water levels have varied in the past and the lake has dried up several times (Lancaster, 1979; Kabwazi and Wilson, 1996; Nicholson, 1998; Chavula, 1999).

Lake Chilwa has been studied extensively by researchers dating as far back as the late seventies. Kalk *et al.* (1979) studied the economic importance of the lake to Malawi. Other studies conducted in the Lake Chilwa basin include those on water quality, water flow, management plans, and climate change adaptation interventions by Non-Governmental

Organizations (NGOs). On the ecosystem management plans, Njaya (2011) has documented the history of how management plans were drawn up since the colonial era in Malawi. The study identified gaps in the management plans including issues like pollution control, proper farming practises that reduce surface runoff and thereby decreasing silt load into the lake, use of fertilizers on rice schemes and tree planting that the author felt should have been considered during the planning of activities in the Lake Chilwa basin. The focus of this study, the Likangala River, has previously been studied by researchers; for instance, Chavula and Mulwafu (2007) undertook studies on water quality, Mulwafu (2000) Peters (2004), Ferguson and Mulwafu (2003) and Mulwafu and Nkhoma (2003) studied the conflicts over water use in irrigation. Land use changes and impact on fisheries have also been studied (Jamu *et al.*, 2003; Jamu *et al.*, 2005). Ethno-botanical studies have been done at the country-wide scale, not at river catchment level (Morris, 1991).

Ecosystem services management embrace both environmental and human elements and therefore a coupled human-environment systems approach is needed (Turner, 2010; Carter *et al.*, 2014). An important knowledge gap in the relationships between ecosystem services the connexions between levels of ecosystem services and how ecosystems change in the long-term has been pointed out (Norgaard, 2010). Specific provisioning ecosystem services such as medicinal plants, wild foods, ornamental products and construction materials have not been documented at the catchment scale in Malawi. This study attempts to address this need and uses several research methods; including quantitative (water quality and land use changes); qualitative (focus group discussions with communities) and spatial mapping method using participatory geographic information systems to examine provisioning ecosystems services in Likangala River. This study is a first attempt at studying the ecosystems services in Likangala River catchment in Southern Malawi using this multi-pronged approach.

1.7.1 Rationale for the choice of Likangala River

Likangala River is a diverse system, as it passes through varied landscapes. It originates from the forests of southern part of the Zomba Plateau, passes through the urban area of Zomba city and then flows through farmlands where tobacco and rice are grown before flowing through the Lake Chilwa wetland and into the lake proper (Jamu *et al.*, 2003). Lake Chilwa is a wetland of international significance being a Ramsar Site (The Ramsar Convention Secretariat, 2000; Birdlife International, 2011) and UNESCO Biodiversity Reserve

(UNESCOPRESS, 2006) located in Southern Malawi which shared by Mozambique on its eastern side. It has been observed that people continuously drift into the Lake Chilwa Basin, to take advantage of fish production and agriculture, making the basin one of the most populous areas in Malawi. Seven major rivers drain into Lake Chilwa namely; Domasi, Likangala, Thondwe, Namadzi, Phalombe, Sombani and Mnembo (which originates from Mozambique). Likangala is the river that is utilized the most as it provides water supply for urban and rural dwellings, irrigation, and fisheries before it flows into Lake Chilwa. Likangala River is located between latitude 15’22°–15’30°S and longitude 35’15°–35’37°E. The river flows along varying topography between heights of 1265m and 790m above sea level and is about 50 km long.

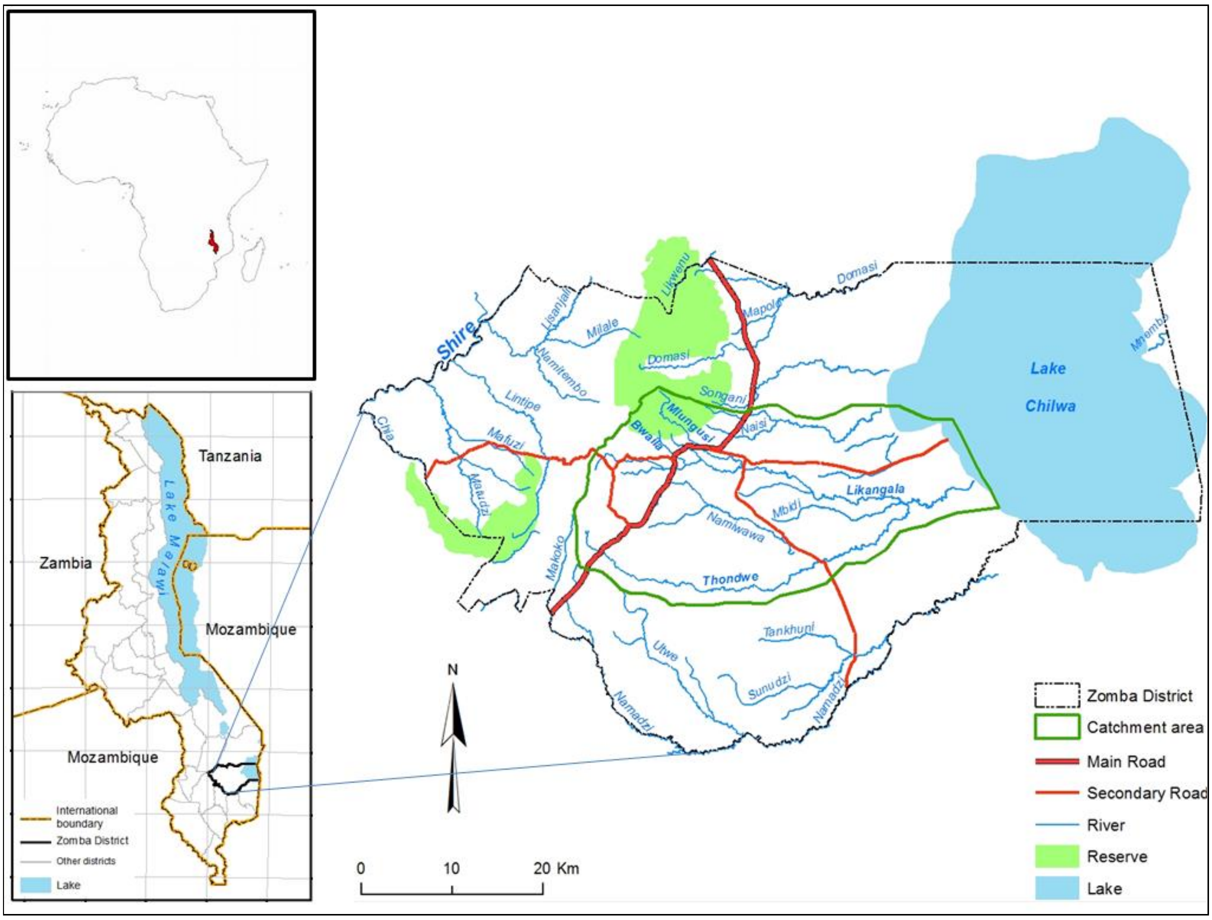


Figure 1: Map of Likangala River Catchment

1.7.2 Justification of the study

Several studies indicate the need for in-depth understanding of ecosystem services and its management because of the human dependence on the services (Becker, 1999; Ricketts *et al.*, 2004; Russ *et al.*, 2004; Carpenter *et al.*, 2006; Naidoo *et al.*, 2008; Johnston and Russell, 2011; Nahlik *et al.*, 2012). The Millennium Ecosystems Assessment stipulates social-ecological feedbacks and uncertainties of how the future will unfold. This study contributes to scientific knowledge by studying in detail one ecosystem, the Likangala River Catchment, and providing recommendations for management which can be replicated in other river catchments.

In Malawi, while there have been many studies undertaken on the Likangala River, such as the land use change and breeding of fish (Jamu *et al.,* 2003); water quality in the river (Chavula and Mulwafu, 2007); domestic water use (Mulwafu, 2003); Likangala Irrigation scheme (Peters, 2003); and conflicts and management of Likangala Irrigation scheme (Mulwafu *et al.,* 2003), there has not, however, been any study on ecosystem services. In addition more updated studies on land cover change since a study by Jamu *et al.* (2003) and water quality by Chidya *et al.* (2011) in the Likangala catchment are needed and is addressed by this study.

1.8 RESEARCH PURPOSE AND OBJECTIVES

The main purpose of the study was to contribute to the growing body of knowledge on ecosystem services by understanding provisioning ecosystems in Likangala River catchment in Malawi. Through this study, knowledge has been generated on how modifications in ecosystems can influence provisioning services that people derive from the ecosystem. This is important in Malawi, as the majority of population's livelihoods are natural resource-based. The historical analysis of land-use change, recent state of water quality and inventory as well as spatial mapping of provisioning ecosystem services in Likangala catchment contribute to updating the scientific body of knowledge and helps better understanding of ecosystem dynamics in poor rural areas.

Specific objectives were to:

1. Prepare an inventory and map the provisioning ecosystem services in Likangala
2. Evaluate land-use changes for Likangala Catchment from 1984-2013
3. Assess seasonal water quality of Likangala River based on dominant land-use
4. Develop a framework for ecosystem services management in Likangala Catchment

Ecosystems contain flora, fauna and humans and therefore to understand them, both environmental and social dimensions are crucial. The reasons for ecosystem change were studied in order to understand why and how they occur. Hence, a socio ecological approach has been taken and a framework developed for ecosystem management which can be replicated in similar river catchments in poor countries.

To achieve the objectives, five specific research questions were focused upon:

1. What are the provisioning ecosystem services provided by Likangala River Catchment and where are they located?
2. How has land-use changed from 1984 to 2013 and how would that impact ecosystem services?
3. What is the current state of water quality of Likangala River?
4. What are the community perceptions of changes in the ecosystem?
5. How can the Likangala ecosystem be better managed to ensure sustainable provisioning services?

1.9 CONCEPTUAL FRAMEWORK

The Drivers-Pressures-State-Impact-Responses (DPSIR) framework is taken as the conceptual framework for this study. The DPSIR framework is a simple framework widely used at multiple scales and understood by decision makers and practitioners (Figure 2). This framework was developed by the Organization for Economic Co-operation and Development (OECD, 1994) and used widely by international agencies (UNEP, 1994; Dutch National Institute for Public Health and the Environment, 1995; Pierce, 1998; EEA, 1999; UNEP, 2007) as well as used in national documents such as the State of Environment Report for Malawi (Government of Malawi, 2011). The DPSIR framework is the suggested analytical tool in the Decentralized Environment Management Guidelines of Malawi (Government of Malawi, 2013). The DPSIR is a good tool to analyse ecosystems, because it can be used at various levels from river catchments to country level. This framework helps understand the factors that change the environment including human activities and in so doing, helps develop meaningful recommendations that address the causes, rather than treating the symptoms of degradation.

Drivers are forces that cause social, demographic and economic change in order to fulfil humans' basic needs and these forces can be global, regional or local. These drivers can be human activities that exert pressure on the environment. Pressures are stresses caused by driving forces on the environment such as land use and land cover change, pollution and extraction of natural resources and can vary from local to regional and global scales. State is the condition of the ecosystem including its biotic and abiotic constituents. The state of an ecosystem may be altered due to pressures put on it. Impacts are changes in the ecosystem that affect human well-being, for example provisioning ecosystem services. Impacts can be both positive and negative, depending on the health of the ecosystem. Responses are the actions humans take in response to the impacts on the ecosystem and this can be at policy level or local actions for remediation. Responses can address the pressures or try to maintain or improve the state of the ecosystem and thereby improve positive impacts (UNEP, 2007).

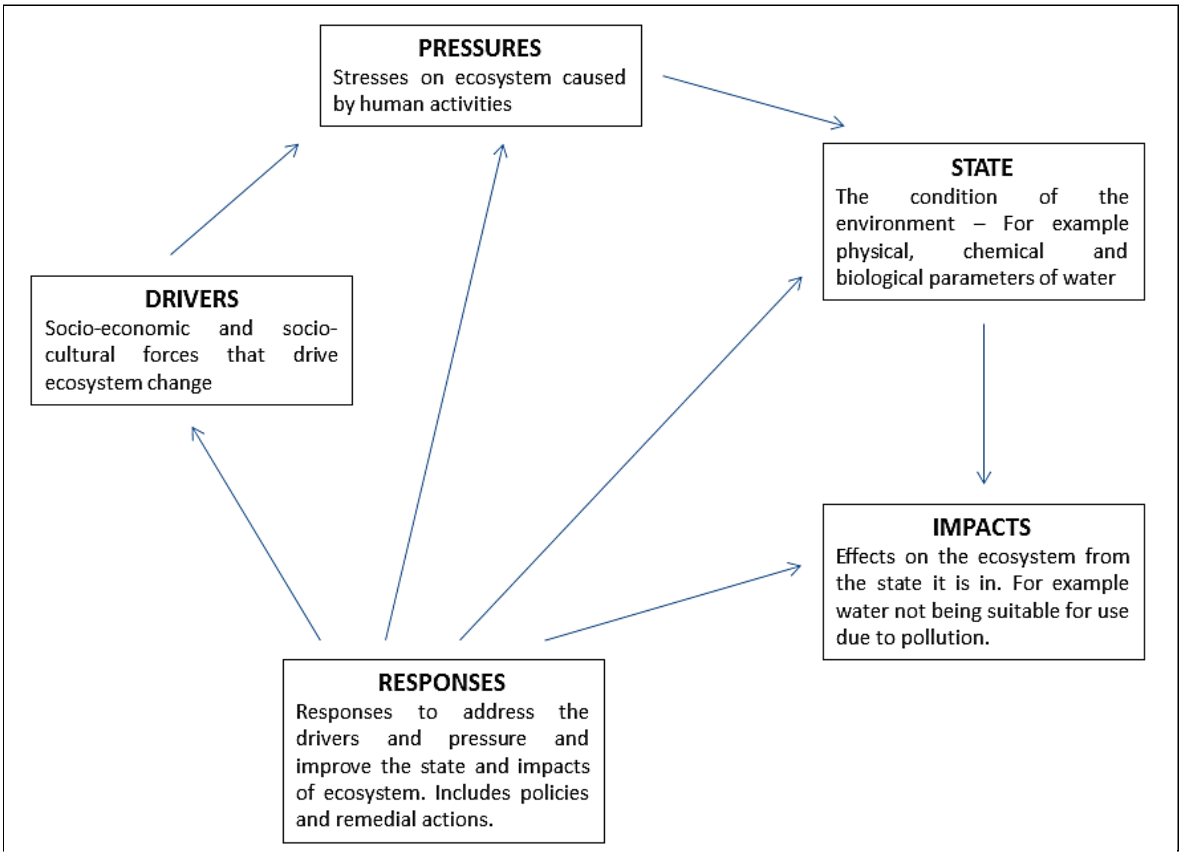


Figure 2: The DPSIR conceptual framework

(Adapted from UNEP, 1994; UNEP, 2007)

1.10 THESIS OUTLINE

Chapter 1 provides an introduction to the study including background, the rationale for selecting the study site and summarizes global, regional and local literature on ecosystem services. Gaps identified in literature that are relevant to this study are highlighted. The chapter centres on research gaps filled, aims, objectives and conceptual framework used for the study.

Chapter 2 gives an inventory of important provisioning ecosystem services derived from Likangala Catchment and maps the ten most important provisioning services produced through participatory mapping exercise with communities. Anecdotal evidence of changes in availability of provisioning ecosystem services is also provided.

Chapter 3 analyses land cover change from 1984-2013 in Likangala Catchment and identified the hotspots of land degradation which impact on availability of ecosystem services.

Chapter 4 provides information on the current state of water quality in Likangala River and looks at how dominant land use and land cover affects water quality. Impacts of water quality on communities are also discussed in particular health impacts and usability of water for domestic purposes.

Chapter 5 presents a design of a framework for managing river catchment using the analytical tool the Driver-Pressures-State-Impacts-Responses (DPSIR), where responses were outlined using an integrated management approach, the Population-Health-Environment (PHE). In this chapter, a holistic framework the Ecosystems Services Integrated Response Framework (ESIRF) is provided which uses a systems approach, and makes recommendations for sustainable management of ecosystems.

Chapter 6 finally provides conclusions and recommendations. Specific recommendations for policy makers, practitioners, organizations working in river catchments and the scientific community at large are provided. Areas of the study’s contributions, further research and limitations are also clarified.

CHAPTER 2

2 INVENTORY AND MAPPING OF PROVISIONING ECOSYSTEM SERVICES

2.1 INTRODUCTION

Malawi is a country where the majority of its populations depend on provisioning ecosystem services for their survival and livelihoods, as 85% of its population lives in rural areas (FAO, 2011; Government of Malawi, 2011). The World Bank (2014) states that about 50.4% of the population lives below the international poverty datum line and relies on subsistence rain-fed agriculture for survival. Thus, land becomes extremely important for such communities. Pressure for land is increasing as the population has increased from 9,933,868 in 1998 to 13,066,320 in 2008 (NSO, 2008) and then by 2013, the population was 16,362,567 (World Bank, 2014). Population growth coupled with poverty increases natural resource exploitation, for example, Yaron *et al.* (2011) estimated that Malawi is losing US$ 93 million (about 2.4% of its GDP) due to unsustainable use of forest resources including illegal charcoal production. The impacts of uncontrolled natural resource exploitation are likely to change ecosystem services, which in the short term may benefit some, but will in the long term, negatively impact the well-being of people (MEA, 2005). The people living in Likangala River Catchment depend heavily on the provisioning ecosystem services for their well-being. To be able to monitor and manage provisioning ecosystem services in a sustainable manner, the first step is to inventory and map them. This chapter provides information on these services and where they are located using ecosystem services maps.

Studies have indicated that there is a need to visualize ecosystem services at the local scale in order to help with decision making and planning (Troy and Wilson, 2006; de Groot *et al.,* 2010). Ecosystem services maps are a powerful tool to provide spatial information on where ecosystem hotspots exist in landscapes thereby aiding in resource and environmental management (Crossman *et al.*, 2012). These maps help in identifying hotpots of important ecosystem services thereby helping in conservation and in so doing, assist in contributing towards human well-being (Crossman *et al.*, 2012). However, there are some challenges in mapping ecosystem services, as a map can only portray a limited amount of information, therefore most mapping studies focus on selected services, for example, carbon storage

(Milne and Brown, 1997), biodiversity priority areas (Chan *et al.*, 2006) and recreational services (Eigenbrod *et al.*, 2010).

Mapping of ecosystem services has been done using primary data and proxy methods. Researchers have indicated that there are fewer maps produced from primary data than those from proxy methods (Sutton and Costanza, 2002; Chan *et al.*, 2006; Troy and Wilson, 2006; Turner *et al.*, 2007; Egoh *et al.*, 2008). Proxy methods use crude estimates of where ecosystem services may be located. In this study, the methods of Participatory Geographic Information Systems (PGIS) were used along with focus group discussions and transect walks to create the ecosystem maps. The PGIS methodology was selected for this study as against Participatory Rural Appraisal (PRA) because PRA lacks the spatial element while PGIS collects information for both inventory and location of ecosystem services thereby providing spatial information. Furthermore, PGIS methods use a participatory approach where communities are involved in providing information, which is not the case in remote sensing and GIS alone. In addition to mapping of ecosystem services, PGIS incorporates community perceptions and stakeholder perspectives of changes in biodiversity (Gos and Lavorle, 2012). Accordingly, this chapter provides inventories of ecosystem services including different animal and plant species used by communities as well as their locations mapped.

Although there are a number of studies where ecosystem services mapping has been done, there are methodological uncertainties (Crossman *et al.*, 2012). Researchers such as Vihervaara *et al.* (2012) and Rolf *et al.* (2012) have suggested supplementing land-use and land cover information with biodiversity data thereby aiding in further studies in quantifying ecosystem services. Land-use and land cover change in the catchment studied over 29 years (1984-2013) is included in this study and provided in Chapter 3. However, detailed mapping of the extent of availability of these services was not done, as some of the services such as wild animals and birds are mobile.

This chapter fulfils objective 1 of drawing up an inventory and mapping provisioning ecosystem services found in Likangala River catchment with a view to making recommendations on sustainable management of ecosystem services. Specifically, provisioning ecosystem services in Likangala River catchment were recorded and mapped at seven locations of varying land use and land covers. The research question that was answered by this study is: What are the ecosystem services provided by Likangala River catchment and where are they located?

2.2 METHODOLOGY

Drawing up an inventory and mapping of ecosystem services was done using participatory geographic information system (PGIS), which is a combination of participatory rural appraisal and geospatial technology and focus group discussions (Figure 3). The questions asked to communities are provided in (Appendix II). Permission to conduct the study was sought from the District Council.

Figure 3: Participatory mapping of provisioning ecosystem services with communities

2.2.1 Site selection

The sites for PGIS mapping were chosen because of their vulnerability to anthropogenic activities, therefore generated information with regard to ecosystem services and the interface with environmental changes from anthropogenic activities (Table 1). These sites had varying land covers and land uses.

2.2.2 Data collection and PGIS mapping

Focus group discussions held at seven locations (Table 1) reported the inventories of ten important provisioning ecosystem services. Target communities within the sites were selected using a combination of purposive and opportunistic sampling based on their willingness to participate in the PGIS exercise. Relevant literature on PGIS theories and practises, natural resource management, policy and legal frameworks were consulted in order to draw lessons that would guide this PGIS study.

Table 1: Location of PGIS sites

Location	Criteria for selection	Male	Female	Latitude	Longitude
William's falls	Forest ecosystem on Zomba mountain	11	10	0746935	8302245
Mpondabwino	Zomba urban area	10	13	0749724	8295900
Likangala Bridge	Rural area characterised by stone quarrying	10	10	0755903	8295412
Mindano village	Close to large estates	12	10	0761744	8294446
Chirunga village	Subsistence agriculture and sand mining activities	10	10	0765141	8292430
Rice farm	Close to wetlands and large rice irrigation scheme	10	11	0770026	8292523
Kachulu	At Lake Chilwa (the river's outflow)	12	15	0778074	8298902

Communities in these sites were asked to map their area on flip charts. This exercise was done separately for women and men in groups of 10-15. Socio-economic information of community members are provided in Appendix I. Community were asked to identify provisioning ecosystem services that they benefit from in the catchment and indicate these on the map. Ten major provisioning ecosystem services were mapped by communities. The inventory of provisioning services was scientifically validated through literature review and scientific names of flora and fauna collated.

2.2.3 Data analysis

Once the participants had mapped their services, a photograph of the map was taken. A global positioning system (GPS) at 0.5m accuracy was used to store the coordinates of important services identified where possible, for further analysis in ArcGIS 10 software. Furthermore, focus group discussions with key informants based on livelihoods such as fishermen, farmers, hunters, traders and others were conducted at the seven locations within the catchment to validate the PGIS exercise. All formal meetings and interviews were recorded, and transcripts made, with the transcripts later validated from literature.

The participatory sketch maps were incorporated into a digital database, which allowed for use of traditional GIS techniques to analyse these data sets. A rigorous content analysis was employed to analyse the transcripts from focus group discussions and drawing up session notes made by the researchers in order to elicit the answers for various provisioning ecosystem services. The provisioning ecosystem services formed part of the attribute information for the production of maps in the GIS environment. Ecosystem service maps were produced to illustrate the spatial distribution of ecosystem services in the study area and the broad themes included timber production, medicinal plants, wild fruits, fish, birds, wild animals, ornamental flowers, reeds, sand and stone. These themes were chosen after discussions with communities during the survey as they were the main services derived from the ecosystem. The inventory of medicinal plants, wild foods and non-food services were tabulated separately including their scientific names wherever possible. Qualitative information on how ecosystem services were changing over the years was gathered from the focus group discussions.

2.3 RESULTS

The results include an inventory of provisioning ecosystem services in a tabular format with their scientific names and habitats where they are found. This is followed by maps of provisioning ecosystem services at the seven sampling locations and anecdotes from communities.

2.3.1 Inventory of wild foods

Table 2 provides inventory of wild animals, insects and aquatic organisms. The wild foods used by communities consisted of wild animals, fruits and insects. Bushbuck, hares, bush mice and water fowl were some of the wild animals and birds hunted for additional food. Wild animals are a source of food, hides and income through their sale for the communities in the catchment. It is noteworthy that the conservation of habitats for wild animals and aquatic species are important for the sustainable supply of these wild foods. Communities reported that in the past, wild animals were more abundant as forested areas were larger.

> "*Wild animals are now scarce due to deforestation that has forced the animals to run away*". Man in Mpyupyu, May 2013.

Thus, land cover change through declining forested areas has an impact on availability of wild foods.

Table 2: Inventory of wild foods and their habitats

Wild animals and aquatic organisms	Scientific names	Habitat
Hare	*Lepus saxatilis* (Hare) *and Pronolagus rupestris* (Red Rock Hare)	Shrubs, forests, river banks
Wild pig	*Potamochoerus larvatus*	Forest
Vervet Monkey	*Chlorocebus pygerythrus*	Widely found, homesteads, shrubs, woodlots, river banks
Rabbit	*Procavia capensis*	Shrubs
Mice	*Praomys natalensis*	Shrubs, forests, farms
Porcupines	*Hystrix aflicrlerzustmlis*	woodlands
Duiker	*Sylvicapra grimmia*	Forests
Bushbuck	*Tragelaphus scriptus*	Mountain forests (Mpyupyu)
African giant rat	*Cricetomys gambianus Waterhouse*	Homesteads near anthills
Rock rabbit	*Pronolagus rupestris*	Shrubs
Squirrel	*Heliosciurus mutabilis*	Widely found where trees are available
Slender Mongoose	*Herpestes sanguinea*	Shrubs
Tortoise	*Pelusios castanoides*	Lake shores, wetlands
Cane rat	*Thryonomys swinderianus, Thryonomys gregorianus*	River banks
Frogs	*Hyperolius marmoratus albofasciatus, Ptychadema mascareniensis*	Wetlands, river banks
Fish	*Barbus paludinosus, B. trimaculatus, Oreochromis shiranus, Clarius gariepinus*	River and Lake Chilwa
Crab	*Potamon fluviatile*	Rivers, wetlands
Giant cricket	*Brachytrypes membranaceus*	Farms
Grasshoppers	*Acantahacris ruficornis and Cyrtacanthacris aeriginosa*	Homesteads, dambo (wet areas) farms, Bushes
Black flying ants	*Carebara vidua*	Widely found in rainy season
Sand cricket	*Brachytrupes membranaceus*	Widely found in rainy season
Large green bush crickets	*Homorocoryphus vicinus*	Farms and homesteads found in rainy season
Red Locust	*Nomadacris septemfasciata*	Farms
Large termites	*Macrotermessp.*	Termite hills
Soft-shelled turtle	*Cyloderma frenatum*	Wetlands

Table 3 provides an inventory of wild fruits, fungi and wild vegetables gathered by communities in the catchment area. Several wild fruits such as raspberries and mulberries were collected by the community to supplement their daily diet. Farm fruits include guava, mangoes, passion fruit, lemons, pawpaw, avocado, plums and sugarcane.

Table 3: Inventory of wild fruits, fungi and vegetables

Wild fruits, fungi and wild vegetables	Scientific name	Locations
Mushroom	*Agaricus brunnescens*	Farms, homesteads, shrublands, Forests
African Spider Flower	*Cleome gynandra* *Gynandropsis gyncondra*	Farmlands, homesteads (weed)
Black jack	*Bidens pilosa*	Farmlands, woodlands, homesteads (weed)
African spinach	*Amaranthus (Spinosus, Thunbergii, Hybridus)*	Homestead and Farms
Aloe	*Aloe meynharthii*	Forest (Zomba mountain)
Wild Okra / Ladies fingers	*Corchorus Olitorius*	Forest, bush, farms
Wild tuber	*Disa sp./Eulophia sp.*	Forest
Indian plum	*Flacourtia indica*	Forest
African medlar	*Vangueria infausta*	Forest
African chewing gum	*Azanza garckeana*	Forest
Black plum	*Vitex doniana*	Forest
Baobab	*Adansonia digitata*	Close to Lake
Zambezi tail flower	*Strophanthus combe*	Woodlots
Tamarind tree	*Tamarindus sp.*	Forest
Wild custard apple	*Annona senengalensis*	Forest
Granadilla	*Passiflora ligularis*	River banks
Rhubarb	*Rheum rhabarbarum*	River banks
Kandudwa(In the local language-Chichewa)	*Alternanthera sessilis*	Wetland, Gardens
Cocoa yam	*Colacsia esculenta*	mountain Forest, Garden
Sugar plum	*Uapaca Kirkiana*	Forest, woodlots, Homestead
Gooseberry	*Physalis peruviana*	River banks
Wild custard apple	*Annona Senegalensis*	Woodlots
Himalayan Raspberries	*Rubus ellipticus*	Forests, river banks
Nile cabbage or water lettuce	*Pistia stratiote*	Wetlands

The conservation of habitats of these wild fruits, fungi and vegetables are important for their sustainable provision. In some cases, communities reported that cultural practises and beliefs helped in conservation of some ecosystem services. For example, the Zambezi tail flowers (*Strophanthus combe*) were reportedly more abundant near graveyards. This is because graveyards are sacred areas where cutting down of trees is taboo. Some of these wild fruits, fungi and vegetables are found in wetlands, river banks and forests. With increasing demand for agricultural land, these habitats are being converted into farms thereby threatening the existence of these services, as noted from anecdotes from communities.

> "*Land for forests has been used for farming and settl*ement." (Resident of Zomba City, Oct 2013)

Birds are hunted by community members as they provide an important source of protein as well as income to the hunters who sell the birds in the city and village trading centres. A number of waterfowls are found near Lake Chilwa wetlands, many of them migratory Palearctic birds (The Ramsar Convention Secretariat, 2000). Predominantly, bird hunters target water fowls using shotguns and young boys use catapults and traps. An inventory of wild birds that are eaten by communities is provided in Table 4.

Table 4: Inventory of edible wild birds

Edible Wild birds	**Scientific name**	**Locations**
Francolin	*Francolinus sp.*	Homesteads, Bushes, farms
Bulbul	*Pycnonotidae sp.*	Homesteads, Bushes, farms
Dove	*Columbidae sp.*	Trees in homesteads
Streaked fantail warbler	*Cisticola juncidis*	Trees in homesteads
Blue waxbill	*Uraeginthus angolensis*	Homesteads, Bushes, farms
Yellow backed canary	*Serinus mozambicus, Crithagra mozambicus*	Lake, Riverbanks
Wild Guinea fowl	*Numididae sp.*	Trees in homesteads
Southern Red Bishop	*Euplectes orix*	Lake , wetland
Quelea	*Quelea Quelea*	River banks, forests
Bronze mannikin	*Lonchura cucullata*	Grasslands, border between natural vegetation and farmlands
Sunbird	*Nectariniidae sp.*	Homesteads, Bushes, farms
Fulvous whistling ducks	*Dendrocygna bicolor*	Lake Chilwa and wetlands
White-faced whistling ducks	*Dendrocygna viduata*	Lake Chilwa and wetlands
Spur-winged goose	*Plectropterus gambensis*	Lake Chilwa and wetlands
Firecrowned bishop	*Euplectes hordeaceus*	Lake Chilwa and wetlands

2.3.2 Inventory of non-food provisioning ecosystem services

Non-food provisioning ecosystem services are important for communities, as they contribute materials for construction and provide opportunities for income generation. Sand mining was an activity that was observed along the river banks throughout the catchment. In addition, clay was excavated and used for making bricks while stones were quarried for use in the construction of buildings. Some semi-precious stones were also collected from Malosa Mountain and brought to Zomba Mountain to be sold to tourists. Reeds extracted from wetland areas and river banks were used for construction of houses and handicrafts. Near Lake Chilwa, tea rooms for fishermen were entirely made from reeds and elephant grass extracted from the wetlands. Table 5 provides an inventory of non-food provisioning ecosystem services in the catchment.

Table 5: Non-food Provisioning Ecosystem Services

Non-food Ecosystem Services	**Locations**
Stone	Close to Likangala Bridge and a few other places in the catchment where rock outcrops were found
Sand	River banks
Clay for brick making	Widely found. Brick kilns built are close to river to get access to water for moulding bricks
Ornamental stone	Extracted from Malosa mountain, sold at Zomba mountain
Everlasting flowers	Zomba mountain
Elephant grass for thatching	Wetlands, river banks
Reeds (*Phragmites mauritianus*) for baskets, thatching, mats	Wetlands, river banks
Wood for handicrafts from the trees *Khaya anthotheca ,Lagenaria sphaerica, Widdringitonia whytei, Cyprus alternifolius, Pericopsis angolensis*	Zomba forest, woodlands
Wood for furniture from the trees *Gmelina arborea, Eucalyptus saligna, Toona ciliata*	Zomba, Mpyupyu
Honey	Forest
Gums	Forest
Firewood	Forest, woodlots, homesteads with trees, estates
Typha domingensis used as mattress and pillow fillings	Lake Chilwa wetlands
Fodder for livestock	Widely spread in grasslands and shrublands

2.3.3 Inventory of medicinal plants

In the Likangala River catchment, medical facilities are few and remote. Rural areas depend on traditional healers and indigenous knowledge of the use of medicinal plants for common ailments. The inventory of medicinal plants is provided in Table 6. Likangala health facility caters to a population of 33,786, with 31 Health Surveillance Assistants (HSA), four nurses and one Medical Assistant (Zomba District Health Office, 2013). These statistics translates that within the Likangala River catchment, the ratio of HSA: rest of population is 1:1090 and nurses: rest of the population is 1:8446.5 which is way above the recommended ratio of 1 HSA per 1000 in the population and 1 nurse to 1000 people in the population (Zomba District Health Office, 2013). This makes it reasonable for communities to rely on local medicinal plants to cure ailments, as health workers are not adequate in number to attend to their needs. The study revealed that the medicinal plants gathered, treat and prevent a number of ailments (Figure 10 shows image of a traditional healer's shop at Mpondabwino). For example, Southern cattail (*Typha domingensis)* is used as a mosquito repellent, thereby assisting communities in keeping mosquitoes away. Mosquito bites can transmit malaria which is the most serious infectious killer in Malawi. Another example is the Silver cluster-leaf (*Terminalia sericea*) which treats a plethora of ailments including bilharzia, pneumonia and diarrhoea. Thus, the importance of medicinal plants as a provisioning ecosystem service rates very high in such poor communities.

The location where medicinal plants were found has also been recorded in Table 6. This is important to understand or management of provisioning ecosystem services, as loss of habitats cause loss of medicinal plants that grow in the habitats. For example, the Stem bark tree (*Entada abyssinica*), whose leaves are used as medicine to cure incessant menstruation and Winter cassia (*Cassia singueana*) whose leaves and roots treat dysentery, are only found in woodlots. Thus it is necessary to conserve woodlots to sustain access to such medicinal plants. Similarly, there are many medicinal plants found in river banks. Due to river bank cultivation, they are under threat.

Table 6: Inventory of medicinal plants

Plant/tree (common name)	Scientific name	Part of plant used	Medicinal use/benefits	Locality
Fever-bark tree	*Croton megalobotrys*	Leaves, berries	To treat headaches and Sexually transmitted diseases (antibacterial) reduces fever in malaria, berries crushed and used for skin infections). (Bark and seeds used as fish poison)	Flood plains and river banks
African Custard apple	*Annona senegalensis*	The leaves and gum from bark used for sealing wounds	To treat headaches, diarrhoea, respiratory infections, small cuts and wounds and snakebite	Widely distributed in the catchment
Bluegum (Eucalyptus)	*Ecucalyptus spiciformis*	Leaves	To treat headaches, antiseptic oil used for wounds and cuts, common cold, coughs, use oil vapour as decongestant	Widely distributed
Acacia (white stem thorn)	*Acacia polyacantha*	Roots, barks, leaves	Leaves to treat headaches, roots for snake bite,	River banks
Himalayan Raspberry	*Rubus ellipticus*	Bark, fruit	Fruit seed for treatment of fever, cough, bark used for gastric troubles, diarrhoea, dysentery, as renal tonic and an antidiuretic	Found abundantly on Zomba mountain in the forest (invasive)
Wild aloe vera	*Aloe vera*	Leaves	To treat stomach ache, peptic ulcer, cosmetic use (skin)	Found in dry areas in the catchment
Guava	*Psidium guajava*	Leaves	To treat stomach ache, worms in stomach, diarrhoea	Widely distributed and planted in homesteads
Silver cluster-leaf	*Terminalia sericea*	Leaves	To treat stomach ache, also said to be useful for bilharzia, pneumonia, and diarrhoea.	Found in open woodlands
Fig tree	*Ficus natalensis*	Roots	To treat stomach ache, arthritis, headache (root has analgesic properties)	River banks and woodlands

Plant/tree (common name)	Scientific name	Part of plant used	Medicinal use/benefits	Locality
Marijuana	*Cannabis sativa*	leaves	For constipation, promoting hair growth	River banks and shrublands
Carrot tree or cabbage tree	*Steganotaenia aralicea*	Leaves, stem, roots	To treat sore throat, fever, used as aphrodisiac, stem used as antibacterial against typhoid, roots used for snake bites	Woodlands, rocky outcrops
Gooseberry	*Physalis peruviana*	Fruit	To treat coughs	River banks, woodlands
Neem	*Azedirichita indica*	Leaves, flower	Antiseptic and used to treat body pain, gastro disorders	Widely distributed, woodlands
Avocado	*Percea americanum*	Leaves	To treat anaemia as leaves are rich in iron	Widely distributed, homesteads
Mwanamphepo (In local language - Chichewa)	*Cirius integrifolia*	Root	To treat loss of appetite, improve digestion	In shrub land, woodlots
Moringa	*Moringa oliefera*	Leaves, fruit, seeds	Increase immunity especially those on anti-retro viral drugs	In homesteads and dry areas
Asparagus fern	*Asparagus africanus*	Roots	To treat fever in babies, diarrhoea and pneumonia medicine and to dilate birth canal	Homesteads, woodlots
Stem bark	*Entada abyssinica*	Leaves	To cure incessant menstruation	Woodlots
Winter cassia	*Cassia singueana*	Leaves, Roots	To treat dysentery	Woodlots
Whites Ginger	*Mondia whitei*	Roots	Used as an aphrodisiac	Forests, woodlots
Mango	*Mangifera indica*	Bark, leaves	Extract of bark for diarrhoea and dysentery, leaves for asthma and coughing	Homesteads, woodlots
Ntetema (In local language-Chichewa)	*Mellera lobulata*	Roots	To treat bilharzia	Forest
Southern Cattail	*Typha domingensis*	Leaves	Mosquito repellent when burnt	Wetlands

2.3.4 Crop production

Provisioning ecosystem services also include crops produced in the catchment. The main crops produced in Zomba District are maize, rice, sorghum, millet, cassava, sweet potato, groundnuts, pulses, tobacco and cotton (Appendix III). Generally, yields fluctuate over the years and were low in 1994, 2005 and 2012 for most of the crops. This may be attributed to climate variability, as rain-fed agriculture is practiced. Communities reported about changing rainfall patterns affecting agricultural yield.

> *"Rainfall patterns are changing over years, reducing our harvest over years. When we have low harvest we buy maize".* Farmer at Jali, May 2013.

FAOSTAT (2014) reports that cultivated area in Malawi has been increasing over the years due to land cover conversion of woodlands and shrublands into cultivated areas. This is also observed in Likangala catchment. In addition to crops, livestock and poultry farming were practised by communities in the catchment where chicken, goats, rabbits, pigs, cows, ducks, pigeons and guinea fowl were reared. Exact numbers of livestock in the area were not obtainable.

Farmers practise subsistence agriculture in the study area. In order to increase yield of crops, applying fertilizers is common. Communities reported that soil fertility was declining and therefore more fertilizers are being applied.

> *"To grow fruits and vegetables one need to apply fertilizer than before. In the past years people did not need to have fertilizer".* Farmer at Mpondabwino, May 2013.

> *"Nowadays there is low harvest than in the past years .In the past there used to have maize harvest that would last for a year than now. Then we did not use fertilizer to grow our plants but harvested plenty but now what we harvest is few".* Farmer at Mindano Village, May 2013.

As demand for agricultural land is high and soil fertility is declining, communities have resorted to farming in marginal lands such as hill slopes and wetlands as well as deforesting woodlands in order to farm there. Decreased soil fertility translates to declining yield which prompt farmers to expand area of cultivation into marginal lands and woodlands causing deforestation which in turn increases soil erosion, rapid runoff and flooding downstream

(Jamu *et al.*, 2003; Njaya *et al.*, 2011). Soil erosion causes siltation in rivers, clogging of downstream irrigation systems and can also possibly damage fish spawning areas in the rivers and lake (Jamu *et al.*, 2003).

Land degradation has implications for ecosystem services as habitats for some provisioning ecosystem services such as wild animals and medicinal plants, when degraded are no longer able to sustain delivery of these services. Not only are inventories and lists of provisioning ecosystem services important to monitor change over the years, but the location of these services is of importance to understand hotpots which need conservation. The proceeding sections provide maps of locations of provisioning ecosystem services for each of the seven locations.

2.4 MAPPING OF PROVISIONING ECOSYSTEM SERVICES

2.4.1 Zomba Mountain

Zomba Mountain is the second largest and highest mountain in Malawi. The Zomba Forest Reserve is located on this mountain and is managed by the Forestry Department. The Zomba plateau has a number of tree species including natural trees and plantations. The tree species found on the plateau include *Widringtonia whytei*, *Pinus taeda*, *Pinus patula*, *Pinus pseudostrobu*, *Pinus oocarpa*, mixed pines, evergreen, *Eucalyptus sp*, *Cupressus lusitanica* (Chirwa *et al.*, 2011). The pine plantation provides timber and fuelwood for Zomba City as well as its vicinity. Firewood is obtained from the slopes of Zomba Mountain. The mapping exercise showed that the Zomba plateau provides many ecosystem services to its residents and beyond. Figure 4 shows the spatial distribution of ten important provisioning ecosystem services found around Williams Falls located on Zomba Mountain.

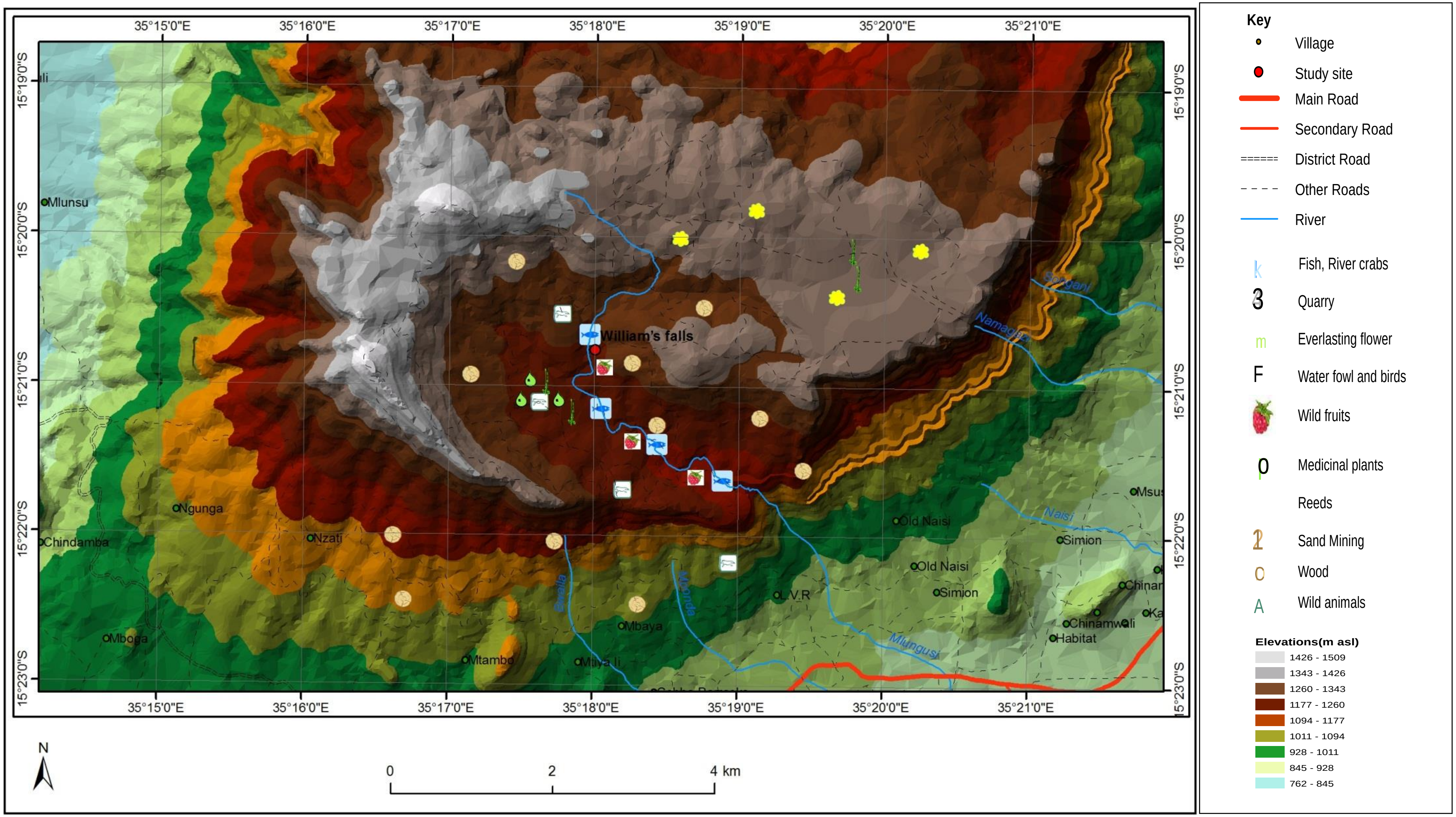


Figure 4: Ecosystem services mapped around William's Falls

Originating from Mulunguzi marsh located on the plateau, Mulunguzi River flows down the mountain and provides water for Mulunguzi Dam, which is the source of water supply for residents of Zomba city and Domasi town. The outflow from the dam then joins the Likangala River. The mountain is popular with tourists for different activities such as hiking, horse-riding and mere scenic beauty. The provisioning ecosystem services at Williams Falls include wood for handicrafts, timber and firewood; everlasting flowers which are sold to tourists; wild fruits such as Himalayan raspberries, passion fruits and other berries that grow along the Mulunguzi River; fish and river crabs found in the Mulunguzi River, Chagwa Dam and streams; wild animals such as monkeys, wild pigs, hares and insects (Figure 4). Occasionally clay bricks are moulded in this area. Communities reported the growing of Irish potatoes and maize through and use of water from Mulunguzi River.

> "*Irish potato is the main cash crop and food grown at the mountain because the amount of rainfall has reduced than before when they used to grow maize*". Man near Trout Farm, Zomba Mountain, May 2013.

> "*To grow maize they use irrigation with buckets water canes (cans). This irrigation is possible through the Mulunguzi River*". Woman at Mulunguzi Dam, May 2013.

On the Zomba Mountain, the water from Mulunguzi River streams and creates waterfalls. It is used by the communities for drinking as well as domestic purposes. Gems and crystals collected by informal miners from the Malosa Mountain are sold to tourists who come to the Zomba Mountain. Medicinal plants are also picked from this area (Figure 4). On Zomba Mountain birds are hunted using catapults. The wetland and rocky areas within the William's Falls provide reeds which are harvested for making mats, ropes, baskets, table mats, bed mats and handicrafts. The sale of such products provides an income to the rural communities. Vegetables and fruits for consumption and for sale are grown in villages on Zomba Mountain by the communities. Livestock and poultry are also kept by the –communities in these areas. Fishing and abstraction of water for any purposes by communities is prohibited in the reservoir of Mulunguzi dam as it is under the jurisdiction of the Southern Region Water Board.

During the study, it was observed that pressure for land was high as the populace were cultivating on mountain slopes, which aggravates soil erosion. The communities around this Zomba Mountain site noted that land was in high demand and forests were being encroached by those who wanted to cultivate. The availability of trees for handicraft making was on the decline, forcing artisans to source wood from distant places such as Liwonde, some 50km away from Zomba. This also reflects the flow of ecosystem services from Liwonde to Zomba as well as deforestation in other areas due to a demand for handicrafts in Zomba. This was reflected in the focus group discussions as evident in the quote below.

> "*Trees are now becoming scarce at the plateau. For making handicrafts we now get wood from Liwonde*." (Handicrafts maker based at Zomba Plateau, Sept 2013)

Maintaining ecosystem services at the Zomba Mountain is beneficial to communities as this will ensure that tourists, who come to see the flora and fauna and buy the fruit grown on this mountain, continue visiting and thereby contributing to the local economy. A holistic approach is needed to manage the environment here, as the increasing population and the demand for farmlands was causing cultivation in marginal lands including along the slopes of the Zomba Mountain which is the main tourist attraction. Diversifying livelihoods away from agriculture and improving tourist attractions and facilities will in turn improve conservation of the Zomba Mountain.

2.4.2 Mpondabwino

The second site for participatory mapping was Mpondabwino, which is an unplanned settlement located in the Zomba City. This is a high population density site with informal and formal markets and unplanned settlements. In this area, some of the provisioning ecosystem services that communities benefit from include food from agriculture; wild animals, birds, insects and frogs to supplement food intake and medicinal plants. They also extract sand through sand mining activities along the river; clay for brick making; reeds and bamboo for making chairs and thatching roofs and stones for building houses (Figure 5). Fodder is derived from the area to feed livestock as well as poultry and wood is extracted from woodlots as well as from the river when deforestation activities on Zomba Mountain (upstream) cause wood to drift down to Mpondabwino. The water from the river is used for domestic use and not drinking as communities perceive the water quality to be poor. There is no fishing at this site, as residents explained that the sewage and household waste being disposed into the river in this area makes it an unsuitable habitat for fishes.

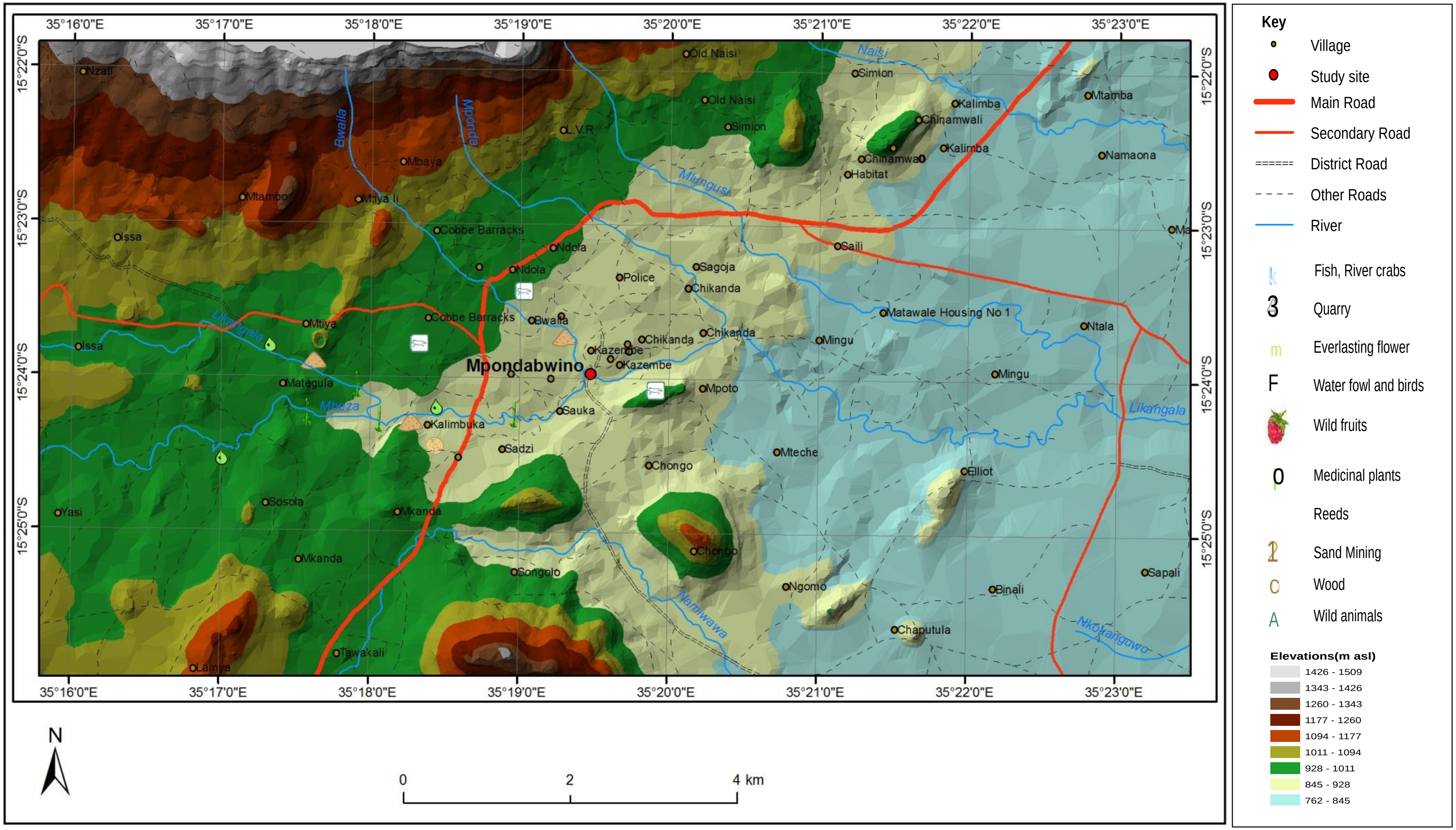


Figure 5: Ecosystem services mapped around Mpondabwino

"There is no fishing in the river because of sewage disposal from the hospital and rubbish disposal from households makes the river not good for fish breeding." (Resident of Mpondabwino, Oct 2013).

Residents explained that in the months between January and July, there is adequate river flow for domestic use, house construction and irrigation. From August to November, residents observed that the flow was reduced as it is the dry season and the water becomes contaminated and hence unsuitable for domestic use. The focus group discussions also revealed that usually in November, the river is dry, but when the rains begin at the end of November or early December, there is localised flooding. This indicates the need for waste management in urban areas and river bank afforestation as a natural flood control measure (Nedkov and Burkhard, 2012). Communities reported threats to provisioning ecosystem services including pollution, which affected aquatic life and there were no fish in the river around Mpondabwino. Waste from Zomba Central Hospital and waste water after treatment from Zomba Wastewater Treatments works is released into Likangala River. Field observations confirmed that both solid and liquid wastes were being dumped into Likangala River at Mpondabwino, which is a busy market place in Zomba City. Hence, the Likangala River water quality is adversely affected around this site (Chapter 4).

2.4.3 Likangala Bridge

Likangala Bridge and its surroundings are characterised by subsistence agriculture. This area has a quarry site with about ten manual stone crushers. River bank cultivation just below Likangala Bridge where the river flows was noted during field observations especially in the dry season. Irrigation using treadle pumps was common. Communities harvest medicinal plants along the river and collect wood from the area. Fishing is done in the river and sand mining was also observed as indicated in Figure 6. Water from Likangala River was used for washing, irrigation and bathing, while drinking water was reported to be obtained from boreholes in the areas. Stone crushers and sand miners around Likangala Bridge reported that there is a high demand for stone and sand as construction activities such as building of houses required these provisioning ecosystem services.

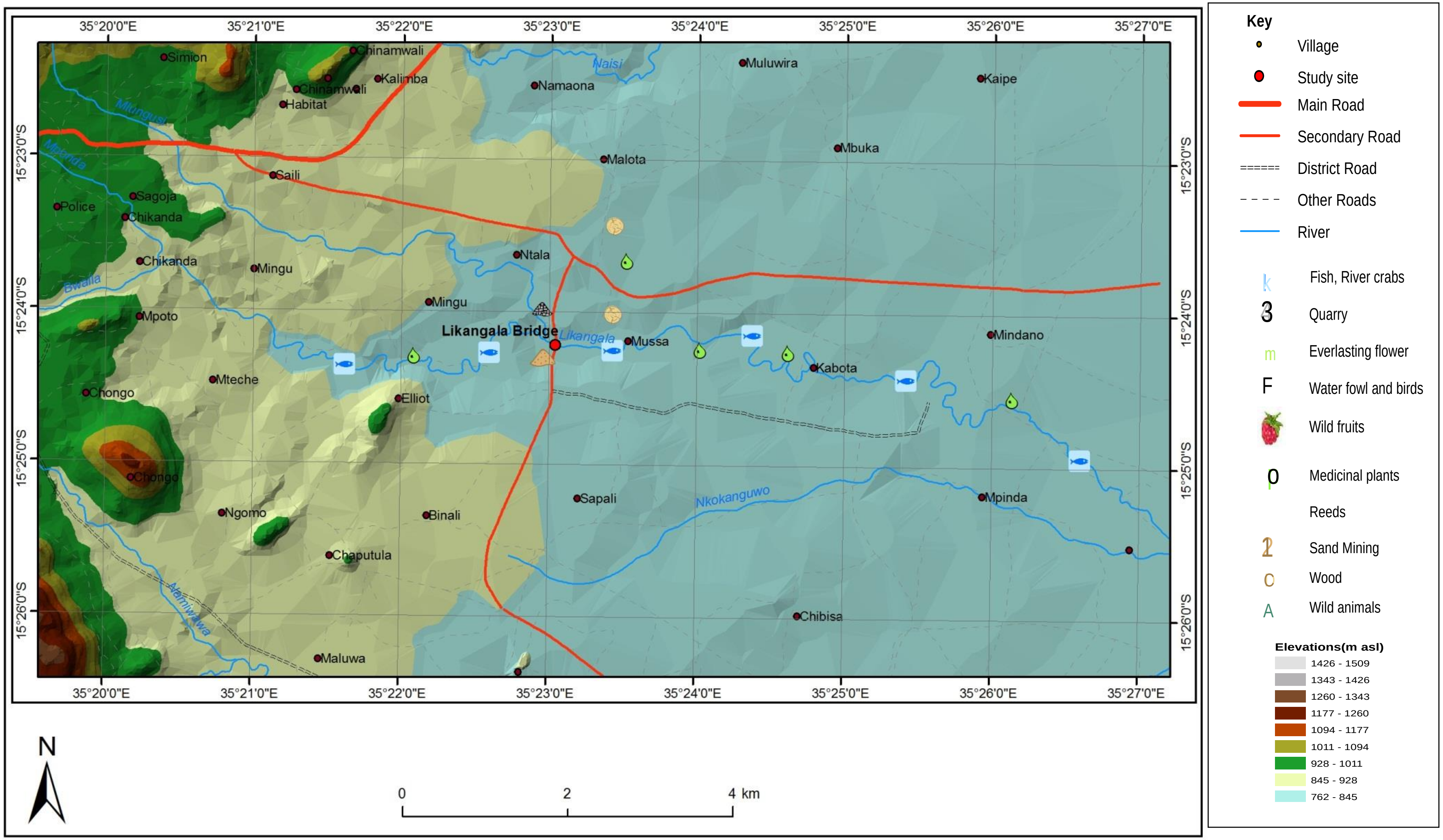


Figure 6: Ecosystem services mapped around Likangala Bridge

Communities were able to link pressure for sand with increase in population.

> "*There has been shortage of sand because there has been high demand for sand to build town houses. This is due to high population*."(Sand miner near Likangala Bridge, Oct, 2013).

2.4.4 Mindano Village

Mindano village is located upstream of large agricultural estates. Wood, fish, medicinal plants, wild fruit, wild animals, birds and water fowl are obtained from this area (Figure 7, 10). Communities here depend on subsistence agriculture and some work at the agricultural estates. They derive water from the river and from standpipes. The communities practise dry season cultivation along the river banks and in the wetlands where sweet potatoes, sugarcane, tomatoes, bananas, turnips, pumpkins and maize are grown while taking advantage of the residual moisture. Wild animals and insects such as crickets, mice, monkey and hare were hunted, while fishing was done in the river. Several wild fruits were available and medicinal plants were harvested from the river banks.

Communities explained during the focus group discussions that the availability of medicinal plants was decreasing over the years. They explained that most of the plants were found on river banks and due to cultivation on the banks, these plants were being removed by farmers. They now have to walk further to collect the medicinal plants. In a country like Malawi where health services are poor, the majority of the population live in rural areas and their livelihoods are heavily reliant on natural resources. It is necessary to ensure that provisioning ecosystem services such as medicinal plants are preserved for the well-being of the population.

> *"Previously I used to find medicinal plants close to my house, now I have to walk far".* Woman at Sitima, Oct 2013.

Some community members in Mindano village said that bush fires are caused deliberately by migrants who come there to hunt for small wild animal such as mice.

"These bush fires are caused deliberately when they hunt for small wild animal such as mice." Man at Mindano Village, May 2013.

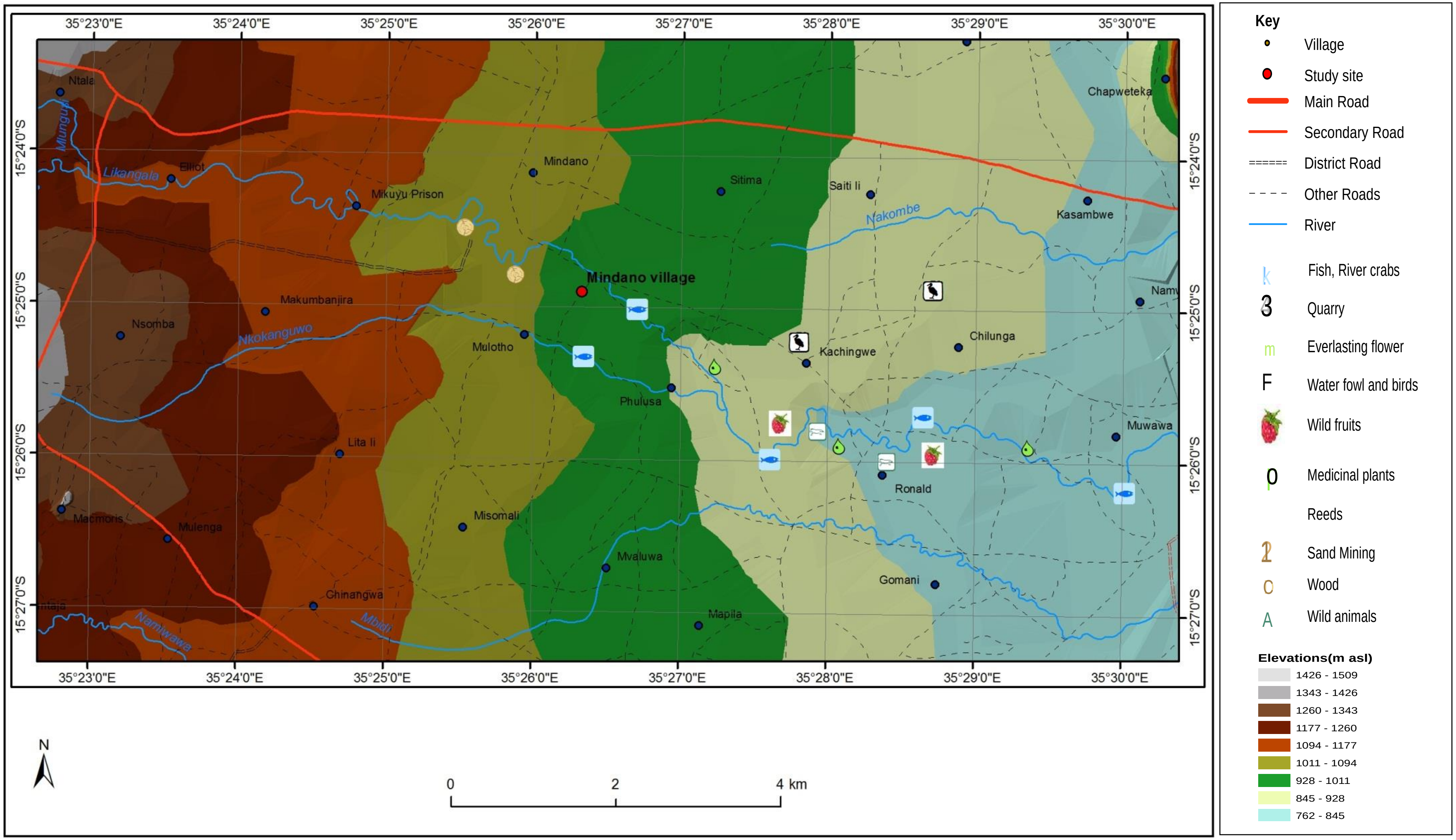


Figure 7: Ecosystem services mapped around Mindano Village

2.4.5 Chirunga Village

Chirunga village is located downstream from agricultural estates. Around this site, fishing and hunting of river crabs was done in the river, wild animals such as hare, monkeys and duikers were also hunted, medicinal plants harvested from the nearby forests while firewood and timber were derived from woodlots (Figures 8and10). Water for washing and bathing was obtained from the river, while drinking water was from boreholes. Medicinal plants were harvested from river banks. Reeds were harvested for thatching at several locations and a number of wild birds were hunted including waterfowls found in wetlands. Communities in this village reported that there were fewer forested areas and as a result, wild animals were fewer in number compared to the past.

Crystals, everlasting flowers and passion fruit (Zomba Mt)

Firewood collected from Zomba Mountain

Sand mining along Likangala River

Bush mice sold along Zomba-Blantyre road

Figure 8: Provisioning ecosystem services derived from the study area

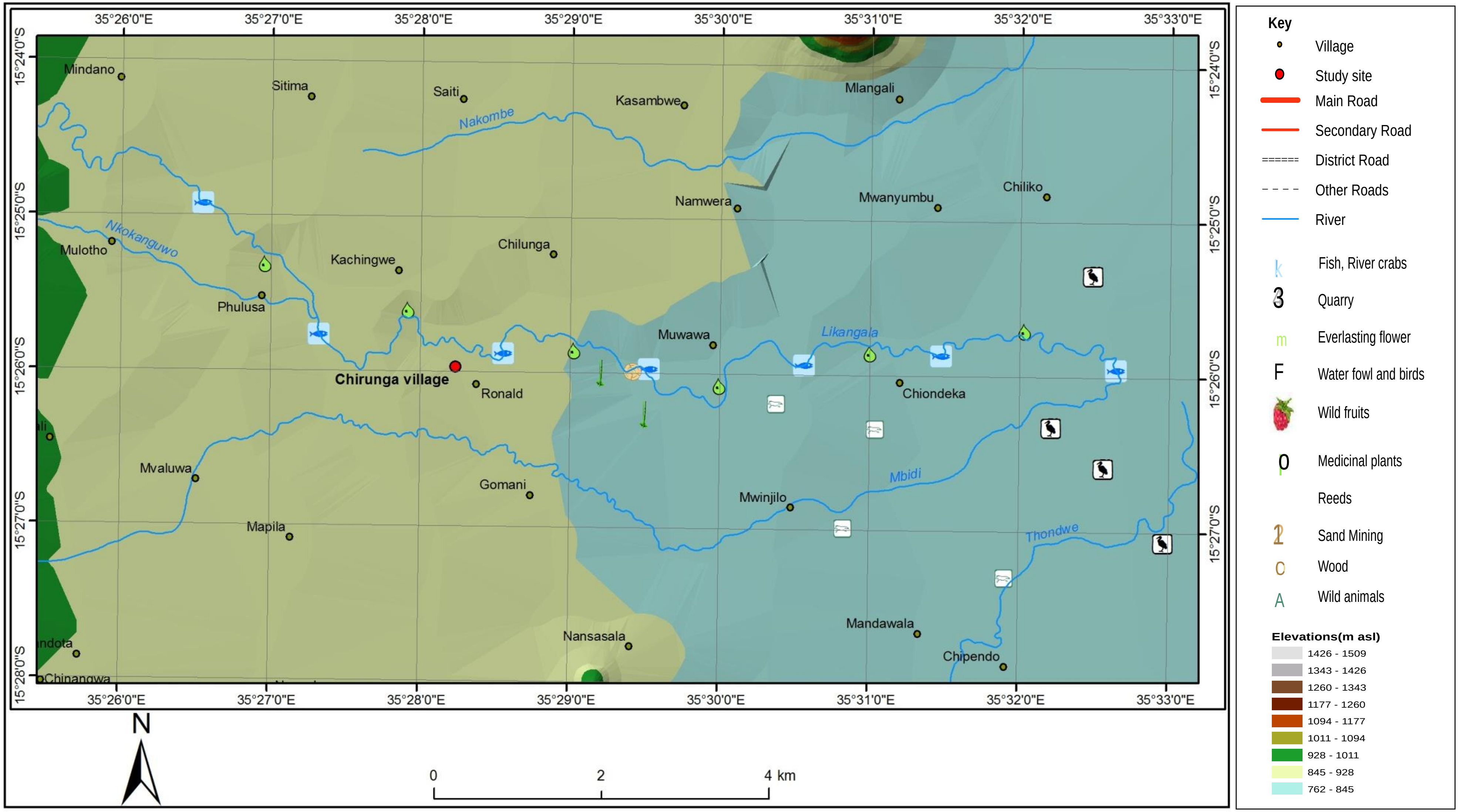


Figure 9: Ecosystem services mapped around Chirunga Village

Figure 10: Medicinal plants sold at market place

2.4.6 Rice farm

This site is located upstream of Likangala Rice Irrigation Scheme. Communities in this area use the water for washing, irrigation and bathing, while drinking water is collected from Mkangali borehole at Mpyupyu, which is a nearby hill. Hunting for waterfowl and fishing in the river were common (Figure 11). The area was close to Likangala Rice Irrigation Scheme which caters for over 200 farmers. This site is close to Lake Chilwa and its surrounding wetlands are habitats for water fowl. Communities in this area reported that in the past there were many wild animals at Mpyupyu hill but due to deforestation, their numbers have declined.

> "*Wild animals are now scarce due to deforestation that has forced the animals to run away*". Man in Mpyupyu, May 2013.

2.4.7 Kachulu

Kachulu harbour is located along the shores of Lake Chilwa and is a busy fish landing site. The main activities here were fishing and bird hunting. Reeds are harvested from the wetlands and used for construction. Wild animals were said to be found at Mpyupyu, the hill close to Kachulu. Fish and river crabs were found in the river and wetlands too. The communities reported that in Mpyupyu hill, in the 1980s there used to be a thick forest and now due to deforestation, the antelopes that used to inhabit this hill have been reduced in number. Figure 12 gives the map of provisioning ecosystem services at Kachulu.

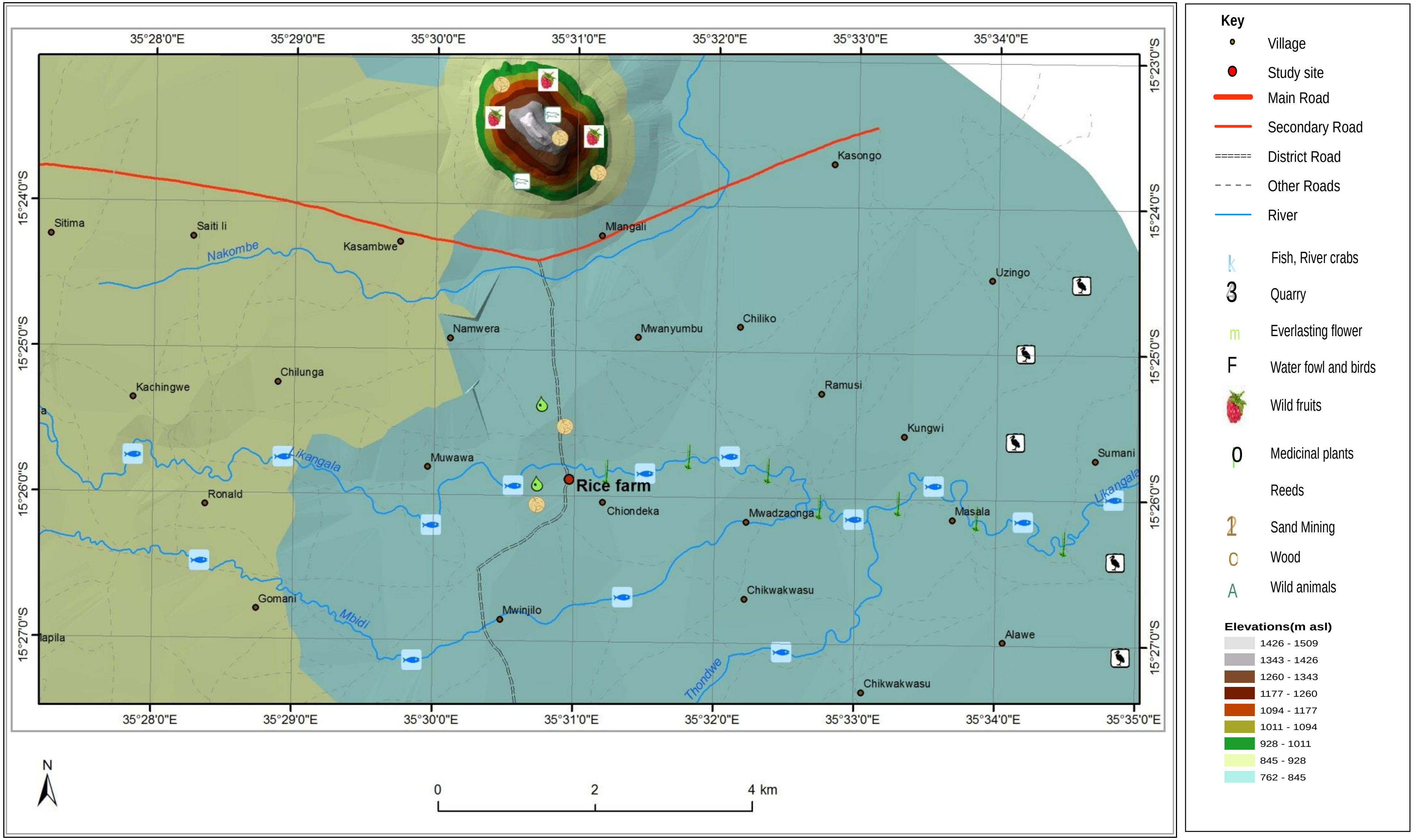


Figure 11: Ecosystem services mapped around Rice farm

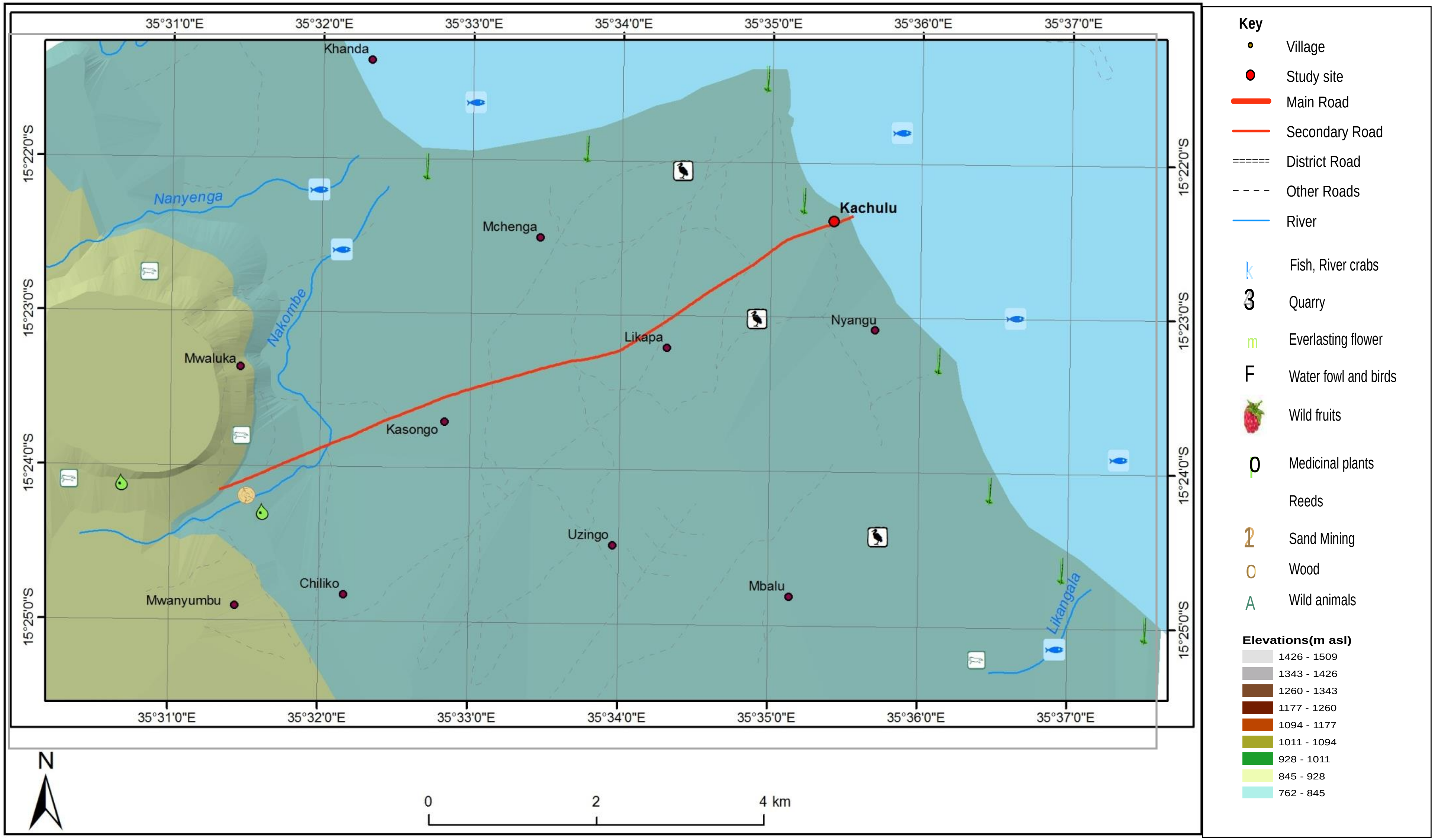


Figure 12: Ecosystem services mapped around Kachulu

2.5. SUMMARY

This chapter has reported and mapped provisioning ecosystem services using a participatory approach in the Likangala River catchment. The presence of several provisioning ecosystem services was verified. Communities in the Likangala River catchment participated in mapping of provisioning ecosystem services and listed ten types of major provisioning ecosystem services. Mapping essential ecosystem services is indispensable for managing them sustainably for future generations (Martínez-Harms and Balvanera, 2012). The inventory of wild foods, medicinal plants and non-food services exhibit how productive the Likangala River catchment is. The regular consumption of provisioning services saves cash resources which can be used for other household needs (Shackleton and Shackleton, 2004). In spite of their importance, the study found that provisioning ecosystem services were threatened. The communities reported that deforestation, river bank cultivation, pollution and over extraction of natural resources were threatening sustainability of provisioning ecosystem services in Likangala River catchment.

While the inhabitants of the Likangala River catchment consciously exploit the natural resources through harvesting, gathering and land cover changes, they are unconsciously destabilizing the very ecosystem services that they benefit from. This calls for the users themselves to become aware of their actions, reflect and come up with mechanisms to use these services in a sustainable manner. When the users themselves participate in sustainable management of ecosystem services, there will be ownership. This calls for a "bottom-up" or community-based approach in ecosystems management. In this "bottom-up" approach, the local community, who are the beneficiaries of these services, participate in identifying problems and decision making. Thus, communities can identify areas of their ecosystem which are degraded and need to be protected in order to maintain provisioning services. They can then come up with bye-laws on use of land to ensure provisioning services are not over extracted. The conservation plans can be elevated into village and district plans, consequently, deriving funds from higher administrative (district council or ministry) level.

The drive to maintain provisioning ecosystem services can be thought of as environmentalism of the poor especially in rural communities who are at subsistence level as seen in the Likangala catchment (Davey, 2009). When ecosystem services decline, it is the poor that are most affected, as they directly depend on these services. It is in the best interest of those whose livelihoods directly depend on the provisioning ecosystem services that these services are maintained.

Having inventoried and mapped provisioning ecosystem services in Likangala River catchment, it is important to understand how the ecosystem changes over time in order to ascertain if provisioning ecosystem services can be sustained. An indicator of ecosystem change is land cover change. The next chapter reports on land-use and land cover changes over a period of 29 years (1984-2013) in Likangala River Catchment and identifies hotspots or degraded areas in the ecosystem, as they impact on provisioning services and thereby human well-being.

CHAPTER 3

3 LAND USE/LAND COVER CHANGE IN THE LIKANGALA RIVER CATCHMENT

3.1 INTRODUCTION

Land-use change from anthropogenic activities has transformed land cover globally. The demand for producing food has increased use of land for cultivation and livestock grazing. Urbanization with construction of human settlements has driven land cover change worldwide and this has escalated with the increasing population in the world (Lambin *et al.*, 2001). These changes have implications for ecosystem services. Land use and land cover change influences ecosystem services provisioning (Daily, 1997; MEA, 2005) and therefore studying how land cover has changed historically becomes important, in order to make recommendations for sustainability of the ecosystem services.

Several studies have provided evidence that if not suitably managed, land-use change affects the ecosystem services negatively. For example, in the Gulf of Mexico, Mendoza-González *et al.* (2012) found that expansion of agriculture and urban sprawl affected ecosystem services including water provision. The study recommended that land use and policy making ought to take into consideration the losses to ecosystem services when such land cover changes occur and strive to protect ecosystem services. Similarly, in China, a reduction in forests significantly affected stream flows in the Chaobai River Basin (Zheng *et al.*, 2012). Yet another study in the Lake Victoria Basin reported land use changes such as expansion of croplands, reduction of forests and increase in urban settlements affected human well-being through an increase in erosion, siltation of the lake affecting fisheries and flooding of estuaries, which led to increase in poverty for those dependent on the natural resources of the basin for their livelihoods (Odada *et al.*, 2009). Thus, land-use management becomes important to maintain ecosystems services.

In order to detect land-use and land cover change, satellite images are crucial. Remote sensing techniques have been applied extensively for monitoring actual and spatial change in a variety of natural environmental settings (Townsend, 2002; Wilson and Sader, 2002; Cohen *et al.*, 2003; Dowson *et al.*, 2003; Jin and Sader, 2005; Claessens *et. al*., 2009). Remote Sensing and Geographic Information System (GIS) are now providing new tools for advanced ecosystem management, land-use mapping, and planning. The collection of remotely sensed data facilitates the synoptic analyses of earth-system functions, patterning, and change at local, regional, as well as at global scales over time (Lambin, *et al.*, 2001). Remote Sensing and Geographical Information Systems (GIS) have been combined to understand land-use and land cover change.

In Malawi, land cover has been changing mainly due to deforestation and agricultural expansion (Government of Malawi, 2011). This affects habitats of wild animals, birds, insects, wild flora and the availability of wood and fibre, which are important for human well-being through contribution to food intake, income generation (through sale of provisioning ecosystem services) as well as enhancement of health of those using wild medicinal plants, as described in Chapter 2. In order to understand the drivers of ecosystem change, it is important to know how the changes occur both spatially and temporally. Therefore, in this chapter land cover changes over the past 29 years (1984-2013) in the Likangala River catchment were evaluated to understand the trend of changes and how these may influence provisioning ecosystem services. The focus included land cover changes of important types encompassing woodlands, urban areas and agricultural land, which are linked to provisioning services in the catchment.

A land-use and land cover change study in the Likangala River catchment was done for the period of 1982 to 1995 (Jamu *et al.*, 2003). The assessment of vegetation cover focused on the impacts of catchment degradation on fish, soil erosion, river flow, siltation and water quality within the Likangala River catchment (Jamu *et al.*, 2003). The study revealed that increasing deforestation has contributed to increasing sediments in the river and there was a net increase in agricultural land. The authors modelled soil loss and concluded that increasing canopy cover through afforestation activities will reduce soil loss in the catchment. The Jamu *et al.* (2003) study used black and white aerial photographs for 1982 and 1995 land-use maps. However, this study used GIS techniques and satellite images of 1984 to 2013 to update information on land use and land cover in the catchment.

3.2 METHODOLOGY

3.2.1 Land use and land cover mapping

Data sources

Landsat TM images of 1984, 1994, 2005 and Landsat OLI-8 of 2013 were downloaded from the United States Geological Survey (USGS) website. The strategy for selecting Landsat imagery for development of land cover database for the Likangala River catchment was governed by cost-free availability of multi-temporal images. All images were captured in October/November which is at the beginning of the wet season in Malawi, thereby providing distinctive phenology and portraying diverse land cover in a clearer fashion. Likangala River catchment was demarcated to include all tributaries. The catchment boundary shapefile was used to sub-set the individual Landsat image data. Sub-setting was necessary to contain the land-use/land cover change analysis to an area of 756.02 km^2 which was taken as the catchment area. The area of the shapefile was modified from a reference base map of the study area (Jamu *et al.*, 2003).

Data processing

Land cover mapping and subsequent quantitative change detection required geometric registration between image scenes, and radiometric rectification to adjust for differences in atmospheric conditions, viewing geometry and sensor noise and response (Jensen, 2005; Lillesand *et al.*, 2007).

Geometric corrections

A pre-processing step was necessary to improve the quality of the data. The pre-processing included geometric registration between image scenes and all the Landsat images were geo-referenced by the process of co-registration. This process is aimed at minimizing geometric distortions in an image caused by systematic and unsystematic sensor errors. All the images were re-sampled using the nearest neighbour option and were projected to the Universal Transverse Mercator (UTM) system. Mean Root Mean Square (RMS) errors of less than one pixel resolution was achieved. The images were registered to the *Malawi GP UTM Zone36/Arc1950* datum projection system to match them with available *in situ* vector data (Malawi Government and Satellitbild, 1993).

Image enhancement

In order to better visualize and interpret the imagery, image enhancement techniques using the Image Analyst within ArcGIS 10.0 were used. With a false colour composite, band combination of 4, 3, and 2 for Landsat 5 (5, 4 and 3 for Landsat 8), various features in the imagery such as woodland, water, cultivation, shrubs and wetland were identified. In this standard false colour composite, the vegetation appears in shades of red, urban areas are cyan blue, and soils vary from dark to light browns. Generally, deep red hues indicate broad leaf and/or healthier vegetation while lighter reds signify grasslands or sparsely vegetated areas. This TM band combination gives results similar to traditional colour infrared aerial photography and highlights vegetation in red colour thereby making it easy to visualise (Figure 13).

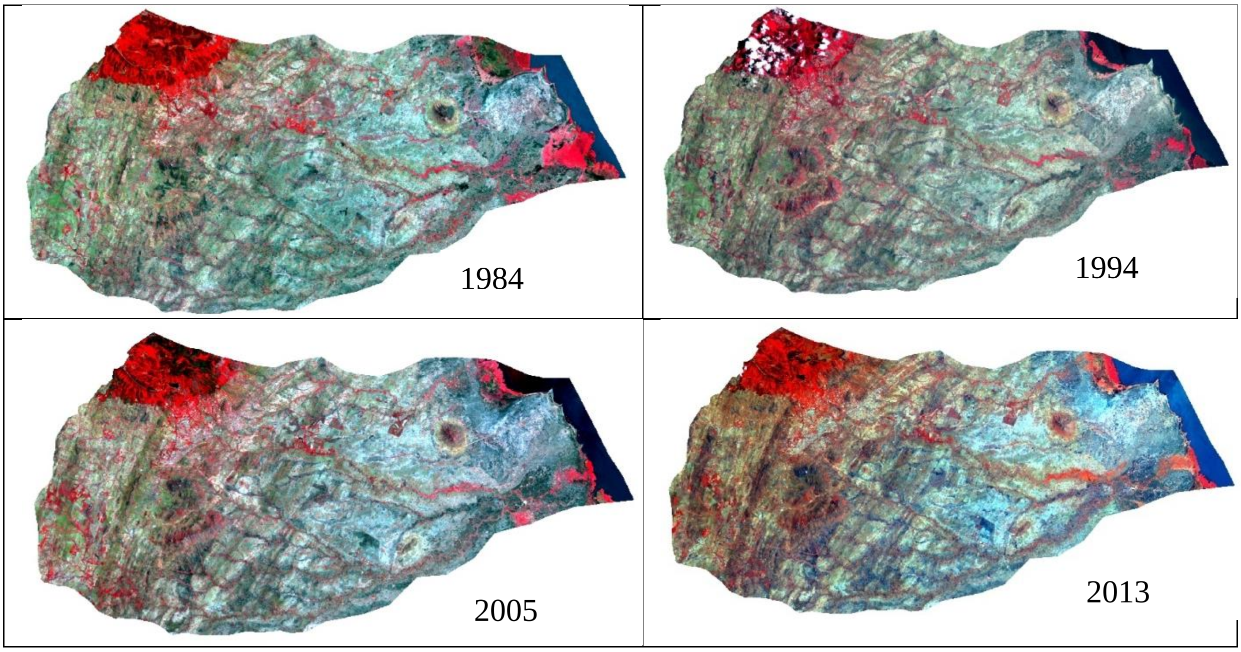


Figure 13: Colour Composite Maps for Likangala River catchment

Normalised Difference Vegetation Index

The Normalised Difference Vegetation Index (NDVI) was used to assess the presence of live green vegetation. NDVI is computed using following formula:

$$NDVI = \left(\frac{NIR-RED}{NIR+RED}\right) \quad \text{Equation I}$$

RED = Red band
NIR = Near-infrared

NDVI values range from -1 to 1. The higher the NDVI, the higher the fraction of live green vegetation present in the scene. Landsat band 4 (0.76 - 0.90µm) measures the reflectance in NIR region and Band 3 (0.63-0.69µm) measures the reflectance in Red region. However, for Landsat 8 the NIR and Red regions have different wavelength ranges. Therefore NDVI for the Landsat 8 image was computed using bands 4 and 5 for Red and NIR respectively. To generate NDVI in ArcGIS 10.1, Equation II was used.

$$NDVI = \left(\left(\frac{IR-R}{IR+R}\right) * 100\right) + 100 \qquad \text{Equation II}$$

IR= Infrared
R = visible red

This will result in a value range of 0-200 and fit within an 8-bit structure. Green colour shows presence of vegetation and other colours show absence of green vegetation (Figure 14). The differences in colour are also dependent on the status and type of land cover. These attributes were useful in classifying the images.

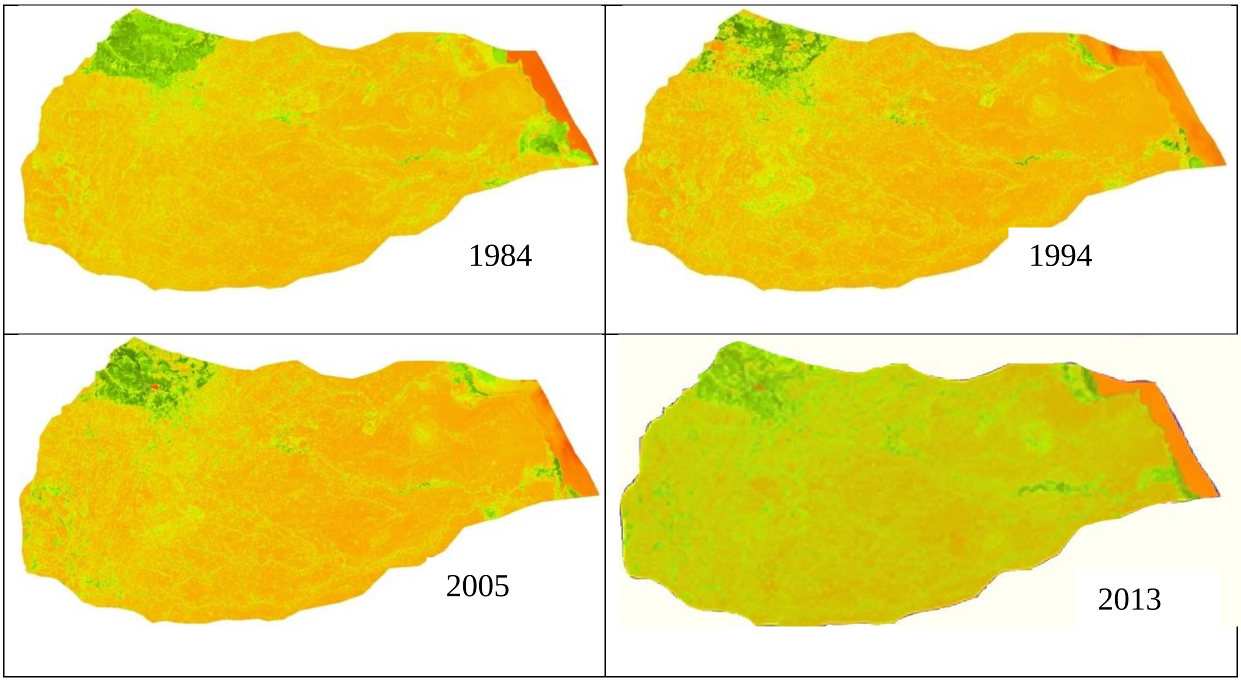


Figure 14: NDVI Images for 1984, 1994, 2005 and 2013

Image classification

Image classification is the process of assigning the pixels to different classes and usually each pixel is treated as an individual unit composed of values in several spectral bands. In this study, a supervised Maximum Likelihood algorithm was used to extract the thematic classes from the images and for which area statistical data were generated. This method was used due to familiarity of the study area.

Land Cover Classification System

Land-use classifications were done using a simplified hierarchic 2-level approach as shown in Table 7. It was developed by modifying the land-use categories developed by Jamu *et al.* (2003) for Likangala River catchment. In this study; woodlands, shrublands, cultivated land, urban areas, estates, wetlands, water bodies and rice irrigation schemes were mapped. It should be noted that due to the marked boundary portrayed by the Likangala rice irrigation scheme, estates and urban areas, Image Analyst in ArcGIS 10.0 was used to digitise these areas and later masked during the classification process.

Table 7: Description of land-use/land cover categories

Land-use/land cover	**Description**
Urban areas	An area with permanent concentration buildings and manmade structures and activities, ranging from large villages to city scale
Forest/woodland	Tall trees <30m and less shrubs or no undergrowth. Mostly miombo woodlands at Zomba plateau and escarpments, and Mopane woodlands dominated by *Colophospermum mopane* elsewhere. Woodlands include tree species: *Brachystegia stipulata, Brachystegia manga, Brachystegia speciformis* and *Jusbemadia globifora*. (Zomba City Assembly, 2009) (Figure 15 provides photograph of woodlands)
Cultivated	Agricultural areas where cropping is practised at subsistence level during wet season and grazing land during dry season
Estates	Medium to large scale cultivated areas dominated by tobacco plantation
Rice schemes	Medium to large scale irrigated areas dominated by rice cultivation (Figure 15 provides photograph of rice irrigation scheme)
Shrub	Consists of open woodland with a fairly dense shrub layer, with trees >5-10m.
Wetland	Seasonally inundated grasslands found along the shores of Lake Chilwa and the Likangala River.
Water	All open bodies of water, including streams, rivers and lakes

Post- processing classification

A post-processing of the classification result was done by reclassifying inaccurately classified or ‘‘mixed’’ pixels utilizing several filter algorithms to clean the resultant land use and land cover maps. In this study, a 5x5 mode filter window was utilised to the generalization of the Likangala River catchment maps.

Figure 15: Woodlands on Zomba Mountain (a) and Likangala rice irrigation scheme (b)

Change detection

Image differences were used to define land cover changes. Land cover classification results were compared on a pixel-by-pixel basis using a change detection matrix where areas of change were extracted. Quantitative statistics were compiled to determine specific changes between the two images i.e. magnitude and direction of change in each land cover type (Calder, 2002). Pie charts were created for each of the years under study to understand the changes in land cover for the years studied.

Accuracy assessment

Finally, accuracy assessment of the classified maps was based on the independent field data set, consisting of observations at 100 homogeneous sampling areas (Figure 16). The product of the accuracy assessment was a confusing matrix showing errors of omission (producer's accuracy) and commission (user's accuracy), overall classification accuracy and a *k* coefficient. The overall classification accuracy is a percentage expressed as the number of correctly classified sample pixels over the total number of sample pixels. This percentage indicates how accurate the classification is with respect to the reference data (Story and Congalton, 1986). The *k* coefficient of agreement is a measure of the actual agreement minus chance agreement.

Figure 16: Hundred random points used for accuracy assessment on Google earth image of 2013

In this study, a Kappa coefficient of 0.72 and an overall accuracy of 85% were achieved for the classification results. However, during dry periods when there is little chlorophyll in the vegetation, grazing causes exposure of soil between remaining vegetation resulting in similar spectral values making it difficult to distinguish the classes. This was the case between cultivated areas, woodlands and shrubs. Basically the land-use classes that could be classified with consistently high accuracies (100%) were water bodies, wetlands, estates, rice scheme and urban areas (Table 8).

Table 8: Error matrix for the Likangala land use and land cover classification

	Cultivation	**Woodland**	**Shrub**	**Water**	**Wetland**	**Estate**	**Rice scheme**	**Urban**	**Row total**	**User's accuracy (%)**
Cultivation	46	0	9	0	0	0	0	0	65	84
Woodland	1	13	2	0	0	0	0	0	6	81
Shrub	3	0	11	0	0	0	0	0	14	79
Water	0	0	0	3	0	0	0	0	3	100
Wetland	0	0	0	0	2	0	0	0	2	100
Estate	0	0	0	0	0	5	0	0	5	100
Rice scheme	0	0	0	0	0	0	2	0	2	100
Urban	0	0	0	0	0	0	0	3	3	100
Column Total	50	13	22	3	2	5	2	3	100	
Producers' accuracy (%)	92	100	52	100	100	100	100	100		

3.3 RESULTS AND DISCUSSIONS

3.3.1 Spatial distribution of land cover classes in 1984

In 1984, 46.3% of the land area was covered by cultivated and grazing land which covered 350.1km^2 of the catchment while 180.6km^2 of the catchment was covered by shrub land, which was 23.9% of the total area. Woodlands covered 135.3km^2 (17.9%) of the area. Wetlands covered 32.5km^2 which was 4.3% of the catchment area. The other land cover classes were below 4% for each type of land cover class (Table 9). Figure 17 shows land cover in 1984. It is noteworthy to observe that woodlands on Zomba Mountain were intact and there were many places with smaller woodlands in the catchment. The area of wetlands was also large in comparison with other years.

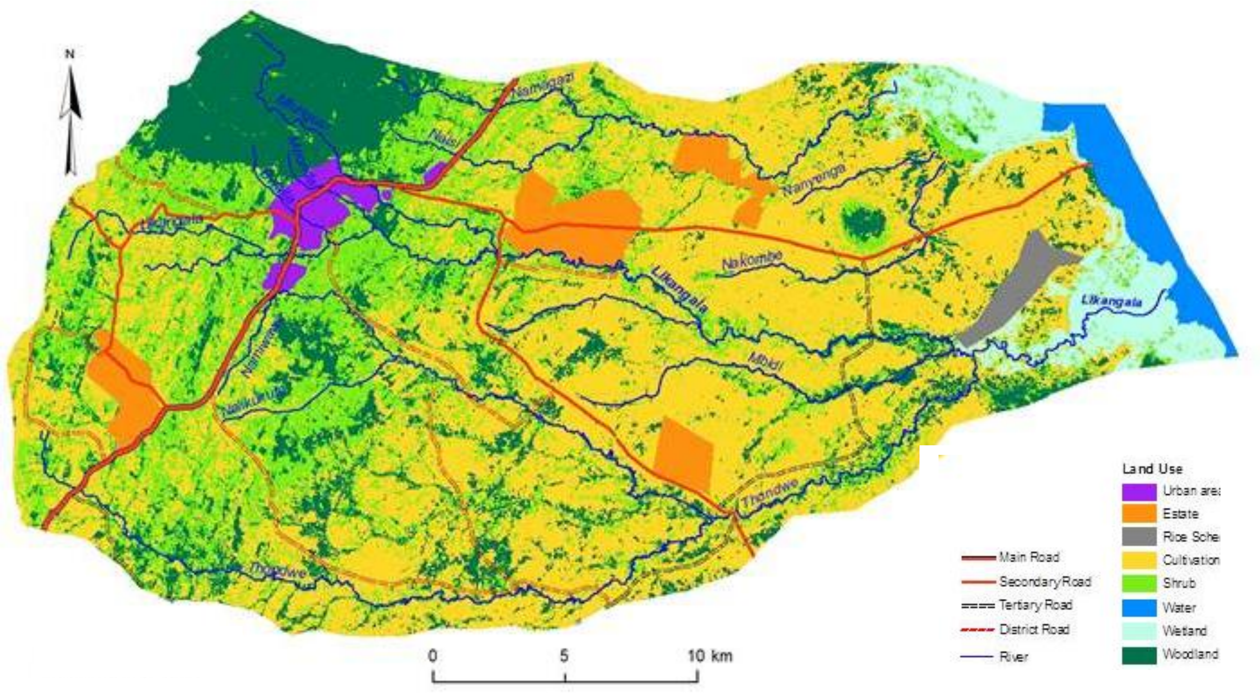


Figure 17: Land use and land cover map in 1984

3.3.2 Spatial distribution of land cover classes in 1994

The classification in 1994 indicates largest area (325.2 km^2) was for shrub-land followed by cultivated and grazing area (289.8 km^2). These classes formed 43% and 38.3% respectively of total catchment area. Woodlands decreased to 52 km^2 which was only 6.9% of total catchment area. Thus, in comparison with 1984, woodlands decreased by 83.3 km^2 in 1994, while cultivated and grazing land reduced by 59.9 km^2 and shrub-land increased by 144.6 km^2 in 1994. It is to be noted that accuracy assessment indicated that cultivated land and woodlands were misclassified as shrub-land (Table 8). This may have contributed to the increased area of shrub-land in 1994. It could also be due to deforested areas being covered with shrubs during this period. Urban areas increased from 9.8 km^2 in 1984 to 13.8 km in 1994 (Table 9). Figure 18 shows that woodlands declined in 1994 especially around Zomba Mountain. The wetlands decline was also evident in 1994, while an increase in cultivated lands and shrublands was noticeable.

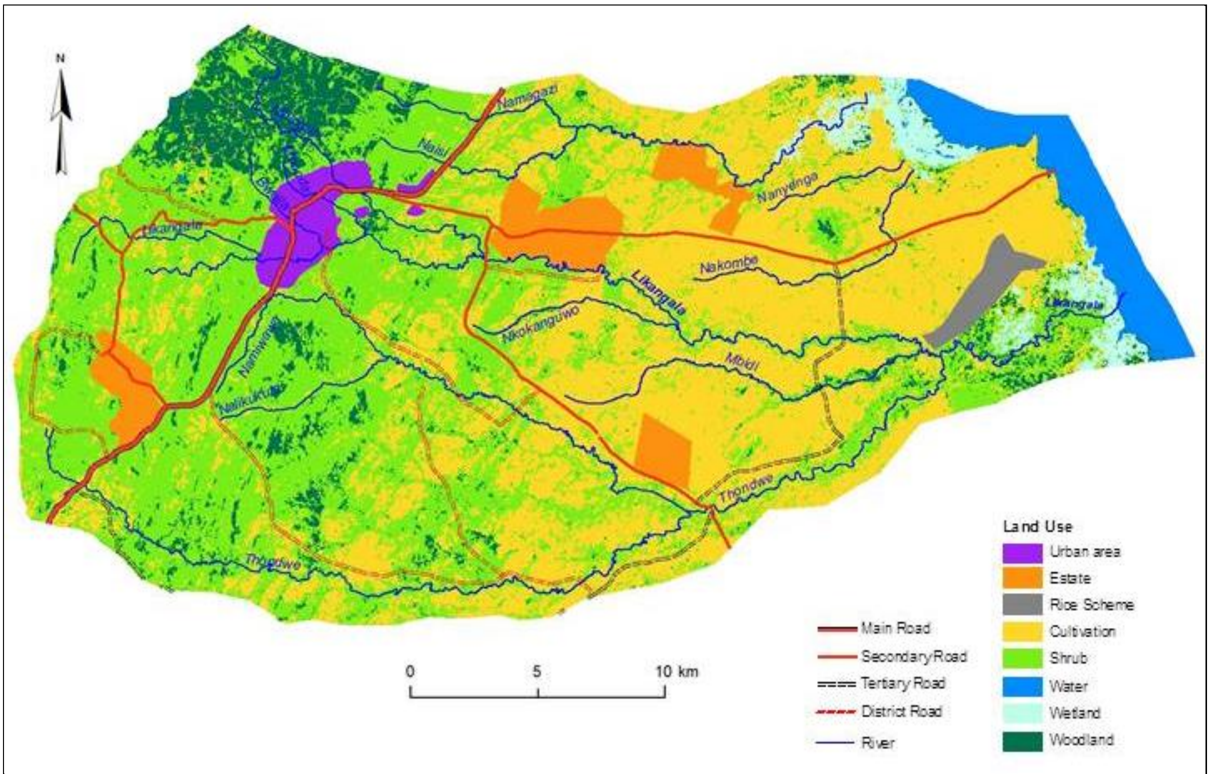


Figure 18: Land use map in 1994

3.3.3 Spatial distribution of land cover classes in 2005

By 2005, cultivated and grazing land increased to 478.5km^2 and covered 63.29% of the catchment, while shrub-land declined to 155.1km^2 representing 20.52% of the catchment. Woodlands had declined to 4.52% of catchment area compared with 6.9% in 1994 and 17.9% in 1984. Wetlands had also declined to 1.57% of catchment or 11.9 km^2. The major change in this year appears to have been the increase in cultivated and grazing land which had increased by 188.7 km^2 (Figure 19). Urban areas increased from 13.7 km^2 in 1994 to 21.3 km^2 in 2005 (Table 9).

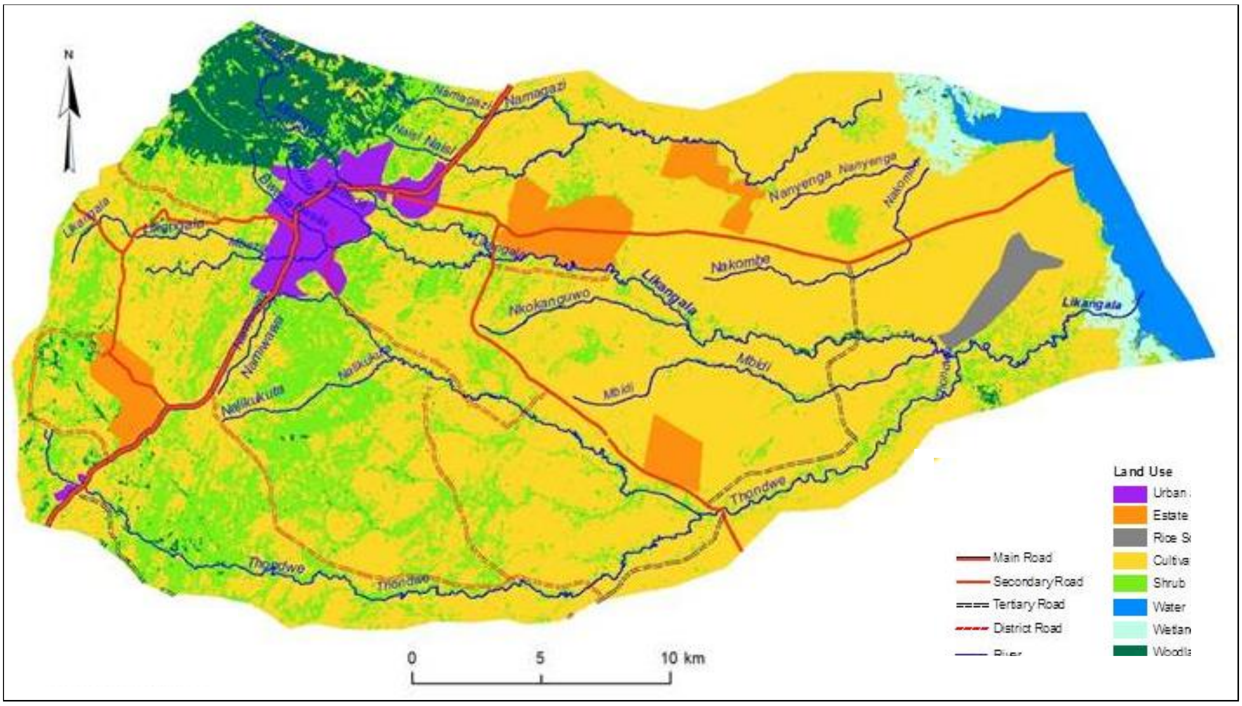


Figure 19: Land use map in 2005

3.3.4 Spatial distribution of land cover classes in 2013

Cultivated and grazing land increased to 505.2 km^2 in 2013, while shrub-land decreased to 150.4 km^2 and woodlands decreased further to 15.5 km^2. Wetlands decreased to 6.2 km^2. Estates and rice irrigation scheme areas remained the same over the years, while urban areas increased to 23.8 km^2 in 2013 (Table 9).

Table 9: Spatial distribution of land cover classes 1984 -2013

	1984		1994		2005		2013	
Land use class	**Area (km^2)**	**%**	**Area (km^2)**	**%**	**Area (km^2)**	**%**	**Area (km^2)**	**%**
Cultivation and grazing land	350.1	46.3	289.8	38.3	478.5	63.29	505.2	66.8
Shrubs	180.6	23.9	325.2	43.0	155.1	20.52	150.4	19.9
Water	14.7	1.9	25.5	3.4	22.0	2.91	22.0	2.9
Wetland	32.5	4.3	16.8	2.2	11.9	1.57	6.2	0.8
Woodland	135.3	17.9	52.0	6.9	34.2	4.52	15.5	2.0
Urban	9.8	1.3	13.7	1.8	21.3	2.82	23.8	3.1
Estates	28.9	3.8	28.9	3.8	28.9	3.82	28.9	3.8
Rice Scheme	4.2	0.5	4.2	0.5	4.2	0.56	4.2	0.5
Total	756.02	100.0	756.02	100.0	756.02	100	756.02	100.0

In 2013, the predominant land cover was cultivated and grazing land which covered 66.8% of the area of the catchment. Shrubs covered 19.9% of the area, while other land cover classes were below 4% (Table 9). Figure 20 shows the land use map of 2013 depicting a decline of woodlands and wetlands, and an increase in cultivated and grazing areas.

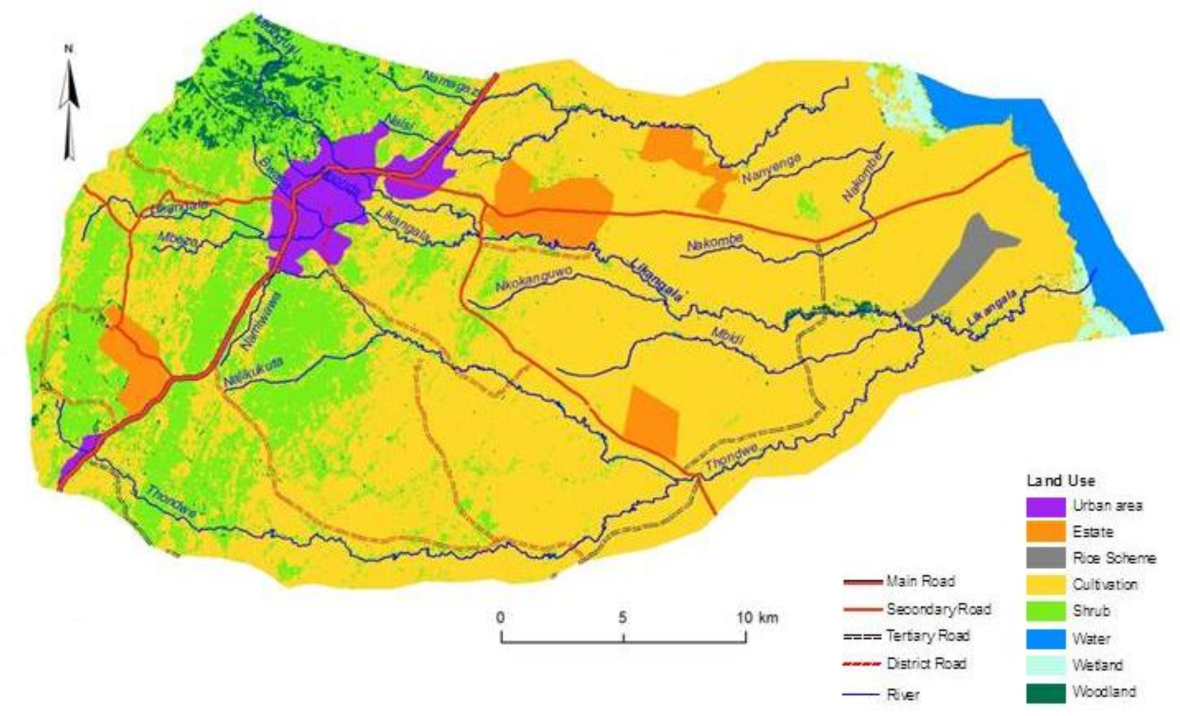


Figure 20: Land use map in 2013

3.4 DYNAMICS OF LAND COVER CHANGE IN THE LIKANGALA CATCHMENT

As shown in Table 9, between 1984 and 2013, the Likangala catchment was dominated by cultivation followed by shrubs while estates and rice scheme spatial extents remained the same over the study period. The spatial extent of woodlands depicts a declining trend from 17.9% in 1984 to 2% in 2013, amounting to a decline of about 4.13 km^2 per year. The plausible explanation for this decrease could be timber harvesting, firewood collection and forest fires. Some of the pine plantations grown by the Forestry Department on Zomba Mountain are routinely harvested for timber, leading to a decrease of the woodlands. In 1994 and 2004, fire episodes caused by disgruntled Forestry workers over wage disputes affected Zomba Mountain and the forest (Zangazanga Personal Comm., 2014). However, small forest fires that occur naturally are common on a yearly basis.

Demands for agricultural land has increased with the growing population and farmers have resorted to using marginal lands such as hill slopes for farming, causing deforestation and soil erosion. In addition, Zomba city and Thondwe town have experienced urban growth from 9.80 km^2 in 1984 to 23.76 km^2 in 2013 representing an increase of 143%. Zomba town was designated as a city in 2010. Thondwe town, which is located to the south-west part of the Likangala catchment, has been growing in size over the years (Figures 13, 14). With urban sprawl, waste management problems have ensued and the Likangala River has been affected by pollution from waste and sewage disposal (Chavula and Mulwafu, 2007; Chidya *et al.*, 2011). Field observations revealed that human settlements built in the urban areas did not follow buffers for streams and rivers and were built close to such natural features. Clay brick making and sand mining were observed in urban areas such as Kalimbuka (Zomba City).

Wetlands declined from 32.53km^2 in 1984 to 6.17km^2 in 2013, with a net loss of 26.36km^2. Since wetlands retain water, they support the vigorous growth of grass and provide good dry season grazing areas when other forms of grazing are in short supply. Wetland margins are also used for cultivation (during the dry season) providing a more reliable crop output to supplement rain-fed harvests (Ferguson and Mulwafu, 2003).

The area of shrubs decreased by 30.15 km^2, this could be attributed to changes in land cover from shrubs to cultivated areas and settlements. Seasonal variations in Lake Chilwa levels attributable to changing rainfall patterns and changes in flows of rivers that feed into it, causes variations in lake levels and thereby area of water. Policy changes may also have contributed to land cover change in the catchment. Malawi became a democracy with a multiparty system introduced in 1994. Prior to this, strict controls on deforestation and austere environmental management were followed. Climatic changes could also be an explanation to some of the changes in land cover. Both of these need further research. The pie charts in Figures 21 and 22 depict the changes in land use and land cover in the four periods under study.

The land cover classification of 1984 showed woodlands occupying 18% of the catchment and wetlands occupying 4%. By 1994, woodlands were reduced to 7% and wetlands to 2%. The area of shrubs and cultivation in 1984 was 24% and 46% respectively, while by 1994 shrub-land had increased to 43% and cultivated areas declined to 38%. The changes between shrub-land and cultivated areas could be due to confusion in classifying cultivated land as shrub-land since 1994 was a dry year with low rainfall (Njaya *et al.*, 2011).

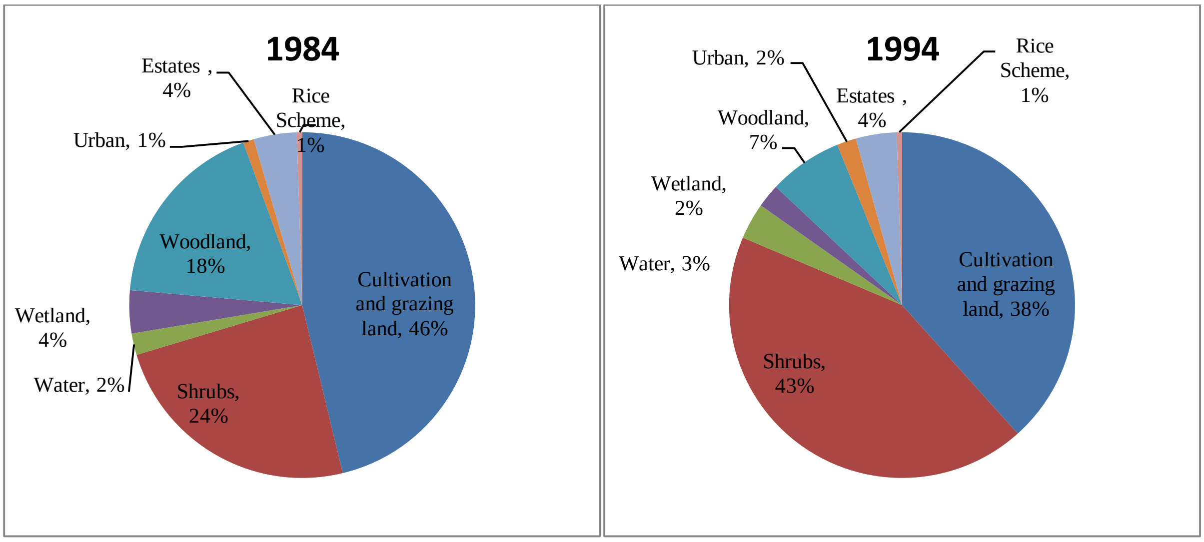


Figure 21: Spatial distribution of land cover classes in 1984 and 1994

Therefore, communities may not have cultivated crops in 1994 causing grasses to grow in farm areas thereby confusing cultivated areas with shrub-land. Estates and the rice scheme remained the same during both periods, while urban areas increased by 1%. Woodlands were mostly found on Zomba Mountain, Mpyupyu hill, and spread widely in the catchment including close to the wetlands of Lake Chilwa.

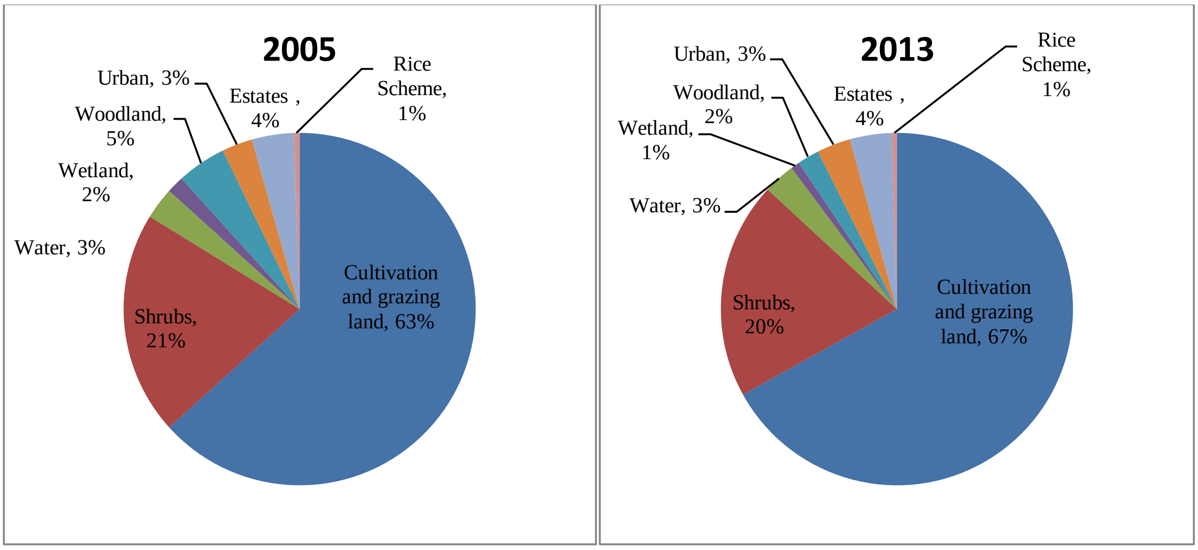


Figure 22: Spatial distribution of land cover classes in 2005 and 2013

By 2005, woodlands declined to 5% and then to 2% by 2013. Cultivated areas increased from 63% in 2005 to 67% in 2013, while shrubs decreased from 21% to 20% in the same years. Wetlands declined by 1% and there was a marginal increase in urban areas (2.5km^2) while, water, estates and the rice scheme remained unchanged. Thus, declining woodlands, wetlands and shrub-land have contributed to increasing the cultivated land and urban areas in the four periods under study. Of all the land cover classes, cultivated area is the largest in 1984, 2005 and 2013. The trend appears to be that of conversion of woodlands, wetlands and shrub-land into cultivated areas. A decline in woodlands and cultivation on slopes result in soil erosion and accelerated runoff which affects water quality of rivers downstream. This negatively affects those who depend on the water downstream of these areas.

3.4.1 Post classification and land cover change in selected areas

The results from post classification analysis are presented in four change maps which help visualise the change in the hotspot for the 29 years. Figure 23 shows how woodlands have been declining at Zomba Mountain over the years.

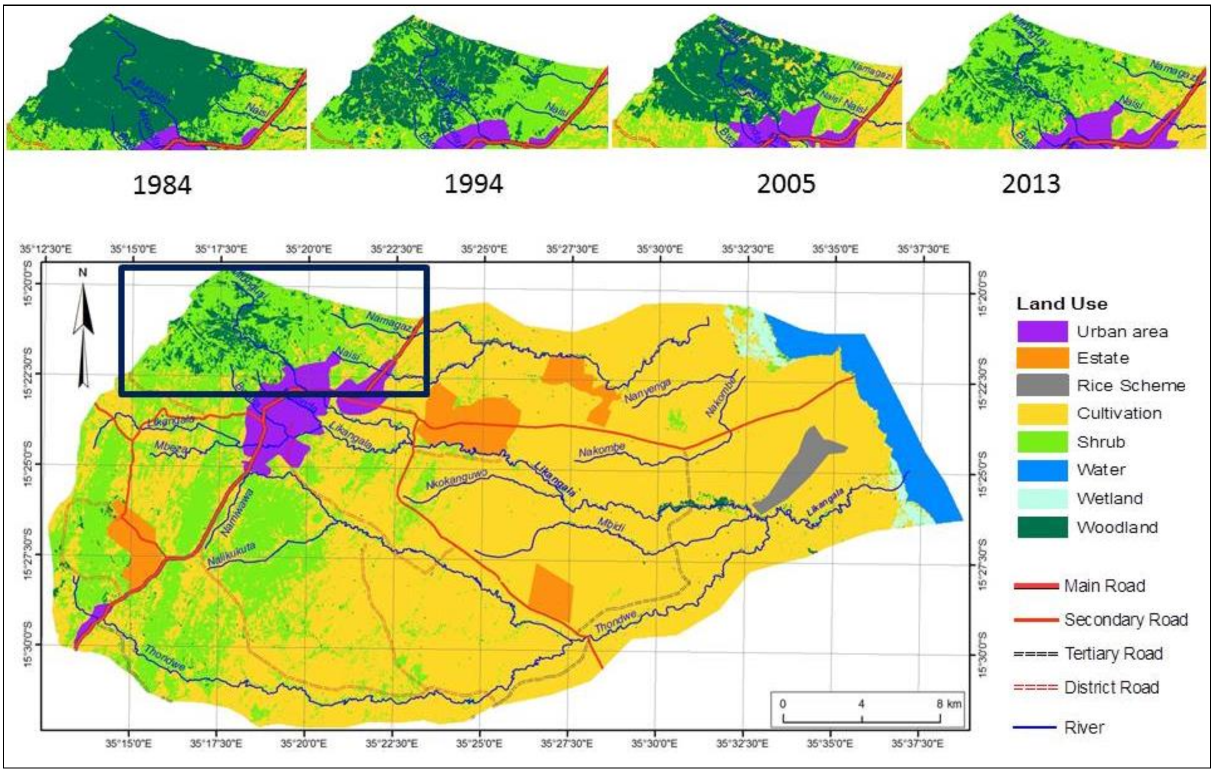


Figure 23: Land cover change in Zomba Mountain

Zomba Mountain has experienced rapid deforestation from 1984 to 2013 with woodlands being converted to shrub-land and cultivated areas (Figure 23). Zomba Mountain is a tourist attraction and many tourists come for hiking, nature trails, horse riding and picnicking at the Mulunguzi Dam and Chagwa dams as well as the various water falls, cliffs and viewpoints. Although there are not many villages on the plateau, the slopes of the mountain are home to a number of communities. The demand for firewood and timber drives deforestation on this mountain. Bush fires set by communities who want to hunt for game also cause deforestation.

Demand for firewood can be reduced through the promotion of fuel efficient stoves, which are being promoted by NGOs that work in this area.

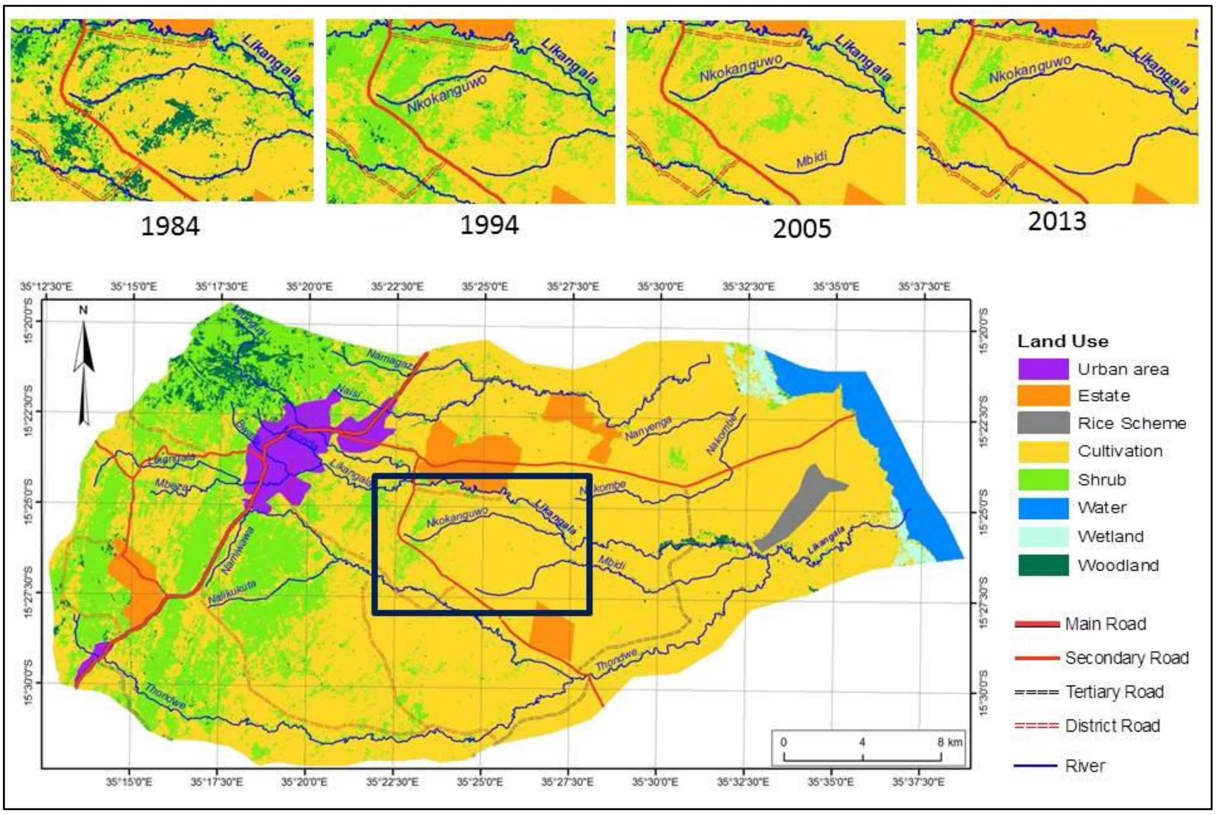


Figure 24: Land cover change in Mindano village and its surrounds

Figure 24 shows how river bank cultivation has contributed to the decline of tree cover along the river banks. This is due to the demand for cultivation land and use of residual moisture in river banks for dry season cropping. Population growth is a driver for increasing cultivation. Land cover change in Mindano village and its surrounds (Figure 24) is representative of most of the catchment, where woodlands and shrub-lands have given way to cultivated land. In 1984 in this area the land cover included woodlands, shrub-land and cultivated areas, while in 2013, the cultivated areas has increased at the expense of woodlands. This is due to pressure for meeting the demand for food as the population has increased.

The trade-offs between ecosystem services is explicit, while cultivation increases food production, loss of woodlands and shrub-land reduces biodiversity affecting wild foods and medicinal plants as well as other products. Communities reported that Mpyupyu hill was affected by deforestation and thereby habitats for wild animals were impacted leading to their decline in numbers over the years. Figure 25 shows how woodlands in 1984 have been converted to shrub-land in 1994 and 2005 and then into cultivated land in 2013. Cultivation along steep slopes of this hill may contribute to siltation. There have been some attempts to carry out re-afforestation on the hill using *Eucalyptus* trees. However, this species is exotic and may alter the water cycle, as they contribute to an increase in evapotranspiration as compared to indigenous varieties (Soares and Almeida, 2001).

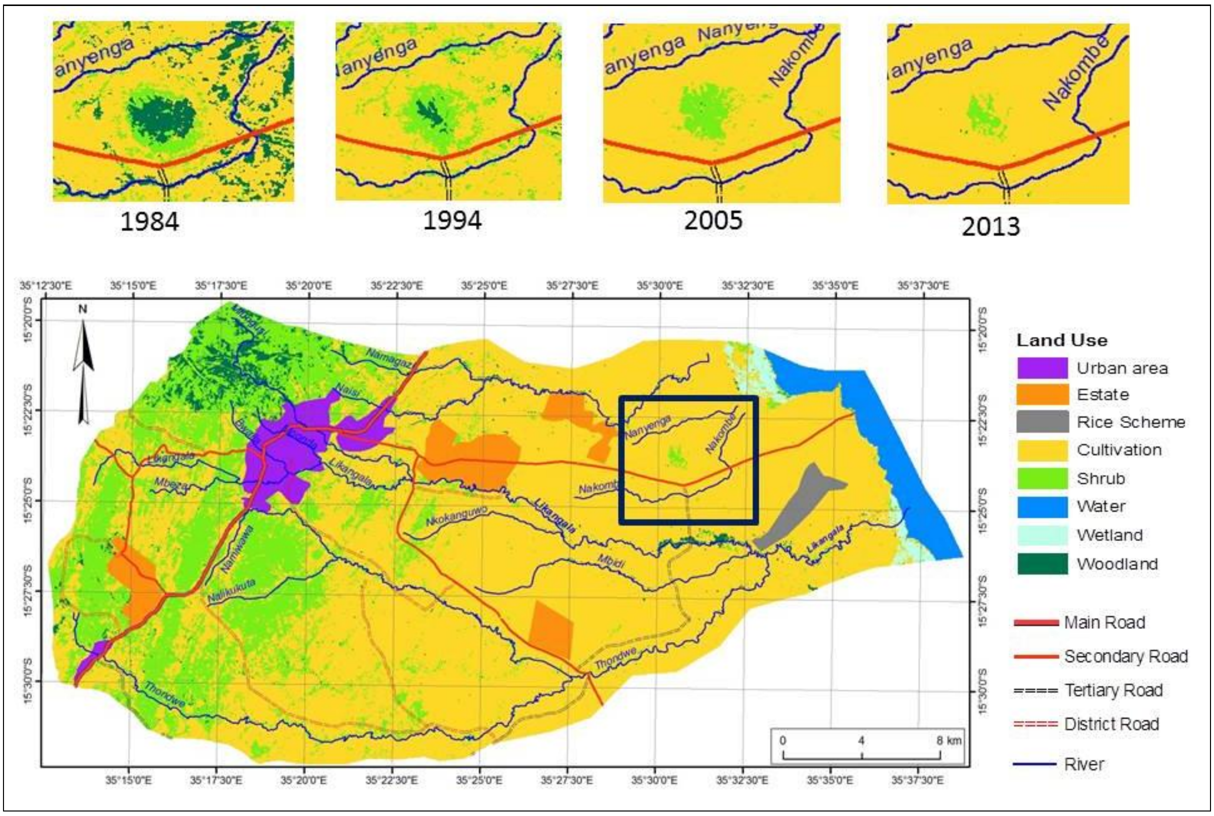


Figure 25: Land cover change at Mpyupyu Hill

Mbalu and its surrounding wetlands are important for bird biodiversity, reeds, elephant grass and aquatic species such as river crabs (Figure 26). The Likangala Rice Irrigation Scheme has remained unchanged in area over the years under study. The area of the wetlands has been declining from 1984 to 2013, and it was converted into shrub-land and then into cultivated land. Field observations confirmed the conversion of wetlands into rice farms close to the shores of Lake Chilwa. This was to take advantage of the residual moisture especially during dry months. Cultivation in wetlands will affect its natural function as an ecological flood control through changes in soil texture and therefore affects the ecosystem integrity.

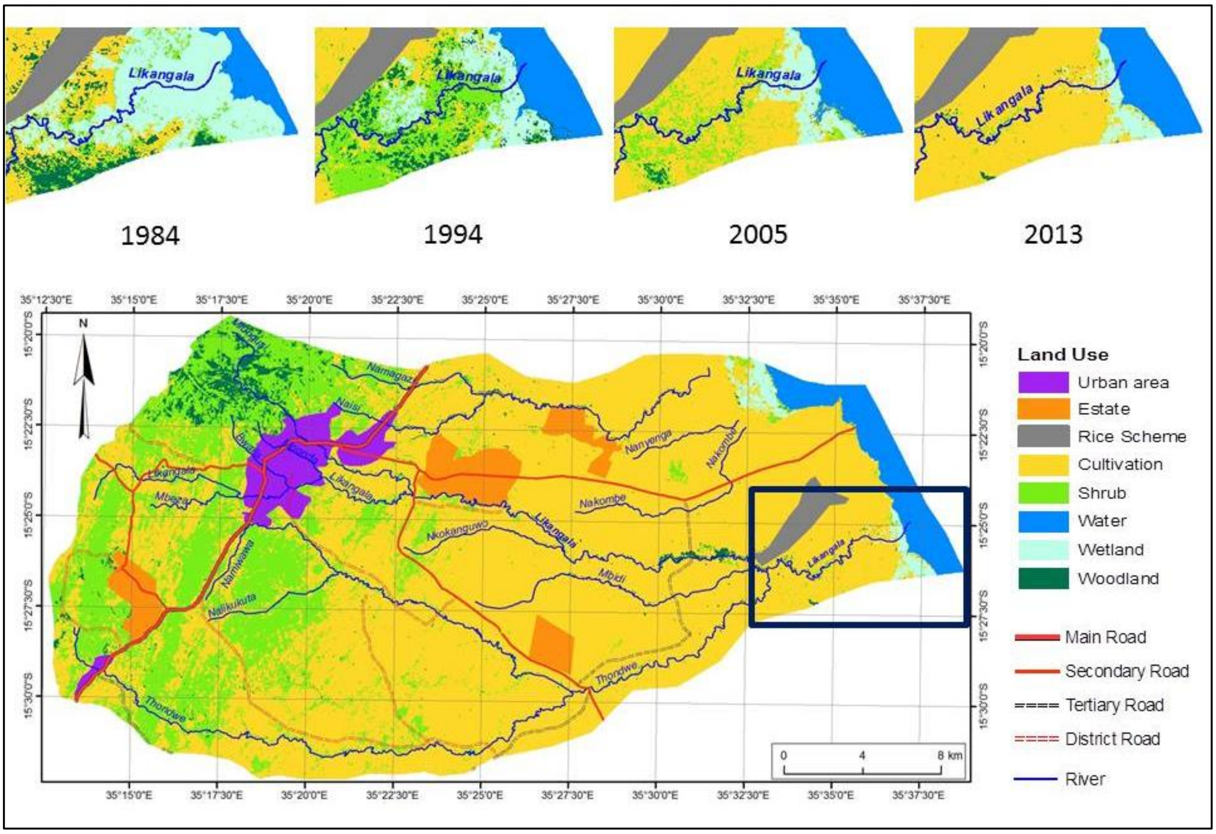


Figure 26: Land cover change near wetlands, Likangala Rice Scheme and Mbalu area

The findings of figures 23, 24, 25 and 26 show that deforestation and expansion of cultivated areas impacted provisioning ecosystem services through loss of habitats for medicinal plants and wild foods, which has the potential to negatively impact the well-being of humans. There are many areas in the Likangala River catchment which are identified as hotspots which are important for provisioning ecosystem services as well as biodiversity, but have suffered environmental degradation. These include woodlots on Zomba Mountain and Mpyupyu hill, river banks and the wetlands.

3.5 SUMMARY

This study provided information of how land-use and land cover changed in 29 years from 1984 to 2013 in the Likangala River catchment. The land use maps indicate that, during this period, there has been a decline in woodlands, shrub-land and wetlands with increasing trends in cultivation and urban areas and this was identified in the land-use maps with an overall accuracy of 84%. Hotspots of land cover change have been identified as woodlots in Zomba Mountain and Mpyupyu hill, which have experienced declines in trees with conversion into shrub-land then cultivated areas. River banks in the catchment have been affected with river bank trees gradually being reduced and cultivation increasing. Wetland areas have declined and converted into cultivated lands.

The major finding from this study is that woodlands have declined from 135.3 km^2 to 15.5 km^2 indicating a decline of 88.5%. Land-use/land cover change in the past 29 years revealed that shrub-land declined by 16.7%, agricultural areas have increased by 44.3% and urban areas increased by 143%. This has serious implications for ecosystem services as biodiversity of wild animals, insects, and birds. The provision of wild fruits and medicinal plants will be affected by a decline in woodland habitat. Furthermore, trees along river banks have important hydrological function and when they are cut down and river banks used for cultivation, there are water quality implications as well as soil erosion problems.

There is little doubt that the existing trend of land use will continue in the Likangala River catchment. Therefore, the drivers of land-use change need to be addressed in order to sustainably address ecosystem degradation. Afforestation activities need to be improved and deforestation controlled as a matter of urgency. Further research needs to be taken on simulating future projections of land use change in order to provide decision makers with information on the various scenarios of change and their possible impact on human well-being. There is a need to understand impacts of land use change on water quality of the Likangala River as this is also an indicator of ecosystem health. This is covered in Chapter 4.

CHAPTER 4

4 THE IMPACT OF LAND USE ACTIVITIES ON WATER QUALITY

4.1 INTRODUCTION

Human activities have affected water quality in many river catchments worldwide. For example, in Pangani River in Tanzania, agriculture, horticulture and livestock keeping affected water quality by increasing nitrates and nitrites, and reducing dissolved oxygen (Hellar-Kihampa *et al.* 2013). While in Chesapeake Bay in Potomac River Estuary, USA, discharge of wastes and runoff from agricultural practises increased sediment and nutrient loads (Bricker *et al.* 2014). Whereas in Densu River in Ghana, industrial effluents and urban wastes discharge contributed to increasing nutrient load (Attua *et al.* 2014). A positive correlation between population density and deterioration in water quality was found along the Bagmati River in Nepal (Bhatt *et al.* 2014). Thus, changes in land-use, increase in population, anthropogenic activities and their impact on rivers need to be evaluated in order to effectively manage river catchments.

However, beyond water quality changes, land-use change such as deforestation affects the integrity of the catchment and causes localised flooding, as the natural vegetative cover is removed. Removal of woodlands and forest cover is a phenomenon across the country with forests in Malawi declining from 41% in 1990 to 34% in 2010 (Malawi Government and Satellibild, 1993; Government of Malawi, 2011). This is driven by the need for firewood, as Malawi has the lowest access to energy in its rural areas compared with its neighbouring countries with only 4% of people in rural areas having access to electricity (Ruhiiga, 2012). As a result of deforestation, natural flood control mechanisms have failed and runoff increased leading to an increase in flash floods. Deforestation and land-use change induced flooding have human health impacts including diseases such as cholera and other waterborne ailments. In 2012, areas around Likangala and Matiya in Zomba District were affected by floods and cholera cases were reported to have affected over 2000 people and three persons died (Chingaipe Pers.Comm., 2013). The frequent occurrence of floods submerging low-lying areas would increase the incidences of malaria due to the expansion of mosquito-breeding grounds (Government of Malawi, 2011). Thus, how land is used affects human health, and this link is noteworthy, as it ultimately disrupts human well-being.

Malawi's river catchments, in spite of being important for its population, have been deteriorating (Government of Malawi, 2011). The Likangala River catchment is affected by changes in land use as detailed in Chapter 2. Previous studies indicate that deforestation, agricultural expansion, waste disposal, river bank cultivation and sand mining have affected water quality of this river (Mulwafu, 2000; Jamu *et al.*, 2003). Changes in land cover play an important role in managing the environment including hydrological regimes of rivers (Li *et al.,* 2008, Palamuleni *et al.,* 2011, Bieger *et al.,* 2013). Water quality measurements are important as these provide information for water use for agriculture and domestic purposes. Therefore, this study assessed water quality of the Likangala River with the intent of identifying the major land-based activities that cause change in water quality. Water quality is an indicator of ecosystem health and has implications for provisioning ecosystem services.

4.2 CATCHMENT CHARACTERISTICS

Communities in rural areas of Malawi depend on natural resources for their livelihoods and 95% of them depend on biomass for their energy needs, therefore the increasing rural population in Malawi puts pressure on natural resources (Government of Malawi, 2011). Communities in these areas are predominantly at subsistence level and reliant on rain-fed agriculture (Government of Malawi, 2011). This is also mainly observed in the Likangala catchment area, although there are a small number of irrigation schemes and irrigated farms. People living in the Likangala River catchment area, in addition to irrigation use the water from the river for bathing, washing and recreation. Communities also derive other productive ecosystem services such as fish, forest products, medicinal plants, wild animals, fruit and insects, sand, stone and reeds from this ecosystem as provided in Chapter 2.

In spite of the benefits the river provides, it is threatened with pollution including indiscriminate release of waste and sewage, illegal sand mining, deforestation and waste from urban sprawl. The Likangala River catchment area is affected by the increasing population which has resulted in urban sprawl with many new settlements built in Zomba City and Thondwe town, the two major urban areas in Zomba District. This has increased waste generation and waste management problems. Institutions in the Zomba District, including the Zomba Central Hospital and Zomba Municipality wastewater works release solid and liquid waste into the river. The indiscriminate disposal of waste has impacted human health. Nevertheless, due to inadequate water supply facilities, communities resort to using river water for domestic purposes, leading to dysentery and cholera epidemics (Jamu *et al.,* 2003, Mulwafu *et al.*, 2003, Jamu *et al.*, 2005, Chavula and Mulwafu, 2007, Chidya *et al.*, 2011). In addition, poor land management practises have led to siltation in the river thereby negatively impacting the health of fish and their breeding patterns (Jamu *et al.*, 2003). Furthermore, use of fish poison and fish weirs has resulted in declining fish stocks in the river (Jamu *et al.*, 2003). In order to manage the Likangala River catchment area, it is important to assess water quality and link it to land use activities to preserve the river and the ecosystem services in its catchment. This chapter provides an assessment of the impacts of land use changes on water quality of Likangala River. The specific objectives were to examine physical, cation, anion and faecal pollution in seven locations along the river. Further discussions highlight differences in water quality based on land-use change.

4.3 MATERIALS AND METHODS

A combination of desk studies and experimental techniques involving water quality testing were done in this study.

4.3.1 Sampling points

Water samples were collected upstream and downstream of sites with the following dominant land cover classes: forested areas, urban areas, agricultural estates, subsistence farming including rice farms and at Lake Chilwa. Sub-catchments around these sampling points were observed for dominant land-use; topography and socio-economic activity in the field and using Google Earth before sampling sites were chosen. Water quality samples were collected for both dry and wet seasons to assess the health of the river in totality, as there are seasonal variations caused by rainfall and increased runoff that can affect water quality (Chidya *et al.*, 2011).

Four sets of water samples from each of the seven sampling sites indicated in Table 1 were collected, two of them during the dry season (May 2013) and two during the wet season (October 2013) totalling twenty eight samples. The seven sampling points included: SP1 at the head of the river located on the Zomba Plateau, SP2 downstream of Zomba City, SP3 upstream of agricultural estates, SP4 downstream of agricultural estates, SP5 upstream of subsistence farming and small rice farms and SP6 downstream of small rice farms and SP7 at the outflow of the river into Lake Chilwa (Figure 27).

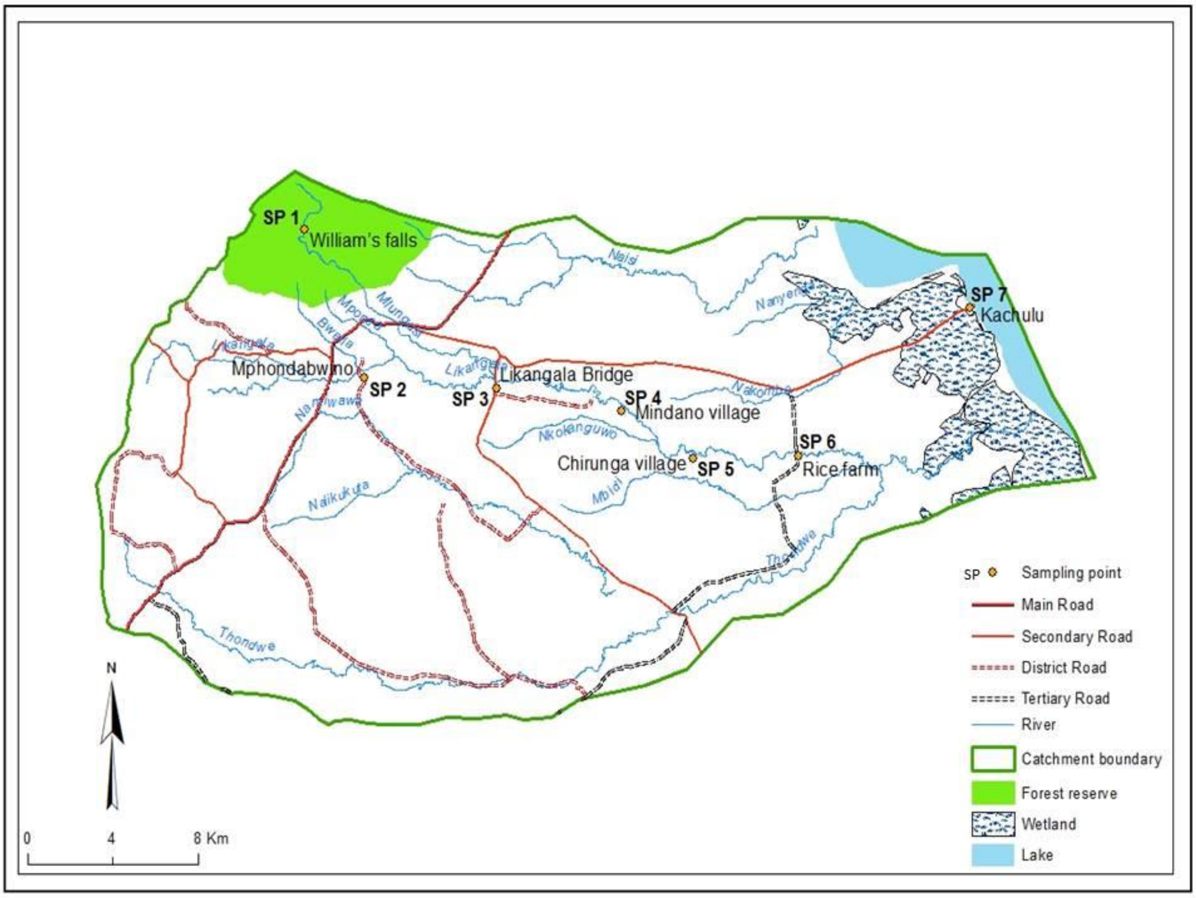


Figure 27: Water quality sampling points along Likangala River

A description of the sub-catchment characteristics for each sampling point based on topography, land use, social aspects and livelihood activities is given below:

SP1 is Williams Falls which is a waterfall located on Zomba Plateau, fed from Mulunguzi Marsh located on the mountain. This sampling point is upstream of Zomba City and the areas around this sampling point are characterized by mixed species of indigenous and exotic forests and pine plantations. Being a popular tourist attraction, activities such as horseback riding, picnicking and hiking are done in this area. Accommodation is available for tourists in hotels and guest houses and a trout farm caters to tourists and residents. Mulunguzi Dam is situated in this area and this dam provides water to residents of Zomba. A number of villages and middle income residential areas are located along the slopes of Zomba Mountain.

SP2 is Mpondabwino, a busy market area, which is in Zomba City downstream of Zomba Central Hospital and in the vicinity of the Zomba Wastewater Treatment works. The hospital releases waste including medical waste and the treatment works is overloaded by the increased population that it serves, and releases waste water which is not completely treated into the Likangala River. River bank cultivation was common and sand mining activities observed in the areas. Brick making from clay using large quantities of firewood was also observed along the river. Residents around this sampling point are of middle income category that lives at residential areas such as Kalimbuka and low income that reside in unplanned settlements and household waste management remains a concern.

SP3 is at Likangala Bridge close to Jali, where a number of stone crushers work on the igneous rocks found close to the river. River bank cultivation and sand mining were also observed and the area was primarily characterised by subsistence agriculture. This is downstream of the city and predominantly rural while being located upstream of large agricultural estates. Generally, low income residents live in this area.

SP4 is Mindano Village located downstream of agricultural estates that grow mainly tobacco and cotton. The village is downstream of Mikuyu Prison and the nearby villages are Sitima and Phulusa. A number of streams that flow into Likangala River and Lake Chilwa are also found in the vicinity and they are Nkokanguwo, Mbidi, Namiwawa and Nakombe. The communities that live in this area include subsistence farmers and estate employees.

SP5 is Chirunga Village upstream of small rice farms and characterized by sand mining activities on the river bank. The sampling point is upstream of rice farms and subsistence agriculture is practised in the surrounding villages, namely, Ronald, Chilunga I, Chilunga II and Kachingwe. Some small trading centres exist.

SP6 is located downstream of small rice farms, sugarcane farms and is close to the Likangala Rice Irrigation scheme. Small scale irrigated agriculture was observed using mostly organic fertilizers. The area has a number of low lying wetlands. Communities were mostly dependent on agriculture and trading at nearby trading centres.

SP7 is Kachulu which is a fish landing site at Lake Chilwa, where the Likangala River flows into Lake Chilwa. It is a busy fish trading site with many tea shops constructed from reeds that cater to fishermen. The surroundings are typically wetlands with reeds and grasses that communities harvest or cut to make baskets, mats and are used as construction materials. A few ponds for aquaculture and fish processing solar fish dryers are also present. In the wetlands, rice cultivation is done when water levels are low, taking advantage of the residual moisture. Fishing and farming communities reside here.

4.3.2 Water quality parameters

The water quality parameters that were analysed included physical parameters, cations, anions and biological parameters (Table 10). Sampling procedures used were according to American Public Health Association (APHA) Standard Methods for the Examination of Water and Wastewater (1998). Samples were collected using one-litre polyethylene bottles and sample bottles were kept closed until filled and caps replaced immediately. For physicochemical analysis, sampling bottles were rinsed three times using sampling water and labelled adequately. Samples for bacteriological testing were stored in a cooler box at 4ºC and tested within 24 hours. For bacteriological analysis, one sample from each site was collected in 250 ml bottle whereas the other two were collected in one litre bottles, one of which was acidified with three drops of concentrated nitric acid, HNO_3 (for cations determination). The un-acidified water samples were refrigerated at 4ºC before analysis. Standard APHA methods (1998) were used for the water quality analysis to determine *E.coli* and total coliforms, the standard plate count method was used.

Table 10: Water quality parameters analysed including physical parameters, cations, anions and biological parameters

Physical parameters	**Cations**	**Anions**	**Biological**
Turbidity	Calcium (Ca^{2+})	Bicarbonates (HCO_3^-)	Total coliforms
pH	Magnesium (Mg^{2+})	Chlorides (Cl^-)	*Escherichia coli*
Electrical conductivity	Sodium (Na^+)	Sulphate (SO_4^{2-})	
Total Dissolved Solids	Potassium (K^+)	Total Iron (Fe)	
Total hardness		Nitrates (NO_3^-)	
Total alkalinity		Phosphates (PO_4^{3-})	
Suspended solids		Silica (SiO_2)	
		Fluoride (F^-)	

Other parameters such as heavy metals, dissolved oxygen, chemical oxygen demand and biological oxygen demand were not analysed due to constraints in availability of equipment. Table 11 shows the equipment used for testing the parameters.

Table 11: Equipment used for water quality analysis

Parameter	Equipment	Model	Manufacturers	Country
pH	Digital pH Meter	pH 55	Martini Instruments	U.S.A
EC/TDS	Digital EC/TDS meter	EC 59	Martini Instruments	U.S.A
Cl^-, HCO_3^-, CO_3^{2-}, $CaCO_3$	Electric Autotitrator	#775 Dosimat	Metrohm	Switzerland
PO_4^{3-}, NO_3^-, SO_4^{2-}	UV/Visible Spectrophotometer	T90	Wagtech Projects	China
F^-	Digital Ion Selective electrode	Orion	Mettler Toledo	Switzerland
SiO_2	Muffle Furnace	EML Carbolite	Phillip Harris	England
Fe, Ca, Mg, K, Na	Microwave Plasma Atomic Emission Spectrophotometer	4100 MP-AES	Agilent Technologies	Germany
Turbidity	Turbidimeter	DRT – 15 CE	HF Scientific Incorporation, Ft Myers, FL	U.S.A
Suspended Solids	Analytical Balance	AE 163	Mettler Toledo	Switzerland

4.3.3 Water quality analyses

Water quality data collected at the seven locations were analysed by calculating mean and standard deviation at each sampling point and comparing values for dry season and wet season. The results were compared with the water quality standards of the World Health Organisation (WHO) and the Malawi Bureau of Standards (MBS). An independent *t*-test was used to establish significant differences in mean values of all upstream samples compared with downstream. This method was used because it assesses whether the means of two groups are statistically different from each other and this was important to identify which land-use significantly altered the water quality. T-test was done using the Statistical Package for Social Sciences (SPSS). The technique has been used in several studies that link the impact of land use on water quality, for example, the impact of industrial areas on water quality in Lesotho (Pullanikkatil and Urama, 2011), hydrological effects of various land-use at a regional scale in Ohio in the United States of America (Tong and Chen, 2002), and urban areas on upper Han River Basin in China (Li *et al.*, 2008).

Further analysis was done using a Water Quality Index (WQI) that was developed by Brown *et al.* (1970). The index uses a set of standards to measure changes in river water quality that are then used to compare the water quality of different sections of a river. The WQI numerically encapsulates various water quality parameters into one value and provides an indication of the health of the water source. The parameters that were entered into the WQI calculator for this study were pH, change in temperature between laboratory and temperature on site, *E.coli*, total phosphates, nitrates and turbidity. The WQI is calculated from the standard formula (Brown *et al.,* 1970) Equation 4.1.

$$\mathrm{WQI} = \sum_{i=0}^{n} \mathrm{QiWi} \qquad \text{Equation 4.I}$$

Where:

Qi= sub-index for i^{th} water quality parameter;

Wi= weight associated with i^{th} water quality parameter;

n= number of water quality parameters.

The WQI is determined as the weighted average of all water quality parameters of interest. The NSF WQI values are rated as per WQI values from 0 to 100 where 91-100 is excellent, 71-90 is good, 51-70 is medium, 26-50 is bad and 0-25 is very bad water quality (Brown *et al.* 1970).

This index is considered the most comprehensive available and uniquely rated by the scientific community (WHO, 1999, Bharti and Katyal, 2011). WQI incorporates several environmental variables into one number by ascribing different weights for the several parameters and thereby diminishes the negative impacts of one or more variables (Simo˜es *et al.,* 2008, Tyagi *et al.,* 2013). WQI turns complex water quality data into an aggregate rating that reflects the combined influence on the overall water quality as opposed to the univariate water quality assessment approaches such as that used by the Malawi Bureau of Standards (Brown *et al.,* 1970). The index has been widely used, for example in Malawi (Wanda *et al.,* 2012), Romania (Ionuş 2010), Brazil (Sa´nchez *et al.,* 2007, Simo˜es *et al.,* 2008), Iraq (Alobaidy *et al.,* 2010), India (Parmar and Parmar 2010, Kankal *et al.,* 2012, Rao and Nageswarao, 2013), United States, South Africa, Mexico, Scotland, Ukraine, Croatia and Israel amongst others (Hambright *et al.*, 2000).

4.4 RESULTS AND DISCUSSIONS

In this section, water quality parameters that were tested are reported in detail and results compared with WHO and MBS values. Values upstream and downstream of the identified land-uses were compared and further evaluated between dry and wet seasons. Then, the water quality index values were reported which indicated the overall health of the river.

4.4.1 Physical pollution of water within Likangala River Catchment

Table 12 provides mean the values of the two samples taken during dry season and two samples during wet season for the physical parameters; turbidity, pH, electrical conductivity, total dissolved solids, total hardness, total alkalinity and suspended solids at all seven sampling points along the Likangala River. Silica was below detection levels at all sampling points and therefore not included in the analysis.

During dry season, all sampling points except SP7 were within MBS standards for turbidity, while WHO standards for turbidity were exceeded at all points except SP1. Suspended and colloidal matter such as clay, silt, fine organic matter and inorganic matter cause water to be turbid. Turbidity downstream of urban areas was higher than upstream and this is due to river bank cultivation, sand mining and construction activities close to the river. Deforestation in Zomba Mountain, soil disturbance at agricultural estates and rice farming activities may also have contributed to increasing turbidity in the water in sampling points SP2 to SP7.Turbidity in general increased in the wet season compared to the dry season at all sampling points.

During wet season, turbidity increased due to runoff carrying silt and organic matter. During the wet season, all points except SP1 exceeded the WHO and MBS standards. For the period of the wet season, turbidity was lowest in SP1 (2.35 NTU) and highest in SP7 (190.5 NTU). At SP1, tree cover and lack of human settlements makes the water less turbid, while at SP7, pollution loads of all rivers that flow into Lake Chilwa gets accumulated contributing to increased turbidity (Chavula, 1999). Turbidity was higher (92.9 NTU) downstream of agricultural estates as compared to upstream (54.95 NTU) and downstream of rice farms. Highly turbid water is unfit for domestic use, is aesthetically unappealing, cause unpleasant taste and odours (Health Canada, 2003), can clog fish gills (Yen and Rohasliney, 2013) and can clog drip irrigation equipment (DWAF 1996). High turbidity found close to Lake Chilwa, is conducive to the propagation of *Vibrio cholerae* (Saka, 2006).

Table 12: Mean values of seven physical parameters in the water samples at sampling locations in both dry and wet seasons

Sampling point (SP)	**Turbidity NTU Dry season**	**Turbidity NTU Wet season**	**pH Dry season**	**pH Wet season**	**E. conductivity µs/cm Dry season**	**E. conductivity µs/cm Wet season**	**TDS mg/l Dry season**	**TDS mg/L Wet season**	**Total hardness mg/L Dry season**	**Total hardness mg/L Wet season**	**Total alkalinity mg/l Dry season**	**Total alkalinity mg/L Wet season**	**Suspended solids mg/L Dry season**	**Suspended solids mg/L Wet season**
SP1	0.57±0.005	2.35±0.05	7.43	6.90	40.00	4.00	20.00	2.00	59.69±0.105	38.19±0.81	39.99±0.03	21.47±0.12	23.50±0.50	126.67± 89.57
SP2	13.05±0.005	627±1	7.70	7.20	130.00	46.00	65.00	23.00	160.42±0	61.38±0.04	86.89±0.03	41.21±0.03	71.50±0.50	2423.67±256.48
SP3	6.39±0.005	54.95±0.95	8.05	7.40	140.00	51.00	70.00	25.50	136.13±0.02	49.75±0.07	80.22±0.92	36.66±0.06	55.50±0.50	86.67±61.28
SP4	15.60±0.01	92.95±0.05	7.69	7.10	140.00	56.00	70.00	28.00	125.00±0	50.35±0.04	91.01±0.12	41.60±0.98	33.50±0.50	126.67±89.57
SP5	9.20±0.005	104.50±0.5	8.15	7.40	140.00	56.00	70.00	28.00	127.50±0.21	47.14±0.09	116.15±0.07	52.28±0.31	96.50±0.50	233.33±164.99
SP6	16.26±0.03	141.50±0.5	7.16	7.20	170.00	68.00	85.00	34.00	131.25±0.21	63.55±0.23	108.28±0.06	52.80±0.03	133.00±1.00	186.67±132.25
SP7	92.40±0.005	190.50±0.5	9.22	8.00	3520.00	466.00	1760.00	233.00	174.00±0.02	95.50±0.09	880.83±0.13	218.72±0.82	61.50±0.50	586.67±416.84
WHO Standard	5	5	6.5-8.5	6.5-8.5	Not available	Not available	Nh	Nh	*	*	Not available	Not available	15	15
MBS	25	25	5-9.5	5-9.5	Not available	Not available	450-1000	450-1000	Not available	Not available	Not available	Not available	50	50

All values are Mean values ± Standard Deviation

Nh: Not of health concern at levels found in drinking water * 0-75 soft water, 75-150 Moderately hard, 150-300 Hard, >300 Very hard

NTU Nephelometric Turbidity Unit TDS Total Dissolved Solids, Mg/l Milligrams per litre, MBS- Malawi Bureau of Standards

The pH was within MBS standards for all sampling points except at SP7, where pH exceeded WHO standards and water was alkaline during dry season (pH = 9.22). Total alkalinity had increased at SP7 to 880.83 mg/l during dry season, while in wet season it was 218.72 mg/l. This could be due to dilution from increased runoff during rains, which contributed to reduced alkalinity in the wet season. Total dissolved solids (TDS) were higher in dry season at all sampling points as compared with wet season and this could be attributed to dilution effect from increased runoff and rainwater.

Both conductivity and TDS were increased downstream of urban areas as compared to upstream, due to soil disturbance from river bank cultivation, sand mining and construction close to the river in urban areas. The highest values of conductivity and TDS were found at SP7 which is attributed to pollution accumulated at Lake Chilwa from all rivers that flow into it.

The electrical conductivity varied from 4 to 3520µs/cm during dry season and from 40 to 466 during wet season. For all sampling points, E. conductivity was low during wet season as compared with the dry season. The plausible explanation to this could be total dissolved solids variation in a corresponding manner from 20 to 1760 mg/l during dry season and from 2 to 233 mg/l during wet season.

SP3, SP4 and SP5 did not demonstrate large differences in TDS and E. Conductivity values between the sampling points, while SP6 and SP7 increased in values for these parameters, with SP7 recording the highest values of E. The Conductivity during the dry season was 3520.00 µs/cm and in the wet season it was 466.00 µs/cm, while TDS values in the dry season was 1760.00 mg/l and in the wet season it was 233.00 mg/l. During dry season, water was soft at SP1, hard at SP2, moderately hard at SP3, 4, 5 and 6, and hard at SP7 while during wet season, the water was soft at SP1 to SP6, while moderately hard at SP7 (Table 12).

4.4.2 Cationic pollution within Likangala River Catchment

Calcium concentrations at all the sampling points were within the MBS and WHO standards during both dry and wet seasons. The calcium ion concentration was low at SP1 (0.81 mg/L during dry season and 0.43 mg/L during wet season) where anthropogenic activities were less as compared to other sampling points. The highest concentrations of calcium ions were recorded at SP7 (27.71 mg/L in dry season and 18.89 mg/L in wet season) where pollution loads accumulate. Largely, during the wet season, calcium concentrations were lower than during the dry season at all sampling points due to dilution from runoff and rain water (Natkhin *et al.*, 2013).

Magnesium ion concentrations were within the MBS standards for all sampling points. During the wet season, Magnesium ion concentrations were less than during the dry season for all sampling points and the values ranged from 0.11 mg/L to 11.06 mg/L. Similarly at SP7, where pH was 9.22 in the dry season and 8.00 in wet season, magnesium ion concentration was found to be highest with 11.00 mg/L in dry season and 7.58 mg/L in wet season. The values of magnesium downstream of urban areas were higher than upstream indicative of increased solubility due to pH having increased downstream of urban areas. However, all sampling points were within the MBS standards for magnesium ion concentration.

Hardness of water is caused by calcium and magnesium salts. Generally, hardness was reduced at all sampling points during wet season compared to the dry season and this can be attributed to dilution of $CaCO_3$ concentrations due to increased runoff during the wet season. Less anthropogenic activities and less soil disturbance explains the good quality of water at SP1, while the impact of urban pollution through sewage disposal in the river may have contributed to the increased hardness at SP2. Accumulation of pollution loads explains the increase in hardness at SP7.

All sampling points were within WHO and MBS standards for sodium ion concentration except for SP7 which registered 499.75 mg/L during the dry season. However, during the wet season the value at SP7 was 85.07 mg/L which was within the standards, due to increased runoff, leaching and dilution. Sodium ion concentrations increased from 5.35 mg/L upstream of urban areas to 16.05 mg/L downstream of urban areas during the dry season and from 0.86 mg/l upstream of urban areas to 2.83 mg/L downstream of urban areas during the wet season. Sodium ion concentrations were higher than standards at SP7 during the dry season indicative of accumulated pollution loads at the lake. Sodium ion contributes to hardness of water and water with high sodium cation concentrations may affect irrigation (Saksena *et al.,* 2008) and cause negative health impacts if water is used for drinking and these include hypertension and cardiovascular and renal diseases (DWAF, 1996).

Table 13: Mean values of five major cations at the sampling locations during both wet and dry seasons

Sampling point (SP)	**Ca^{2+} mg/L Dry season**	**Ca^{2+} mg/L Dry season**	**Mg^{2+} mg/L Dry season**	**Mg^{2+} mg/L Wet season**	**Na^{+} mg/L Dry season**	**Na^{+} mg/L Wet season**	**Fe^{2+} Mg/L Dry season**	**Fe^{2+} Mg/L Wet season**	**K^{+} mg/L Dry season**	**K^{+} mg/L Wet season**
SP1	0.81±0.01	0.43±0	0.44±0.02	0.11±0	5.35±0.05	0.86±0.01	0.50±0	0.41±0	0.60±0	0.56±0
SP2	10.47±0.01	10.38±0.08	3.88±0	2.70±0.02	16.05±0.05	2.83±0.01	4.05±0.05	3.37±0.15	3.02±0	2.68±0.01
SP3	10.74±0.005	4.47±0.01	4.94±0.035	1.87±0.02	14.55±0.05	3.74±0.02	1.50±0	0.77±0.02	3.43±0.005	1.22±0
SP4	10.20±0.005	5.58±0.03	4.16±0.005	2.22±0.03	17.05±0.05	4.03±0	1.48±0.005	0.83±0.04	3.86±0.01	1.39±0
SP5	9.83±0.005	5.27±0.05	4.31±0.01	2.20±0.03	15.75±0.05	3.96±0.01	1.37±0.005	0.84±0.04	3.62±0.01	1.23±0
SP6	13.63±0.005	6.46±0.03	5.82±0.02	2.56±0.02	15.55±0.05	4.33±0.01	2.05±0.05	1.37±0.08	4.34±0.01	1.44±0
SP7	27.71±0.01	18.89±0.06	11.06±0	7.58±0.05	**499.75±0.25**	85.07±0.26	2.14±0	1.55±0.08	41.36±0.01	7.97±0.03
WHO Standards	100–300*	100–300*	NA	NA	NA. *200	NA. *200	NA	NA	NA	NA
Malawi Bureau Standards	80-150	80-150	30-70	30-70	100–200	100–200	0.01-0.20	0.01-0.20	25-50	25-50

*Taste threshold value, All values are Mean values ± Standard Deviation, NA Not Available, Mg/l Milligrams per litre

Iron concentrations increased from 0.50 mg/L upstream to 4.05 mg/L downstream of urban areas during dry season and 0.41 mg/L upstream to 3.37 mg/L downstream of urban areas during the wet season (Table 14). Potassium ion concentrations had increased from 0.60 mg/L upstream of urban areas to 3.02 mg/L downstream of urban areas during dry season and from 0.56 mg/L upstream of urban areas to 2.68 mg/L downstream of urban areas during wet season. Higher concentrations were recorded at SP7 where potassium concentration was 41.36 mg/L during dry season and 7.97 mg/L during wet season. Increased potassium ion concentrations were also noted downstream of rice farms from 3.62 mg/L to 4.34 mg/L upstream of rice farms during dry season and 1.23 mg/L to 1.44 mg/L during the wet season respectively. In the study area, sewage pollution and runoff from irrigated lands appear to be the cause of increased potassium ion concentrations downstream of urban areas. Urine has high concentration of potassium and disposal of sewage may contribute to this increase (Saksena *et al.,* 2008). Downstream of rice farms and at Lake Chilwa, high potassium concentrations were noted and this is attributed to manure usage at rice farms and accumulated pollution loads at the outflow into the lake. During the wet season potassium values increased downstream of farms and this may be due to runoff from fertilizers. However, it should be noted that all values of potassium ion and sodium ion were within the MBS standards (Table 13).

4.4.3 Major anion pollution within Likangala River catchment

The major anions bicarbonate, chloride, sulphate, phosphate and nitrates were analysed by calculating the means of both dry and wet season values and results are provided in Table 14.

The bicarbonate ion concentrations increased downstream of urban areas, downstream of agricultural estates and at the Lake. Chloride ion concentrations were within WHO and MBS standards at all sampling points except SP7 where chloride ion concentrations were 689.59 mg/L during the dry season and 105.19 mg/L during the wet season. An increase in bicarbonate ion concentrations downstream of urban and agricultural estates could be due to oxidation of organic matter which increases bicarbonates concentrations (Wanda *et al.* 2012). The high chloride concentrations found at Lake Chilwa may be due to accumulated pollution loads and possibly underground hot springs which are sources of minerals that may contain chloride (Chidya *et al.* 2011).

Table 14: Mean values of six major anions at the sampling locations during both wet and dry seasons

Sampling point (SP)	**HCO_3^- Mg/L Dry season**	**HCO_3^- Mg/L Wet season**	**Cl^- Mg/L Dry season**	**Cl^- Mg/L Wet season**	**SO_4^{2-} Mg/L Dry season**	**SO_4^{2-} Mg/L Wet season**	**NO_3^- Mg/L Dry season**	**NO_3^- Mg/L Wet season**	**PO_4^- Mg/L Dry season**	**PO_4^- Mg/L Wet Season**
SP1	39.98±0.03	21.47±	50.189±0.02	9.90±0.04	4.86±0.05	4.60±0	1.01±0.01	1.08±0	0.18±0.01	1.55±0.03
SP2	86.89±0.03	41.21±	58.93±0	20.45±0.43	17.92±0.05	5.81±0.05	1.58±0	1.89±0.01	0.23±0.01	1.52±0
SP3	80.22±0.92	36.66±	60.55±0.02	16.79±0.60	18.02±0.05	7.39±0.05	2.27±0	1.85±0	0.21±0.01	1.48±0.01
SP4	91.01±0.12	41.60±	53.85±0.04	17.08±0.11	20.02±0.05	25.07±0.05	2.62±0	2.47±0	0.26±0.01	1.62±0
SP5	116.15±0.07	52.28±	60.47±0.02	18.89±0.07	19.86±0.11	22.49±0.11	2.77±0	1.05±0	0.21±0.01	1.62±0.01
SP6	108.28±0.06	52.80±	53.07±0.18	17.00±0.04	18.18±0.11	8.50±0.05	1.40±0	0.80±0	0.20±0	1.44±0
SP7	726.63±0.73	200.51±	689.59±0.89	105.19±1.53	42.76±0.16	18.99±0.05	27.36±0.03	8.26±0.01	1.35±0.01	1.93±0.02
WHO Standards	NA	NA	NA, *250	NA, *250	NA. *500	NA. *500	50 for short term exposure	50 for short term exposure	NA	NA
MBS Standards	NA	NA	100–200	100–200	200–400	200–400	6-10	6-10	NA	NA

*Taste threshold , All values are Mean values ± Standard Deviation, N A Not Available , Mg/l Milligrams per litre, MBS- Malawi Bureau of Standards

Sulphate ion concentrations increased downstream of urban areas in SP2, although their concentrations were within MBS and WHO standards at all sampling locations. Sulphates increased at SP2 due to domestic and sewage waste and have a tendency to accumulate in concentrations in water thereby affecting palatability and imparting a bitter taste to water (Irenosen *et al.* 2012). Iron concentrations were above MBS standards for all sampling points indicating that there is iron pollution in Likangala River.

The r effluent from the wastewater treatment plant, domestic waste, hospital waste and small industries may have contributed to an increase in iron concentrations in the river downstream of urban areas.

Nitrate ion concentrations were within MBS and WHO standards except for SP7 where nitrates average concentrations of 27.36 mg/L were recorded during dry season which was higher than permitted the MBS highest level of 10mg/L. Phosphate ion concentrations increased at all sampling points during the wet season compared to the dry and recorded the highest values at SP7. This is indicative of accumulation of pollution at the Lake due to agricultural practises around the Lake Chilwa Basin contributed from runoff into the Lake. During the rainy season, values of nitrate were reduced at Lake Chilwa due to leaching of nutrients and intake of nitrates by phytoplankton and bacteria.

Phosphates increased downstream of urban areas and agricultural estates. This is suggestive of urban pollution from households and runoff from fertilizers in agricultural estates. Excessive phosphates in water have harmful implications if water is used for recreation and domestic use, as intake of water with high phosphate concentrations may cause osmotic stress, kidney damage and osteoporosis (Arnscheidt *et al.*, 2007, Irenosen *et al.*, 2012).

4.4.4 Levels of faecal coliform and Escherichia coli

Levels of faecal coliform and *Escherichia coli* within the study area were calculated and the mean values for dry and wet season are given in Table 15. Total faecal coliforms and *E. coli* concentrations were above the MBS and WHO standards for all sampling points. The lowest values were found at SP1 and the highest at SP2 compared with the other sampling locations. Faecal coliforms were 3 CFU/100ml during dry season at SP1 while during the wet season it was 4,000 CFU/100ml. At SP2, high bacteriological levels in the river were found with

20,000 CFU/100ml and 43,000CFU/100ml during dry and wet seasons respectively (Table 15).

Total Faecal Coliforms at SP1 at Williams Falls were found to be 3 CFU in dry season and 4 000 CFU in the wet season, although there are no human settlements upstream of the sampling point. However, field observations revealed that women and youth gather firewood from forests above William's Falls and spend several hours collecting firewood and may defecate at the upstream areas as there are no sanitation facilities available there. Furthermore, horses carrying tourists also frequently walk around this area and may also have contributed to the release of faecal matter. The high faecal coliforms at SP2 could be due to the raw sewage or partially treated sewage being discharged into the river (since the Zomba wastewater treatment works is overloaded due to population increase) and also runoff and sub-surface flow from the urban area. Sewage pollution of rivers in urban areas due to incomplete wastewater treatment has been reported in other countries such as in the Pinheiros River in Sao Paulo, Ganges River in India and the East River (Dongjiang) in Hong Kong (Jamu *et al.,* 2003; Ho et al., 2003; Hamner *et al.*, 2006; Abraham, 2010).

Table 15: Mean values of faecal coliform and *Escherichia coli* at the sampling points during both wet and dry seasons

Sampling point (SP)	**Total Faecal Coliforms CFU /100ml Dry season**	**Total Faecal Coliforms CFU/100ml Wet season**	***Escherichia coli*** **Dry season CFU/100ml**	***Escherichia coli*** **Wet season CFU/100ml**
SP1	3	4 000	0	1 000
SP2	20 000	43 000	7 000	7 000
SP3	13 000	12 000	2 500	2 500
SP4	3 500	53 000	9 000	9 000
SP5	970	14 000	3 000	3 000
SP6	300	26 000	7 000	7 000
SP7	570	16 000	2 000	2 000
WHO standards	0	0	0	0
MBS	0-50	0-50	0	0

Notes: CFU Colony Forming Units, ml Millilitres

Household sewage, livestock dung and open defecation may have contributed to coliforms in the sampling points SP3 to SP7. The farmers interviewed at Likangala Rice Irrigation Scheme reported that they use compost and manure while growing rice, which could also contribute to coliform contamination of the river. Furthermore, Chavula and Mulwafu (2007) noted that since there are no sanitation facilities and farmers work all day in their fields they are assumed to defecate in the fields. Communities reported of water borne diseases in the Likangala River Catchment. This was confirmed by studies reporting dysentery (Jamu *et al.,* 2005), bilharzia and scabies (Mulwafu and Nkhoma 2003, Chidya *et al.*, 2011) in the Likangala River Catchment, and a cholera outbreak which occurred from May 2009 to May 2010 in fishing communities around Lake Chilwa (Khonje *et al.,* 2012).

The presence of total coliforms and *E. coli* indicates that the water is not fit for drinking due to faecal contamination of the water. Communities along SP1 to 6 do not use river water for drinking, but those at SP7, in particular the fishing communities, reported that they do use the water for drinking. Observation at Lake Chilwa especially on Chisi Island revealed that communities use the Lake water for drinking by treating the water using *Moringa oleifera* leaves. The *Moringa oleifera* leaves are a natural coagulant and allow for the settling of contaminating wastes (Manning *et al.*, 2014). These communities reported that they are forced to use the Lake water for domestic and drinking purposes as boreholes on Chisi Island were reported to be highly saline.

Impact of urban areas on water quality

In order to find the differences in water quality upstream and downstream of urban areas, water quality impacts of urban area was analysed by comparing SP1 and SP2, where SP1 was upstream of an urban area (Zomba city) and SP2 was downstream of it. T-test of the mean differences was done for the parameters analysed and percentage change in water quality calculated (Table 16). Although all parameters had increased in percentage downstream of the urban areas compared to upstream; pH, calcium and potassium were the parameters which had increased significantly at 5% *p*-value. Calcium and magnesium ions are found naturally and are alkaline earth metals. Calcium and Magnesium in water contribute to hardness of water. Calcium concentrations had increased by 177.55% downstream at a *p*-value of 0.009. While magnesium ion concentrations increased by 169.14% at *p*-value of 0.089.

Table 16: Upstream and downstream impacts of urban areas

Parameters	**Units**	**Upstream of urban (SP1)**	**Downstream of urban (SP2)**	**Mean difference (Upstream-Downstream)**	**Difference in means Downstream - upstream as a %**	**t-stat** Significance (2 tailed)
Ph		**7.16±0.37**	**7.45±0.35**	**-0.31**	**3.9**	**0.033***
Temperature	^{0}C	17.45±2.47	24.25±0.92	-6.80 ±3.39	32.61	0.216
Turbidity	NTU	1.45 ±1.25	320.02±434.13	-318.50±432.87	198.19	0.487
Bicarbonates	Mg/l	30.72±13.08	64.05±32.30	-33.32	70.32	0.246
Carbonates	Mg/l	0	0	0	0	
Total Alkalinity	Mg/l	30.73±13.09	64.05±32.30	-33.32±19.21	70.31	0.246
Total Hardness	Mg/l	48.94±15.20	110.90±70.03	-61.96 ±54.83	77.53	0.356
Suspended Solids	Mg/l	75.08±72.95	1247.60±1663.24	-1172.00±1590.28	177.29	0.487
Chlorides	Mg/l	30.04±28.48	39.69±27.21	-9.65±1.27	27.67	0.059
Fluoride	Mg/l	0	0	0	0	
Nitrates	Mg/l	1.05±0.05	1.74±0.22	-0.69±0.17	49.42	0.11
Phosphates	Mg/l	0.87±0.98	0.88±0.91	-0.01±0.06	1.08	0.93
Sulphates	Mg/l	4.73±0.18	11.87±8.56	-7.14±8.38	85.93	0.441
Electrical Conductivity	µs/cm	22.0±25.46	88.00±59.40	-66.00±33.94	120	0.222
Total Dissolved Solids	Mg/l	12.5±14.85	42.50±31.82	-30.00±16.97	120	0.242
Silicon Dioxide	Mg/l	0	0	0		
Iron	Mg/l	0.46±0.64	3.71±0.48	-3.26±0.42	156.3	0.058
Calcium	Mg/l	**0.62±0.27**	**10.43±0.06**	**-9.81±0.21**	**177.55**	**0.009***
Magnesium	Mg/l	0.28±0.23	3.29±0.83	-3.02±0.60	169.14	0.089
Potassium	Mg/l	**0.58±0.03**	**2.85±0.24**	**-2.27±0.21**	**132.36**	**0.042***
Sodium	Mg/l	3.11±3.17	9.44±9.35	-6.34±6.17	101.02	0.384
Total Faecal Coliforms	CFU/ 100ml	2001.5±2826.31	31500.0±16263.46	-29490.0±13437.15	176.1	0.198
E. coli	CFU/ 100ml	500.0±707.11	4150.0±4030.51	-3650.0±3323.40	156.99	0.364

* Significance *p*-value = 0.05

Total hardness also increased downstream of urban areas by 77.53%. Hard water causes impaired lathering of soap and communities who use the Likangala River for washing experience this. Furthermore, it affects taste for livestock and other animals that drink this water.

Potassium is an alkali metal and occurs in water in association with anions such as chloride, but can also occur with sulphate, bicarbonate, or nitrate. Potassium concentrations revealed significant increase (0.042 *p*-value) downstream of urban areas and this could be due to domestic wastes, runoff from irrigated lands being released into the water. Since there is household waste, sewage and hospital waste being discharged into the river , this could be the most likely reason for potassium concentrations to increase by 132.36% downstream of urban areas. This was in agreement with an earlier study by Chidya *et al.* (2011) who recorded increase in potassium concentrations in urban areas in the Likangala River. Urine has high concentration of potassium, and disposal of sewage may be the main contributor to the potassium concentrations to increase.

Fluoride and silicon dioxide values were below detection levels.

Impact of agricultural estates on water quality

There are four large estates in the Likangala catchment area where tobacco, cotton and maize are grown. A *t*- test analysis was done to determine significant parameters that changed downstream of the agricultural estate at SP4. SP3 was located at Likangala Bridge upstream of one estate and SP4 was at Mindano Village downstream of the estate. Statistical analysis (*t*-test for significance) results are given in Table 17. The values of several parameters increased downstream including turbidity (increased by 55.58%), sulphates (increased by 55.85%), total faecal coliforms (increased by 77.30%) and *E. coli* (increased by 98.32%). Nitrates increased by 21.03% and phosphates by 10.34%, although they were not significant at 5% *p* –value.

The increase in these parameters is indicative of runoff from the use of chemical used in agricultural activities. Increase in coliforms may be due to use of organic fertilizers such as animal dung and open defecation in these areas. Use of water which contains coliforms for drinking or domestic purposes may be risky to human health, as diarrhoea and dysentery may be triggered.

Table 17: Upstream and downstream impacts of Estates

Parameters	**Units**	**Upstream of Estate (SP3)**	**Downstream of Estate (SP4)**	**Mean difference (Upstream-Downstream)**	**%Change in quality**	**t-stat**
					Difference in means Downstream - upstream as a %	Significance (2 tailed)
Ph		7.73±0.46	7.39±0.42	0.33±0.04	-4.37	0.06
Temperature	^{0}C	25.55±0.92	24.50±0.14	1.05±1.06	-4.20	0.40
Turbidity	NTU	30.67±34.34	54.28±54.69	-23.6+-20.36	55.58	0.35
Bicarbonates	Mg/l	58.44±30.80	66.31±34.94	-7.87+-4.14	12.62	0.23
Carbonates	Mg/l	0	0	0		
Total Alkalinity	Mg/l	58.44±30.80	66.31±34.94	-7.87±4.14	12.62	0.23
Total Hardness	Mg/l	92.94±61.08	87.68±52.79	5.27±8.29	-5.83	0.53
Suspended Solids	Mg/l	71.09±22.04	80.09±65.88	-9+-43.84	11.91	0.82
Chlorides	Mg/l	38.67±30.94	35.47±26.00	3.21±4.94	-8.65	0.53
Nitrates	Mg/l	2.06±0.29	2.55±0.11	-0.49+-0.19	21.03	0.17
Phosphates	Mg/l	0.85±0.91	0.94±0.96	-0.09+-0.06	10.34	0.27
Sulphates	Mg/l	12.71±7.52	22.55±3.57	-9.84+-11.09	55.85	0.43
Electrical Conductivity	µs/cm	95.50±62.93	98.00±59.39	-2.5+-3.54	2.58	0.50
Total Dissolved Solids	Mg/l	47.75±31.47	49.00±29.69	-1.25+-1.77	2.58	0.50
Iron	Mg/l	1.14±0.52	1.16±0.46	-0.02+-0.06	1.53	0.71
Calcium	Mg/l	7.61±4.43	7.89±3.27	-0.29+-1.17	3.68	0.79
Magnesium	Mg/l	3.41±2.17	3.19±1.37	0.22±0.79	-6.53	0.77
Potassium	Mg/l	2.33±1.56	2.63±1.75	-0.3+-0.18	12.23	0.26
Sodium	Mg/l	9.15±7.64	10.54±9.21	-1.39±1.56	14.18	0.43
Total Faecal Coliforms	CFU/ 100ml	12500.00±707.11	28250.00±35001.79	-15750+-35708.89	77.30	0.65
E. coli	CFU/ 100ml	1585.00± 1294.01	4650.00± 6151.83	-7922.82	98.32	0.54

* Significance *p*-value = 0.05

Impact of small rice farms on water quality

There are a number of small rice farms and few sugarcane farms between SP5 (Chirunga Village) and SP6 (close to Mwambo Village). The *t*-test of significance was done between SP5 and SP6 to see if there are any significant parameters that changed due to the small rice farms and the sugarcane farms. The results are given in Table 18.

Table 18: Upstream and downstream impacts of small rice farms

Parameters	**Units**	**Upstream of Rice farms (SP5)**	**Downstream of Rice farms (SP6)**	**Mean difference (Upstream-Downstream)**	**%Change in quality**	**t-stat**
					Difference in means Downstream - upstream as a %	Significance (2 tailed)
Ph		7.78±0.53	7.18±0.03	0.59±0.56	-7.96	0.37
Temperature	^{0}C	25.40 ±0.42	27.95 ±0.78	-2.55+-0.35	9.56	0.06
Turbidity	NTU	56.85 ±67.39	78.88 ±88.56	-43.2	32.46	0.38
Bicarbonates	Mg/l	84.22 ±45.16	80.54 ±39.23	3.68± 5.93	-4.46	0.54
Carbonates	Mg/l	0	0	0		
Total Alkalinity	Mg/l	84.22 ±45.16	80.54 ± 39.23	3.68 ±5.93	-7.02	0.54
Total Hardness	Mg/l	87.32 ±56.82	97.40 ±47.87	-19.03	2.90	0.36
Suspended Solids	Mg/l	164.92 ±96.75	159.83 ±37.95	5.08 ±58.80	31.81	0.92
Chlorides	Mg/l	39.68 ±29.40	35.04 ±25.51	4.65 ±3.89	-12.42	0.34
Fluoride	Mg/l	0	0	0		
Nitrates	Mg/l	1.91 ±1.22	1.10 ±0.42	0.81 ±0.79	-53.73	0.39
Phosphates	Mg/l	0.92 ±0.99	0.82 ±0.88	0.10 ±0.11	-11.12	0.43
Sulphates	Mg/l	21.18 ±1.86	13.34 ±6.84	7.84 ±8.70	-45.41	0.42
Electrical Conductivity	µs/cm	98.00 ±59.39	119.00 ±72.12	-21±12.73	19.35	0.26
Total Dissolved Solids	Mg/l	49.00 ±29.69	59.50 ±36.06	-10.5±6.36	19.35	0.26
Silicon Dioxide	Mg/l	0	0	0		
Iron	Mg/l	1.105 ± 0.37	1.71 ±0.48	-0.61±0.11	43.20	0.08
Calcium	Mg/l	7.55 ± 3.22	10.05 ± 5.07	-2.49±1.85	28.37	0.31
Magnesium	Mg/l	3.26 ± 1.49	4.19 ± 2.31	-0.94±0.81	25.12	0.35
Potassium	Mg/l	2.43 ± 1.69	2.89 ± 2.05	-0.47±0.36	17.50	0.32
Sodium	Mg/l	9.86 ± 8.34	9.94 ± 7.93	-0.09 ± 0.40	0.83	0.82
Total Faecal Coliforms	CFU/ 100ml	7485.00 ± 9213.60	13150.00 ± 18172.65	-5665.00 ± 8959.04	54.91	0.54
E. coli	CFU/ 100ml	1585.00 ±2001.11	3515.00 ± 4928.53	-1930+-2927.42	75.69	0.52

* Significance *p*-value = 0.05

No parameters increased significantly downstream of small rice farms. However, total faecal coliforms increased by 54.91% and *E. coli* increased by 75.69% this was indicative of the use of organic fertiliser, livestock dung and open defecation. Farmers worked in the rice farms all day and did not have access to sanitation facilities, as reported by communities during focus group discussions. Nitrates, phosphates and sulphate concentrations declined by 53.73%, 11.12% and 45.41% respectively, indicating uptake of these nutrients by crops.

Impact on water quality of Lake Chilwa

A number of rivers flow into Lake Chilwa, five from Malawi and one river from Mozambique. It may be assumed that runoff from these rivers will impact on Lake Chilwa's water quality. The impact of the rivers flowing into Lake Chilwa is determined by comparing SP6 which is at Likangala River before its confluence into Lake Chilwa and SP7 is at Kachulu, Lake Chilwa.

Table 19 shows that Calcium and Magnesium concentrations increased significantly at SP7 (Lake Chilwa). Calcium and Magnesium concentrations contribute to the hardness of water. Mean hardness at SP6 was 97.40 which is "moderately hard" and at Lake Chilwa it was 549.78, which is "very hard", according to WHO (1999). Hard water impairs lathering of soap when water is used for washing as is the case with water from Lake Chilwa for communities living along its shores and also on Chisi Island located within the Lake. Total faecal coliforms and *E. coli* reduced at SP7 (Lake Chilwa) presumably due to dilution effect.

Electrical conductivity increased by 177.46%, total dissolved solids by 177.46% (as electrical conductivity estimates the total amount of solids dissolved in water), nitrates by 176.69%, chlorides by 167.59%, total alkalinity by 148.89%, potassium by 158.05% and sodium by 186.85%. It is to be noted that Lake Chilwa receives water from a number of rivers in addition to the Likangala and therefore there are accumulated pollution loads in this lake. Some dilution effect may have contributed to decrease in total faecal coliforms and *E.coli* in the lake by 45.39% and 110.38% respectively.

The foregoing review confirms that urban areas, in particular Zomba City significantly contributes to pollution of the Likangala River and the pollution load at Lake Chilwa is high.

Table 19: Impact on Lake Chilwa

Parameters	Units	Upstream of Lake (SP6)	At the Lake (SP7)	Mean difference (Upstream-Downstream)	%Change in quality	t-stat
					Difference in means Downstream - upstream as a %	Significance (2 tailed)
Ph		7.18 ± 0.028	8.61 ± 0.86	-1.43±0.89	18.11	0.26
Temperature	^{0}C	27.95 ± 0.78	28.90 ± 2.26	-0.95±1.48	3.34	0.53
Turbidity	NTU	78.88 ± 88.56	141.45 ± 69.37	-62.57±19.19	56.80	0.14
Bicarbonates	Mg/l	80.54 ± 39.23	463.57 ± 372.02	-383±332.79	140.79	0.35
Carbonates	Mg/l	0 ± 0	86.21 ± 96.16	- 86.20 ± 96.16	200.00	0.43
Total Alkalinity	Mg/l	80.54 ± 39.23	549.78 ± 468.18	-469.2±428.95	148.89	0.37
Total Hardness	Mg/l	97.40 ± 47.87	134.75 ± 55.51	-37.35±7.64	32.18	0.09
Suspended Solids	Mg/l	159.83 ± 37.95	324.08 ± 371.35	-164.2±333.4	67.88	0.61
Chlorides	Mg/l	35.04 ± 25.50	397.39 ± 413.23	- 362.30 ± 387.73	167.59	0.41
Nitrates	Mg/l	1.10 ± 0.42	17.81 ± 13.51	-16.71±13.08	176.69	0.32
Phosphates	Mg/l	0.82 ± 0.88	1.64 ± 0.40	-0.83 ± 0.47	66.71	0.25
Sulphates	Mg/l	13.34 ± 6.84	30.87 ± 16.81	- 17.53 ± 9.96	79.31	0.24
Electrical Conductivity	µs/cm	119.00 ± 72.12	1993.00 ± 2159.50	- 1874.00 ± 2087.38	177.46	0.43
Total Dissolved Solids	Mg/l	59.50 ± 36.06	996.50 ± 1079.75	- 937.00 ± 1043.69	177.46	0.43
Iron	Mg/l	1.71 ± 0.48	1.85 ± 0.42	- 0.14 ± 0.06	7.59	0.21
Calcium	Mg/l	**10.05 ± 5.07**	**23.30 ± 6.24**	**- 13.25 ± 1.17**	**79.52**	**0.04***
Magnesium	Mg/l	**4.19 ± 2.31**	**9.32 ± 2.46**	**-5.13 ± 0.16**	**75.94**	**0.01***
Potassium	Mg/l	2.89 ± 2.05	24.67 ± 23.61	-21.77 ± 21.56	158.05	0.39
Sodium	Mg/l	9.94 ± 7.93	292.41 ± 293.22	-282.40 ± 285.29	186.85	0.40
Total Faecal Coliforms	CFU/ 100ml	13150.00 ± 18172.65	8285.00 ± 10910.66	4865.00 ± 7261.98	-45.39	0.52
E. coli	CFU/ 100ml	3515.00 ± 4928.53	1515.00 ± 2100.11	2000.00 ± 2828.43	-110.38	0.50

* Significance *p*-value = 0.05

4.4.5 Water Quality Index

The need for a simple tool to determine the health of water is addressed through the use of WQI. The WQI was calculated for all the seven sampling points and Q values for each of the parameters included in the index were calculated. Results are given in Table 20. Water quality indices for all seven sampling points ranged from 34.13 to 53.95% (Table 20). This indicates that the water is generally "medium" to "bad" quality and is polluted and unsuitable for direct human consumption without treatment. The water quality was better at SP1 and varied at the different sites and was worst at SP7. In addition, the results clearly indicate contamination of water in all sampling points from *E. coli*, nitrates and phosphates and there is a need to reduce turbidity of the water in order to improve the water quality rating.

Table 20: Water Quality Index

Sampling point (SP)	**Ph**	**Turbidity NTU**	**Total phosphates Mg/L**	**Nitrates Mg/L**	**E coli CFU/100ml**	**Water quality index %**	**Water quality rating**
SP1	7.165	1.46	0.87	1.045	500	53.95	Medium
Q value	91	93	21	72	25		
SP2	7.45	320.025	0.875	1.735	31500	42.4	Bad
Q value	92	5	21	59	6		
SP3	7.725	30.67	0.85	2.06	1585	50.93	Medium
Q value	90	52	22	52	18		
SP4	7.395	54.275	0.94	2.545	4650	46.4	Bad
Q value	92	37	20	49	12		
SP5	7.775	56.85	0.92	1.91	1585	48.87	Bad
Q value	89	35	20	56	18		
SP6	7.18	78.88	0.82	1.1	3515	50.41	Medium
Q value	91	25	22	70	52		
SP7	8.61	141.45	1.645	17.81	1015	34.13	Bad
Q value	69	5	11	3	21		

Turbidity, phosphates and nitrates increase due to poor agricultural practises such as river bank cultivation and runoff from fertilizers. High turbidity and *E. coli* in SP2 indicates pollution from the urban areas, where settlements are close to the river and sewage is discharged into the river system. The Lake Chilwa water quality was the worst of all sampling points with turbidity, nitrates, phosphates and *E. coli* all contributing to pollution of the lake. In addition there are other rivers that flow into Lake Chilwa which also adds to its pollution load.

4.4.6 Water quality and implications for provisioning ecosystem services

Communities interviewed reported that pollution in urban areas affected aquatic life which subsequently impacted on livelihoods. For instance, it was described that fishing has been negatively impacted due to water pollution emanating from the urban area where sewerage disposal systems are overwhelmed due to the growing population. Communities reported that fish life in the river at Mpondabwino was non-existent due to pollution from sewage disposal and waste from the hospital and households. Figure 28 shows high turbidity of water in areas where sand mining was practised and solid waste disposed at Mpondabwino in Zomba city.

It was also reported that previously water from the river was used for drinking and cooking, but due to the present state of the water, it is now only used for other domestic purposes such as washing, bathing and irrigation. It is evident that the poor water quality is affecting use of the water for communities as well as availability of fish. Thus, the presence of pollutants diminishes the ability of the Likangala River to provide clean water for various consumptive uses to the rural communities within the catchment. Further studies need to be undertaken to determine the impact of water pollution on aquatic life and human health.

Figure 28: Sand mining along Likangala River and solid waste disposal at Mpondabwino

4.4.7 Water quality implications for health

Communities reported that they were affected by many water borne diseases in the catchment. Along the shores of Lake Chilwa, water supply challenges force communities to use the water from the lake and there were a number of cholera cases reported. Cases of cholera and deaths in Zomba district are provided in Figure 29. It is noteworthy that all cases originated from Lake Chilwa and in 2012, the three deaths reported were also at Lake Chilwa amongst the fishermen (Chingaipe Pers. comm., 2013).

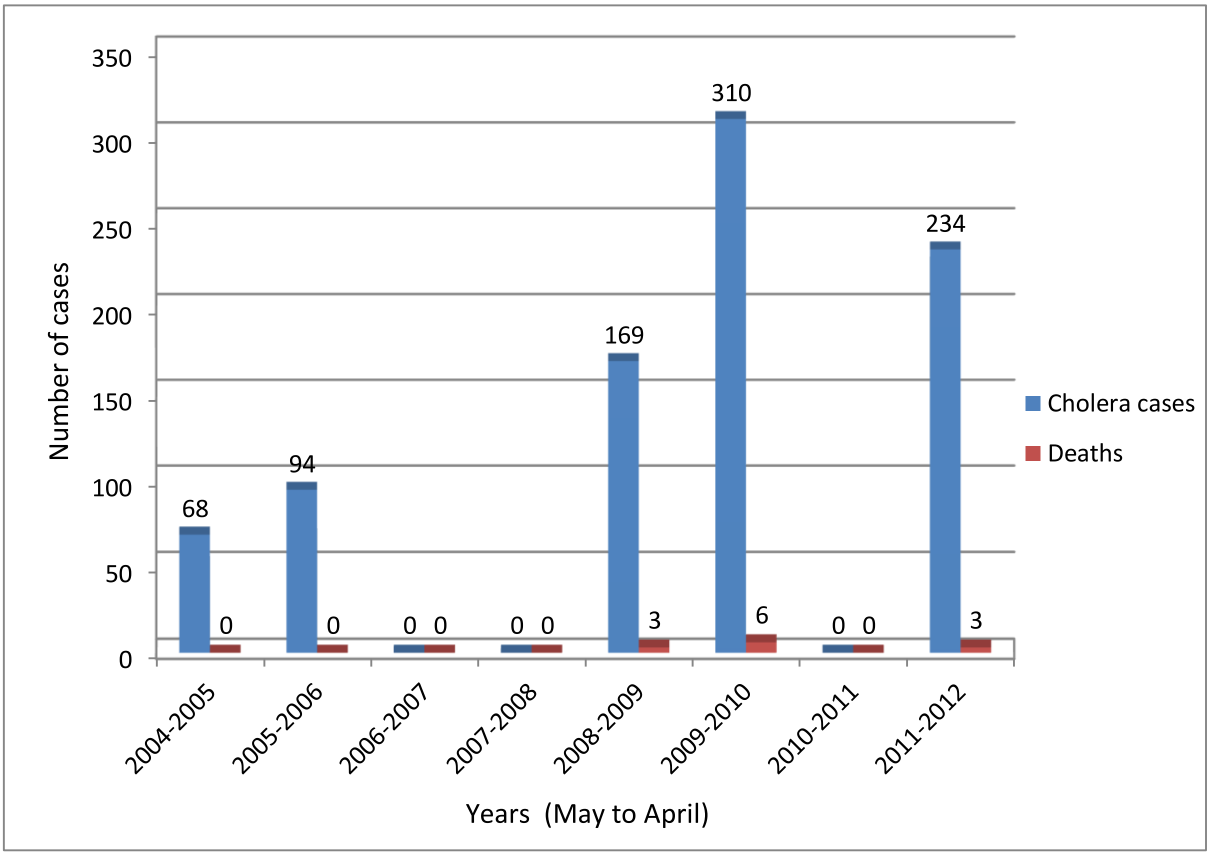


Figure 29: Cholera cases at Lake Chilwa from 2004-2012

(Source: Zomba District Health Office, 2013)

4.5 SUMMARY

This chapter discussed how land-use influenced the water quality of the Likangala River. This water was used for washing, irrigation, bathing and recreation at all sampling points, as revealed from discussions with community members and observations. Communities reported that they do not use the water for drinking or cooking at sampling points SP1 to SP6, however, at Lake Chilwa (SP7), some community members especially fishermen use the water for drinking. The pollution load was highest at the outflow of the river at Lake Chilwa, followed by downstream of urban areas, downstream of agricultural estates, upstream of rice farms, downstream of rice farms and upstream of agricultural estates. The pollution load was lowest upstream of urban area, which was forested and sparsely populated compared to other areas.

Field observations revealed that point source pollution at urban areas were from the Zomba Sewage Treatment works, Zomba Central Hospital and non-point sources of pollution in other areas from farmlands, small industries, sand mining, quarrying and households. In general most parameters worsened during the rainy season due to increased runoff which would carry impurities and silt.

WQI calculations showed that the water quality had registered bad quality downstream of urban areas (SP2), at downstream of agricultural estates (SP4), Chirunga village SP5 and at Lake Chilwa (SP7), while medium quality was for upstream of urban areas (SP1), upstream of agricultural estates (SP3) and at rice farms (SP6). This is indicative of urban pollution, pollution from estates, agricultural activities and accumulated pollution loads found at Lake Chilwa. The use of WQI as a single index which denotes health of the river water at various locations is useful in identifying pollution hotspots. This is a simple method that could be used by authorities in Malawi to determine the health of water bodies and does not need extensive analysis or large resources.

The results clearly indicate contamination of water in all sampling points from *E. coli*, nitrates, phosphates and there is a need to reduce turbidity of the water in order to improve the water quality. Faecal coliforms from livestock dung and open defecation contribute to total coliforms and *E.coli* concentrations. Turbidity, phosphates and nitrates increase due to poor agricultural practises such as river bank cultivation and runoff from fertilizers. High turbidity and *E. coli* in SP2 indicates pollution from urban areas, where settlements are close to the river and sewage may be discharged into the river. Lake Chilwa water quality was the worst of all sampling points with turbidity, nitrates, phosphates and *E. coli* all contributing to pollution of the lake. In addition, there are other rivers that flow into Lake Chilwa which also adds to its pollution load.

Pollution in Likangala River affects the use of water for drinking and cooking as well as aquatic life and thus provisioning ecosystem services of water and fish. This study revealed the linkages between systems of land-use and water quality, and therefore calls for a holistic approach to the management of this river. Water pollution has health implications and diseases such as cholera, dysentery, scabies and diarrhoea have been reported in this catchment. Localised flooding during the rainy season was reported by communities and this is worsening due to reducing tree cover in the catchment. The study found that water in Likangala River is generally unsuitable for consumption without treatment.

The results from the inventory and mapping of provisioning ecosystem services, land cover change, and water quality indicate the need for a holistic approach in management of this and similar ecosystems and this is covered in Chapter 5. .

CHAPTER 5

5 INTEGRATED APPROACH FOR ECOSYSTEM MANAGEMENT

5.1 INTRODUCTION

This study provided evidence that the Likangala River catchment is being degraded through anthropogenic activities of deforestation, pressure from agricultural land expansion, river bank cultivation, sand mining and unsustainable extraction of provisioning ecosystem services. This has affected provisioning ecosystem services such as medicinal plants, wood, wild foods and availability of construction materials such as sand. It has also affected water quality in a number of locations along the river. In order to manage this ecosystem, it is necessary to understand the causes (drivers, pressures) of change and their interactions and address them. Therefore, this chapter provides explanations of the components of DPSIR framework in the context of Likangala River catchment, thereby providing explanations of causes of change in this ecosystem. Responses are addressed through the integrated Population, Health and Environment (PHE) approach and highlight the importance of integrating indigenous knowledge into ecosystem management. Finally, a bottom-up approach on ecosystem management is recommended.

5.2 COMPONENTS OF DPSIR

5.2.1 Drivers

The population size affects and shapes the environmental quality (Hunter, 2001; Stern *et al.*, 1997). Literature (World Bank 2014, NSO 2008) and remarks from communities during focus group discussions have identified population growth as a major driver of ecosystem change in the Likangala River catchment. This growth stems from high fertility in the catchment with TFR=5.6, while wanted fertility rate is 4.2 (Wanted fertility rate is an estimate of TFR if all unwanted births were avoided), as well as influx of migrants into this productive ecosystem (Government of Malawi, 2010). The unmet need for family planning in the Zomba District where the Likangala River catchment is located was 29.4% (Government of Malawi, 2010). Another driver is poverty, predominantly due to natural resource dependent livelihoods. Malawi's purchasing-power-parity (PPP) per capita GDP is about USD 900 in 2013, which puts it in the bottom 10% of the world, making it one of the poorest countries in the world (World Bank, 2014). Poverty and natural resource dependence creates competition for provisioning ecosystem services, resulting in unsustainable extraction and degradative land-uses in this ecosystem. Poverty, coupled with demand for land to grow food, drives people to cultivate in marginal lands and biodiversity hotpots, such as forests, wetlands, river banks and hill slopes. Communities reported deforestation and deliberate setting of bush fires due to increased competition for forest resources driven by the population growth.

> *"The increase on population has caused deforestation and conflicts over land for agriculture*." Man in Mpyupyu, May 2013.

> *"The population of people has increased. This is due to migration of other people who come to look for Jobs at Kuchawe, hunting and to cut trees for timber".* Man at Williams Falls, Oct 2013.

> "*People who come to collect firewood and other resources from areas like Songani, Chinasanji village around Domasi cause bush fires*." Man at Zomba Mountain, May 2013.

Deforestation is linked to the demand for fuelwood, which is also a driver, since 94% of Malawians do not have access to electricity and depend on biomass for their cooking needs (Ruhiiga, 2012). Shortage of sand was also linked to increasing demand in the construction of dwellings for the increasing population.

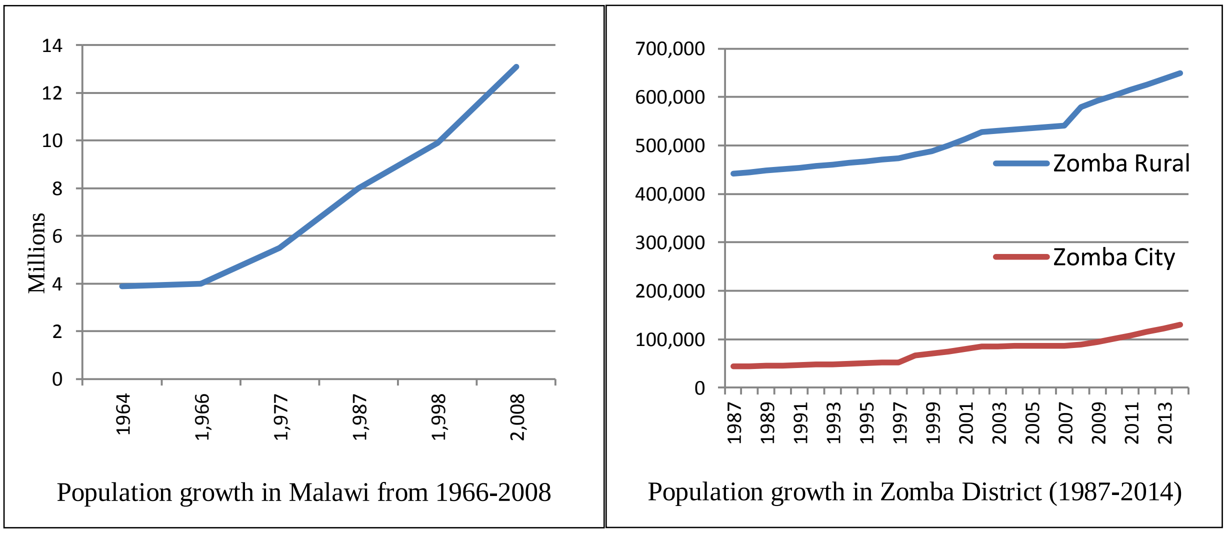
Early marriages were a contributing factor for increase in population in Malawi, as children married off as soon as they reach puberty have a longer reproductive period (Malawi Human Rights Commission, 2014). Anecdotes reveal that early marriages were linked to population growth and ensuing conflicts and competition for agricultural lands.

> "*High population is causing conflict over land for agriculture. This is due to early marriages*." Woman at Kachulu, Oct, 2013.

Unmet need for family planning is the inability of women to access family planning methods, due to cultural reasons or other reasons. This unmet need could be a reason for high fertility and thereby increasing populations. In this catchment, high fertility was reported as a contributing factor for population growth, as noted by the quote:

“The population has increased because of migration of people who come to search for jobs and high birth rates. A mother could give birth to 6 or 12 children”. Woman at Mpondabwino, May 2013.

Other drivers include urbanization, industries and their resultant wastes, which impact the ecosystem. In the Likangala River catchment, urban sprawl has been observed and there are a number of small industries. Industries and economic activities are also drivers of ecosystem change as they generate waste which is disposed into the ecosystem. Tourists who visit Zomba are interested in bird watching, horse riding, picnicking, walking on the nature trails, viewing orchids that grow on the plateau and enjoying the various landscapes and views on the mountain, which are part of cultural ecosystem services. Thus, tourism is also a driver of ecosystem change and impacts provisioning services, as tourists create demand for products derived from natural resources such as ornamental stones and flowers, wood carvings, which they buy as souvenirs. Demand for food due to the growing population is also a driver of ecosystem change. In order to meet this demand, agricultural farms expand into forested areas and marginal lands (Chapter 3 of this thesis).



Population growth in Malawi from 1966-2008

Population growth in Zomba District (1987-2014)

Figure 30: Population growth in Malawi and Zomba District

(Source: NSO, 2014)

5.2.2 Pressures

Another driver at the macro level is government policies on family planning as this has an impact on population growth. Malawi was ruled by a totalitarian regime for 30 years since its independence from the British in 1964. The regime did not promote family planning as it was considered to be a western concept. In 1992, Malawi's contraceptive prevalence rate (CPR) was 7.4%, while after multi-party democracy was established in 1994, CPR increased to 28% in 2004 (NSO and ORC, 2005) and in 2009 it was 39% (Population Reference Bureau, 2009). Therefore, the momentum of population growth had begun before democracy and so the population of Malawi increased from 3.88million in 1964 when the country got independence to 9.85million in 1994 at the beginning of multi-party democracy to 16.36million in 2013 (NSO, 2014; World Bank, 2014). In Zomba district, both urban and rural populations increased (Figure 30) driving ecosystem change. Environmental degradation has been increasing over the years as the population grew, as the majority of Malawi's population depend on natural resources for its livelihood (Government of Malawi, 2011).

As the population increases, the demand for cultivation creates pressure on land in the catchment. The type of agriculture practised also puts pressure on land. In this catchment, it is mostly rain-fed subsistence agriculture, which requires more land in order to produce more food for the growing population (Palamuleni *et al.*, 2010). This has ensued in cultivation on steep slopes, clearing of forests for farmlands and cultivation in wetlands and river banks. Increasing urban sprawl has put pressure on construction materials such as sand, stones and clay for brick making. This has given rise to land degradation through sand mining, quarries and extraction pits for clay, which affect the river catchment ecosystem functions including water quality.

The increasing population and poor health facilities have resulted in increasing pressure for medicinal plants. In addition, population growth puts pressure on water resources for domestic use and fuelwood for cooking in these rural communities. The lack of many alternative income generation activities puts pressure on natural resources through reliance for livelihood; for example through fishing, hunting of wild animals and birds, and gathering and extraction of non-food products. FAOSTAT (2014) data provides information on the increasing pressure for cultivated land (see Figure 31). Increasing cultivated land puts pressure on water resources for irrigation use.

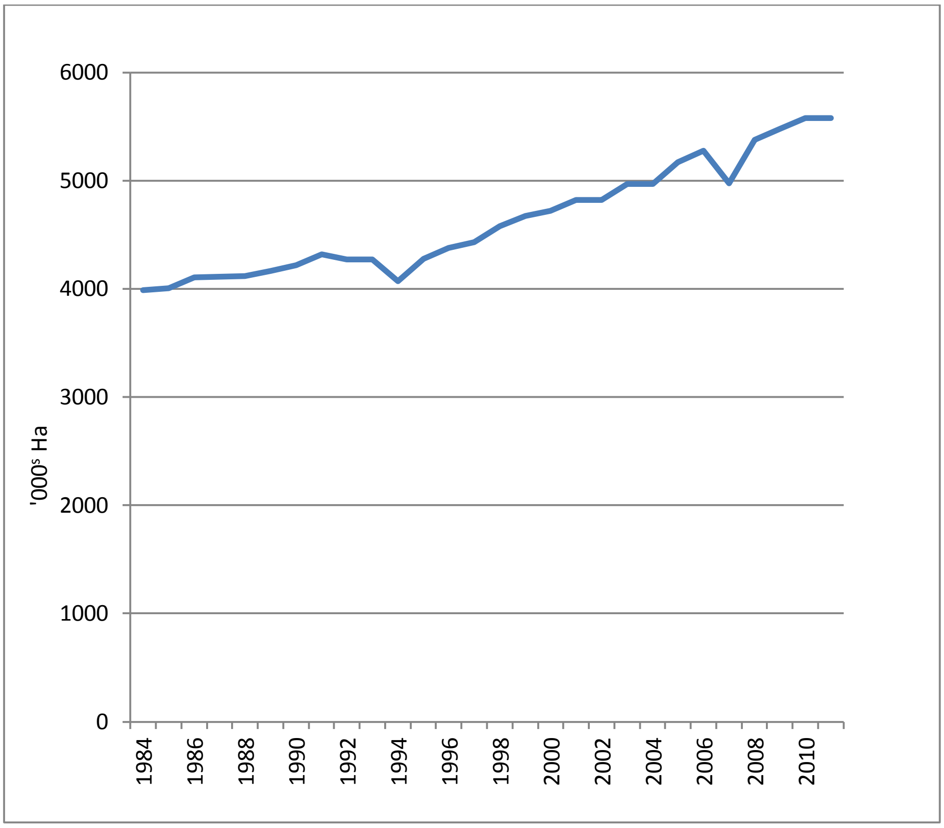


Figure 31: Increase in cultivated area in Malawi from 1984 to 2010

(Source: FAOSTAT 2014)

5.2.3 State

The Likangala River catchment has been affected by a reduction of woodlands, shrub-land and wetlands, with an increase in cultivated land and urban areas. Medicinal plants and wild foods are in a state of decline. Cultivation was taking place in marginal areas such as wetlands, hills and river banks, leading to siltation. The current state of water quality of the Likangala River makes it unfit for direct consumption without treatment and it is heavily polluted at several locations including Zomba City. WQI values rate water quality to be medium at three locations and bad at four locations sampled.

5.2.4 Impacts

A decline in provisioning ecosystem services has a direct impact on human well-being. Although the definition of human and ecosystem well-being are still evolving, for the purpose of this study, the following definitions are used:

"Human well-being: A condition in which all members of society are able to determine and meet their needs and have a large range of choices to meet their potential." (Prescott-Allen, 2001 cited from Garcia *et al.*, 2003).

"Ecosystem well-being: A condition in which the ecosystem maintains its diversity and quality and thus its capacity to support people and the rest of life and its potential to adapt to change and provide a viable range of choices and opportunities for the future." (Prescott-Allen, 2001 cited from Garcia *et al.*, 2003).

In the Likangala River catchment, decrease in woodlands and wetlands have affected biodiversity. The availability of wild animals and birds has been affected as their habitats are damaged. River bank cultivation has affected the availability of medicinal plants. The poor water quality in urban areas has affected aquatic life affecting fishing in Mpondabwino and affecting human health with diseases such as cholera being reported in the catchment. Provisioning ecosystem services such as wood, medicinal plants and wild foods have been reported to be declining over the years, which have an impact on livelihoods and thereby human well-being.

5.2.5 Responses

In rural areas, especially in this catchment, when provisioning ecosystem services are declining, there is little scope for improving livelihoods that are dependent on them, as alternative income generating options are few. Njaya *et al.* (2011) point out that the sectoral approach to address food insecurity, over fishing and land degradation including soil erosion, deforestation and siltation have not been successful in the Lake Chilwa Basin, which includes the Likangala River catchment. The authors called for an integrated approach which takes into cognisance inter-linkages between the sectors. Coupled human-environment systems such as that found in the Likangala River catchment are complex and therefore multiple approaches that address changes in the ecosystem are needed. The Population-Health-Environment (PHE) is one such integrated approach which can address the drivers, pressures, state and impacts and achieve the outcome of balancing human and ecosystem needs (Table 21). In addition, indigenous knowledge system has to be imbedded within the PHE approach.

Population, Health Environment approach

Population, Health and Environment (PHE) is an innovative approach to conservation and development. PHE is gaining popularity in many countries where its projects have been implemented in rural areas with high biodiversity. Its premise comes from the recognition that population, health and environment are interlinked and since communities live integrated lives, they need integrated development. The interrelated challenges of unmet need for family planning, disease burden, food insecurity and environmental degradation can be addressed in a holistic manner using PHE. This study has evidenced environmental degradation in the Likangala River catchment. The effects of poor water quality on human health were witnessed through the cholera cases. Poor health services in the Likangala River catchment heighten the importance of medicinal plants in this ecosystem, as the health of communities depends on these. When the environment is degraded, medicinal plant supplies is affected, which in turn affects human health. Furthermore, there is a strong link between water quality and diseases (Eisenberg *et al.*, 2007). A high population growth increases the demand for natural resources and could lead to food insecurity which exposes households to the risk of malnutrition and poor health.

Population growth and migration have put pressure on natural resources in the Likangala ecosystem. This is particularly important to address as, the Total Fertility Rate (TFR) for Malawi is 5.7 and the unmet need for family planning in Malawi is 26% and 50% of women are married before the age of 18 years (Population Reference Bureau, 2012). Population has trebled in Malawi over the past 40 years (Government of Malawi, 2011). In the Likangala River catchment, communities identified population growth as a major threat to ecosystem services. Unsustainable extraction and abstraction of natural resources and land-use change were driven by population growth in this ecosystem. Thus, the link between population growth and its impacts on ecosystem services and in this manner the effects on human well-being are apparent.

Combining environmental and conservation efforts, family planning, and other primary health care services for poor rural communities helps them reduce their vulnerability and thereby leads to sustainable use of natural resources (De-Souza, 2014). The PHE approach has been found to be successful in addressing conservation and human well-being objectives in rural ecosystems elsewhere in the world such as in Madagascar, the Philippines and Ethiopia (PSDA, 2014). In Madagascar, the PHE project succeeded in bringing about marine conservation and increasing contraceptive prevalence rate from 10% in 2007 to 55% in 2013 (Blue Ventures, 2013).

Table 21: Matrix of DPSI with responses using PHE approach and support from indigenous knowledge

	Drivers	Pressures	State	Impacts
	1. Population growth and migration into ecosystem 2. Urbanization/urban sprawl 3. Industries 4. Energy needs 5. Tourism	1. Demand for agricultural land 2. Demand for construction materials 3. Demand for medicinal plants 4. Demand for wood 5. Waste generation	1. Poor water quality 2. Loss of forests 3. River bank cultivation and wetland cultivation	1. Declining provisioning ecosystem services (Medicinal plants and wild foods) 2. Water borne diseases 3. Biodiversity loss 4. Shortage of wood and forest products
Population	• Meet unmet need for family planning • Dis-incentivize migration			
Health	• Provide integrated reproductive health services with family planning	• Manage waste • Improve food security through intensification of agriculture	• Civic education on water borne diseases	• Water purification technologies promoted
Environment	• Urban planning • Promote fuel efficient technologies • Promote eco-tourism	• Promote intensive agriculture and environment friendly farming technologies • Promote environment friendly brick making • Sand mining to be regulated • Document and conserve medicinal plants and their habitats	• Promote afforestation • Enforce buffers along river banks and wetlands • Waste management	• Biodiversity monitoring • Conservation of hotpots of medicinal plants and wild foods • Sustainable harvesting of forest products • Conservation of forests
Indigenous Knowledge	*Cultural tourism*	*Indigenous methods of improving food security*	*Indigenous methods of conservation*	*Identify habitats of medicinal plants, wild foods*

Source: Adapted from UNEP 2007; Turner and Salomons, 1999.

The PHE Consortium in Ethiopia began an integrated PHE project in 2005, where Guraghe People's Self-Help Development Organization (GPSDO) integrated girls' education, environmental conservation, family planning advocacy and service provision, as well as income generating activities. Within five years, the project increased contraceptive prevalence rate from 8.1% in 2005 to 33.46% in 2010 and increased food security from 5 to 9 months in a year (PHE Ethiopia Consortium, 2012).

PHE approach in the Likangala River Catchment

The PHE approach is suitable for the Likangala River catchment ecosystem because it will deliver integrated responses that address the complex links between humans, their health and the environment. In the Likangala River catchment, using a sectoral approach of addressing deforestation in isolation, without addressing the driver of deforestation, will produce results that are not sustainable. The PHE approach may include provision of family planning and reproductive health services; community-led conservation efforts; health service delivery and using integrated information as well as educational promotions. Furthermore, this approach is more cost effective through sharing of resources, thereby achieving sustained outcomes which have not been possible through traditional single sector approaches (De-Souza, 2008; Njaya *et al.*, 2011). In a nutshell, the PHE approach helps communities achieve sustainable use of natural resources through individuals being able to manage their family sizes and enjoy improved health (De-Souza, 2014; De-Souza, 2008; Mohan and Shellard, 2014). For this study, the analysis of DPSI and Responses through PHE approach is summarised in Table 21. Responses framed according to the PHE approach address all the components of drivers, pressures, state and impacts.

The drivers of change in the Likangala River catchment are summarised in Table 21. A Reduction of the population will reduce competition on natural resources in the catchment. Population growth in the catchment can be managed through meeting the unmet need for family planning and reducing migration into the catchment through providing employment opportunities and economic growth in neighbouring districts where migrants come from. Providing integrated reproductive health services with family planning will assist communities in the catchment, in particular the women, to improve their health. Urbanization is a driver of ecosystem change, Unplanned and burgeoning urban settlements and the accompanying wastes produced could impact negatively on the ecosystem. Urban planning would address this and help control urban sprawl and ensuing waste problems thereby providing environmental benefits. Energy demand for cooking is the driver for extraction of fuelwood. Demand for fuelwood could be reduced by promoting fuel efficient stoves and biogas for cooking. Fish smoking done at Lake Chilwa shores create demand for fuelwood and therefore fuel-efficient fish smoking kilns need to be promoted and local NGOs are currently promoting this (Luhanga and Jamu, 2013). Tourism is a driver of environmental change through demand for natural resource derived products such as wood carvings, everlasting flowers and ornamental stones, as seen in Chapter 2. Promoting eco-tourism will have environmental benefits as areas of high biodiversity will be conserved for tourists.

The pressures identified are demand for agricultural land, construction materials, medicinal plants, wood and waste generation. The pressure for agricultural land can be addressed through promoting intensive farming and environment friendly farming technologies, thereby producing more food in a sustainable manner. Demand for construction materials can be addressed through promotion of environmental friendly brick making using cement bricks instead of clay bricks. Sand mining activities ought to be regulated in order to prevent adverse impacts on water quality while alternatives to using sand for construction need to be explored.

The state of the ecosystem reveals poor water quality with the water being unfit for domestic use in a number of places. Management of waste to prevent water pollution is urgently needed. Civic education on water borne diseases will address the concern of water being unfit for use. The ecosystem has suffered loss of forests, degradation from river bank cultivation and wetland cultivation which impacts on provisioning ecosystem services including availability of medicinal plants and wild foods. There is need to promote afforestation, enforce buffers along the river banks and prevent cultivation in wetlands.

The impacts include declining provisioning ecosystem services, water borne diseases, biodiversity loss through loss of habitats from land use change. The woodcarvers reported that they had to source wood from elsewhere because in the catchment area, especially in Zomba Mountain, deforestation had affected its availability. The impacts can be addressed through promoting water purification technologies so that communities avoid getting infected from water borne diseases. Biodiversity monitoring will be important to help identify species loss and take remedial measures. Conservation of hotpots of medicinal plants and wild foods is a response that will ensure sustainability of these provisioning services. Sustainable harvesting of forest products and conservation of forests are necessary. The PHE approach addresses each of the drivers, pressures, state and impacts.

Utilizing Indigenous Knowledge

Local people have their lives interlinked with nature and they observe changes in ecosystems. Indigenous Knowledge is knowledge that is built up by generations of communities living closely with nature and using natural resources for their well-being (Johnson, 1992). There is a need to integrate local ecological knowledge in ecosystem services monitoring (Kalanda-Sabola, 2007). Local people can provide precise ecological information on declining provisioning services and ecosystem degradation (Kalanda-Sabola, 2007). This information is valuable and is often termed Traditional Ecological Knowledge (TEK) (Posey and Balee, 1989; Gadgil and Berkes, 1991). Local people have knowledge of which resources can be used as food, which ones as medicines, when to collect them and how to avoid degradation of resources. This ecological information is usually passed on verbally from generation to generation.

Intergenerational knowledge of ecosystems is important for conservation and maintenance of provisioning ecosystem services. The older generation has knowledge of areas where provisioning ecosystem services are found and also knowledge of how to conserve them. Therefore, for environmental conservation, it is imperative that local people are involved and participate in conservation as they are the direct users and beneficiaries of the services as well as the ones who are most affected by the decline of provisioning ecosystem services (Western and Wright, 1994; Stevens, 1997; Brosius *et al.,* 1998).

In the top-down management approaches of implementation of environmental projects, indigenous knowledge is often overlooked (Krishna, 2007). This is arising from a Euro-centric viewpoint where indigenous knowledge was grossly undervalued by scientific managers (Hamilton and Walter, 1999). The challenge remains to integrate global perceptions of ecosystem management with indigenous knowledge and practises in some synergy where both scientific and local knowledge are merged for ecosystem management (Kalanda-Sabola, 2007). Co-management and local participation can help in natural resource management projects (Kalanda-Sabola, 2007).

Indigenous knowledge can assist with the PHE response framework (Table 17). Knowledge of cultural ecosystem services can be useful in promoting eco-tourism. Indigenous methods of improving food security will help enhance health and meet the food demand. Conservation efforts can be enhanced using indigenous methods. Indigenous knowledge is useful in identifying habitats of medicinal plants and wild foods and the changes in their statuses thereby aiding in ecosystem management and their sustainable use.

5.3 ECOSYSTEM MANAGEMENT FRAMEWORK

There is a plethora of frameworks to manage natural resources. The most common approach globally is the traditional sectoral method and this is followed in Malawi. Malawi has a number of sectors responsible for natural resources; water, land, agriculture, irrigation, forestry, fisheries, energy and other sectors such as industry and public works which impact on the environment. The challenge in using the sectoral approach is that there is lost opportunity for synergy and interaction. Most often, the sectoral approach is contradictory and not complementary. For example, Malawi's National Water Policy of 2005 prohibits river bank cultivation and encourages buffers along river banks, while the agriculture sector encourages use of treadle pumps which promote river bank cultivation, thereby cause soil erosion (Government of Malawi, 2011).

Results from Chapters 2, 3 and 4 informed and guided the development of a framework. The following questions guided the development of the framework in addition to information from literature:

1. Will the framework be suitable for Malawi?

In order for the framework to be suited to Malawi, whose 50.7% of population live below the poverty line of less than $2 a day, the recommendations had to be "pro-poor". Furthermore, 85% of Malawi's population depends on natural resources for its livelihood, with 95% farmers practicing rain-fed subsistence agriculture and large proportion gathering wild foods and natural products (World Bank, 2014; Government of Malawi, 2011); the framework had to include these facets. The framework had scope for conservation of medicinal plants which have an important health enhancement role for the poor. Similarly, other provisioning ecosystem services such as wild foods, fish, birds, wood, construction materials and ornamental plants have direct role in poverty reduction through enhancing food security and providing opportunities for income generation for the poor.

2. Is the framework participatory?

Communities live closely with nature and derive their well-being from the ecosystem, thus the framework had to ensure that it involved communities in a participatory manner with a scope for them to identify challenges in the environment and come up with their own management approaches. Hence, the bottom-up approach involving communities is proposed.

3. Does Indigenous Knowledge or local knowledge have a role?

Indigenous knowledge was found to be extremely important in identifying areas which, being degraded, need conservation, as they may be important for biodiversity, breeding of wild animals and birds, sites of important cultural as well as ecological significance.

4. How will the framework use existing institutional structures of Malawi?

In order for the framework to be accepted and used, existing institutional structures needed to be considered and activities embedded within those structures. Creating new structures is a costly and difficult exercise and may not be acceptable to the stakeholders. The framework has used the existing decentralised management structure of Malawi. How ecosystem management can be embedded into Malawi's existing institutional structure is discussed next.

5.3.1 Embedding Ecosystems Management into Institutional Framework

Decentralization in Malawi has devolved powers to the districts from District Assembly, the District jurisdiction level to Area Development Committee at the Traditional Authority jurisdiction level and to the Village Development Committee at the Group Village jurisdiction level. Below this, are the various village level committees including Beach Village Committee responsible for managing fisheries; Farmers club responsible for promoting farm inputs and microloans to farmers; Natural Resource Committee which takes care of wildlife issues; Village Natural Resources Management Committee (VNRMC) which takes care of forestry and other natural resources; Civil Protection Committee which looks at disaster relief and the School Committee which looks after educational issues (Njaya, 2011).

The VNRMC has been provided with training on plant nursery development and tree planting and appears to be the most suitable committee to coordinate activities related to ecosystem management. In order to maintain provisioning ecosystem services, it is necessary to identify hotspots of high provisioning ecosystem services which need to be conserved. These could be areas of high biological diversity and areas from where high value medicinal plants are derived, and forests from where forest products are derived. Identifying these hotspots need to be done at village level and this is best done by VNRMCs which are already established in the study area. This study proposes using VNRMCs to coordinate all users of provisioning ecosystem services (farmers, fishermen, bird hunters, medicinal plant harvesters, wildlife hunters and wild food gatherers) and identify ecosystem hotspots that need conservation.

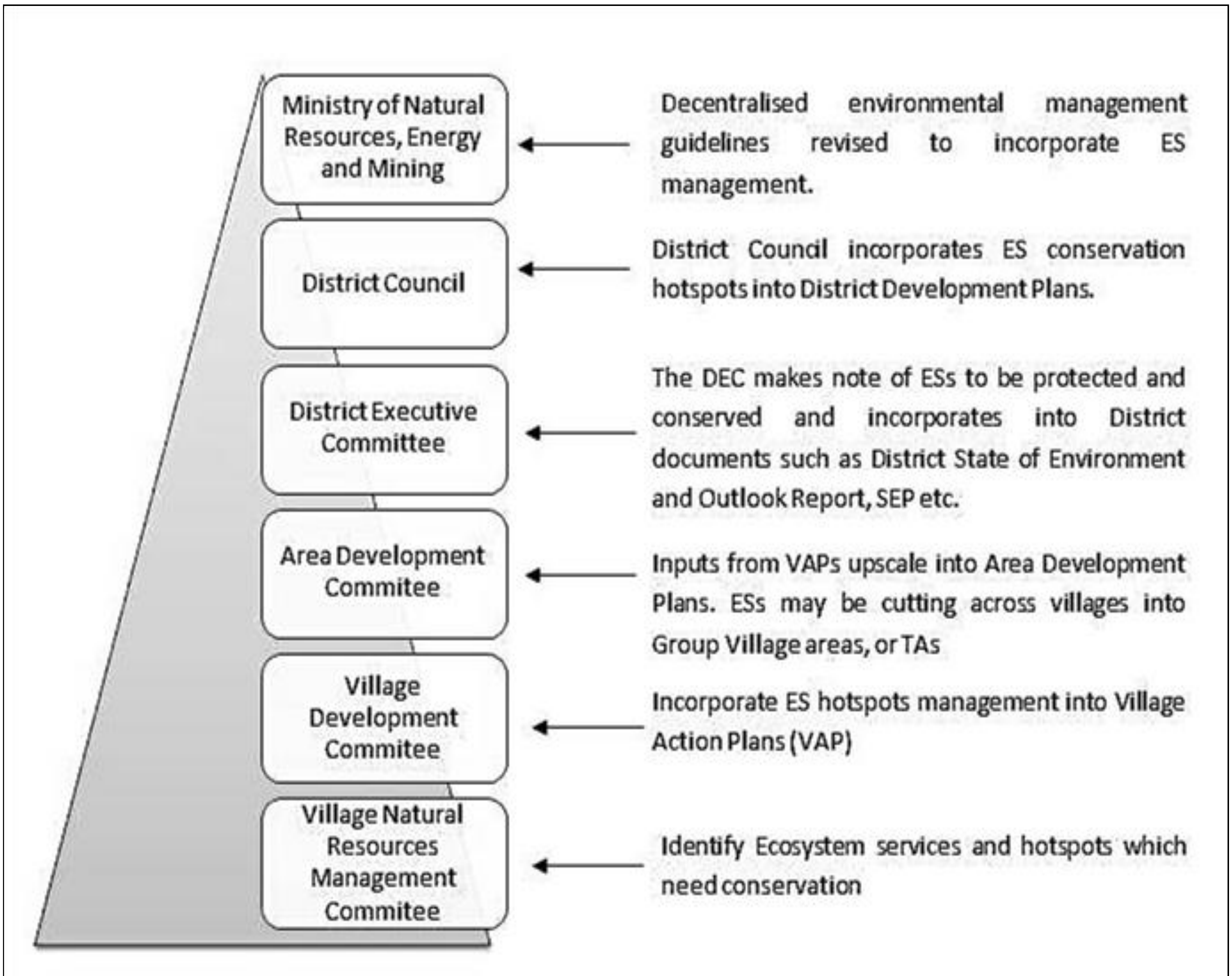


Figure 32: Incorporating Ecosystems Services hotspots conservation into Malawi's Decentralized Environmental Management

Key: ES : Ecosystem Services, VAP: Village Action Plans ,TA: Traditional Authority, SEP: Socio Economic Profile, DEC: District Executive Committee

These hotspots then need to be included in Village Action Plans (VAP) by the Village Development Committee. Several VAPs can then be merged at Group Village level by the Area Development Committee to make an Area Development Plan. This can be submitted to the District Council, which has a District Executive Committee (DEC) consisting of Government Officials from various sectors and Civil Society chaired by the Director of Planning. The DEC produces the District Development Plans (DDP) and using this bottom-up approach, ecosystem services hotspots that need conservation will be elevated into the DDP. In order to formalize this, the Ministry of Natural Resources, Energy and Mining together with the Ministry of Local Government need to include conservation of ecosystem services hotspots into the Decentralized Environmental Management Guidelines (Government of Malawi 2012). This is recommended in order to institutionalize conservation of provisioning ecosystem services and is depicted in Figure 31. This bottom-up approach (Figure 32) is included in the integrated framework recommended in this study which is discussed next.

5.3.2 Ecosystem Services Integrated Response Framework

The DPSIR framework provides an analytical basis for decision-making (UNEP, 2007). The origin of this framework was in a decision-making Pressure-State-Response model which evolved into the DPSIR framework which illuminates how human society affects the ecosystem state (Levin *et al.*, 2008; Bowen and Riley, 2003). The DPSIR is a good framework that links scientific findings and socio economic changes thereby helping to make natural resource management decisions. Cause and effect relationships are illustrated in the DPSIR, and it is useful for broad environmental assessment, such as at country level. Malawi's State of the Environment and Outlook Report of 2010 uses this approach (Government of Malawi, 2011).

However, its drawback is that it is too broad and does not explicitly include ecosystem services and therefore does not address the needs of management at river catchment level that can meet needs of communities and become ideal for the ecosystem (Kelble *et al.*, 2013). Responses that are derived from the DPSIR framework rarely address multiple human and ecosystem needs and do not significantly address the drivers. Furthermore, community based responses and use of indigenous knowledge in responses is not manifestly included. The sustainability of ecosystem services has not been adequately addressed using this approach (Kelble *et al.*, 2013). Often, DPSIR analysis is done at a higher level involving practitioners and scientists, and communities are left out.

Many scientists have observed that there is a critical need to move from traditional single sector response into a more integrated and multi-sectoral ecosystem-based response (Kelble *et al.*, 2013; De-Souza, 2014; Ghiron *et al.*, 2014). The integration of biophysical and human dimensions to better inform holistic ecosystem management is called for (Kelble *et al.*, 2013;

De-Souza, 2014; Ghiron *et al.*, 2014). The proposed framework in this study thus addresses this need for integrating environmental and human concerns.

The Population, Health and Environment (PHE) approach is a fairly new method of small-scale, community-based efforts that concurrently address population issues which are often the drivers of environmental change, public health and environmental concerns which affect human well-being (Ghiron *et al.*, 2014). The PHE programmes have succeeded in providing multiple benefits to communities including diversifying livelihoods, improving health, meeting the unmet need for family planning, enhancing environmental conservation and, improving participation and decision making (Ghiron *et al.*, 2014; De-Souza, 2014). The advantage of PHE approach is that it is very participatory and bottom-up and addresses some of the drivers, pressures, state and impacts of environmental change. Thus, this systemic method becomes a suitable approach for ecosystem management.

This study has identified the need for a bottom-up approach in ecosystems management, where communities have a voice and decision-making power. Both ecosystem and community needs are addressed at the same time to achieve sustainable provisioning ecosystem services for present and future generations. This is the rationale for bringing a new framework called “Ecosystem Services Integrated Response Framework” (ESIRF). The ESIRF framework is based on a systems approach of addressing drivers, pressures, state and impacts of ecosystem change and coming up with integrated responses through PHE approach in order to balance human and ecosystem needs.

Figure 33 shows the Ecosystem Services Integrated Response Framework (ESIRF) where challenges faced in river catchments are addressed through a bottom-up approach and in an integrated manner. In order to manage an ecosystem, the first step is to identify the drivers, pressures, state and impacts. This provides information on the “causes” of ecosystem change and how they influence the ecosystem and thereby affects human well-being. Data on ecosystem health including inventory and maps of provisioning ecosystem services, land cover change, water quality and species decline need to be collected. This will inform communities and practitioners about sensitive areas of high degradation and importance for provisioning ecosystem services that need conservation.

Identification of areas for conservation (or hotspots) should be done in a participatory manner. Hence, indigenous knowledge plays a role and is important in identifying the hotspots. Participation of local people in this decision making process is very important for the sake of “ownership” when conservation programmes are rolled out in the ecosystem. Traditional healers, fishermen, hunters, farmers, gatherers, women who derive natural resources for their households and youth who hunt wild animals are all users of provisioning ecosystem services and need to be involved in choosing areas of conservation.

The ESIRF brings forth the PHE approach as the “response” in DPSIR. The PHE approach addresses drivers, pressures, state and impacts through interventions in population, health and environmental management. Multiple sectors need to work together to provide this integrated response. The outcome is sustainable management of ecosystems where provisioning ecosystem services are maintained and thereby protecting human well-being.

Monitoring and evaluation will be an integral part of this framework and will be driven by the users themselves i.e. the communities. A feedback loop and review mechanism is included for regular checking whether or not the responses have addressed the challenges of the ecosystem. In case of lack of implementation, efforts must be made to address the challenges that have not been addressed. Thus, more data or inputs may be required, or improved participation may be needed and activities may require to be altered accordingly.

The Government of Malawi has been implementing environmental management using a sectoral approach (Government of Malawi, 2011) and this ESIRF framework challenges this thinking and calls for a systems approach. The ESIRF requires that relevant sectors work together to bring forth integrated management where aspects of the population, health and environment are implemented in a united fashion. This means that resources are pooled and there is greater synergy than when following the siloed sectoral approach. The outcome of this ESIRF will be a balance between ecosystem and human needs. Through this framework, ecosystem hotspots will be conserved, land degradation will be kept under check and communities will be involved in managing their own ecosystem from which they derive benefits. NGOs and development practitioners may use this framework and pool their budgets to implement integrated projects. For government sectors, integration will mean merging of budgets and sharing of resources which may need some structural adjustments and guidance at policy level.

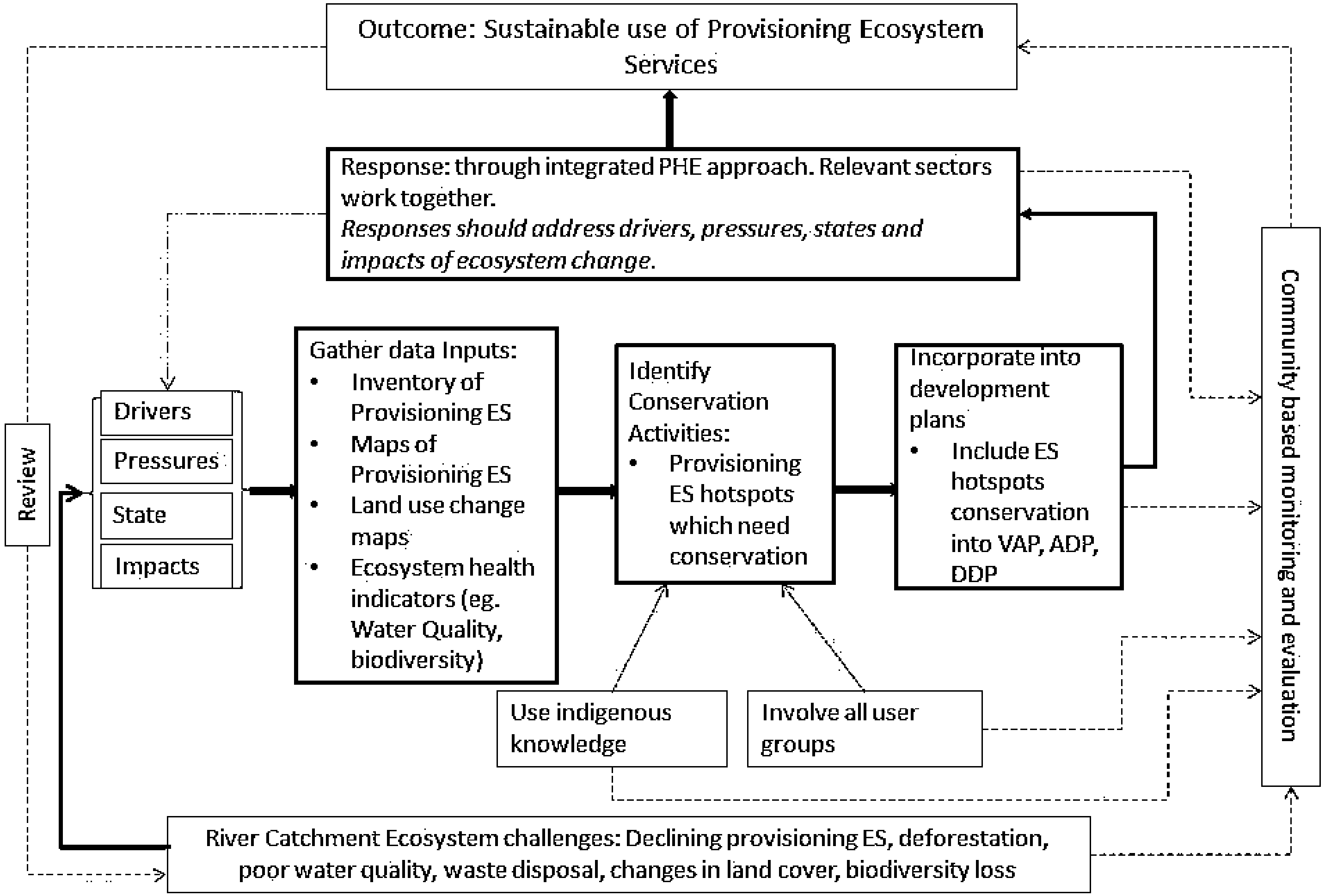


Figure 33: Ecosystem Services Integrated Response Framework (ESIRF)

Key: ES: Ecosystem Services, VAP: Village Action Plan, ADP: Area Development Plan DDP: District Development Plan, PHE: Population, Health and Environment

5.3.3 Assumptions and Limitations of the framework

There are a number of assumptions and limitations for the ESIRF. Assumptions of this framework are:

- That communities will be willing to participate in identifying hotspots of conservation and participate in the conservation activities;
- That the institutions of decentralisation in Malawi will be able to implement this framework using existing funding mechanisms; and
- That multiple sectors will work together including communities, practitioners and government officials to provide responses for sustainable ecosystem management.

Limitations of the Integrated Response Framework are:

- The framework is designed for use at river catchment level using existing institutional structures of Malawi and has not yet been tested;
- Policy changes and decentralization laws may affect implementation of this framework;
- The framework has not considered addressing disasters and mega challenges such as climate change;
- There is emphasis on community knowledge and participation and caution must be taken to avoid conflict with priorities of the ecosystem identified by scientists;
- The quantification of progress, valuation of ecosystems and payment for ecosystem services has not been included in this framework and are identified as areas of further research.

The ESIRF, thus provides a structure for sustainably managing ecosystems whilst at the same time providing for human needs through integrated responses that address population, health and environment challenges.

5.4 SUMMARY

In this chapter, the drivers, pressures, state and impacts of ecosystem change were identified for the Likangala River catchment. Recommendations on conservation of ecosystem hotspots using a participatory bottom-up approach and using existing decentralised environmental management structures of Malawi was illustrated. The importance of indigenous knowledge in conservation has been articulated. Examples of successful projects which have used the PHE approach were explained.

To conclude, this chapter analysed the Likangala River catchment ecosystem using the DPSIR framework and proposed an Ecosystem Services Integrated Response Framework (Figure 32) where Population, Health and Environmental issues are addressed in the responses thereby addressing the drivers, pressures, state and impacts of ecosystem change. The outcome will be sustainable use of provisioning ecosystem services. Furthermore, integration of ecosystem services management through identification and conservation of hotspots using the ESIRF will involve communities and ensure their participation as well as integrate indigenous knowledge. Consequently, sustainable management of ecosystems and meeting human needs can be achieved.

CHAPTER 6

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 OVERVIEW OF STUDY

This is an original study of provisioning ecosystem services of the Likangala River catchment located in southern Malawi. The conceptual framework used for this study was the Drivers-Pressures-State-Impacts-Responses structure. The study used multiple methods including inventory and mapping of provisioning ecosystem services, assessment of land use and land cover change, water quality analyses and compilation of community perceptions of ecosystem changes. The approach of using multiple methods and bringing out a broad understanding of the river catchment with focus on provisioning ecosystem services is a novel one and contributes to scientific knowledge.

This study observed the presence of provisioning ecosystem services in the Likangala River catchment and how they are important for livelihoods and well-being of communities that live in the catchment. Community members undertook participatory mapping to map provisioning ecosystem services that they derive from the catchment. They reported and mapped ten important provisioning services, namely, wild animals, wild fruits, sand, stone, fish, medicinal plants, birds, ornamental flowers, wood and reeds. These services are important for the community's well-being and livelihood; however, they are under threat from over extraction and anthropogenic activities that threaten the ecosystem integrity.

Results from the study revealed that land use/land cover change in the past 29 years (1984 to 2013) affected woodlands (a decline of 88.5%); shrub land (a decline of 16.7%); agricultural areas (an increase of 44.3%) and urban (a huge increase of 143%). Declining woodlands, forests and shrub-land have implications for the provisioning services such as wild foods and medicinal plants that communities derive from these habitats. In addition to land cover, another good indicator of river catchment ecosystem health is the water quality. The study established that the water quality of the Likangala River is affected by pollution from urban areas, runoff from farms and degrading land use activities along the catchment including deforestation, sand mining and river bank cultivation, making the water unfit for drinking without treatment. Faecal coliforms were found in all sampling sites presumably caused by use of organic fertilizers and open defecation.

The study identified drivers, pressures, state and impacts that affect the ecosystem. Communities reported that with an increasing population and the influx of migrants into the catchment; there was increasing competition for provisioning services. Thus, population growth was identified as a main driver of ecosystem change. The most prominent impact of ecosystem change was its effect on human health. Diseases such as cholera and diarrhoea due to consumption of polluted water were reported by communities. The environment is very important to communities in the Likangala River catchment, as their livelihoods depend on it. Hence, through this study, the linkages between population, health and environment (PHE) became explicit and this called for a holistic approach to manage the ecosystem.

To realize this holistic approach, a novel framework called the Ecosystem Services Integrated Response Framework (ESIRF) was recommended. In the ESIRF, the PHE approach is the response that addresses the elements of drivers, pressures, states and impacts in this river catchment. The ESIRF also incorporates indigenous knowledge and emphasises participation of all actors in managing the ecosystem using a bottom-up approach where local actors have decision making roles and ecosystem conservation plans get elevated from the village level to the district level. Using existing institutional structures, the study described how ecosystem hotspots that need conservation can be incorporated into village, area and district development plans. The outcome of the ESIRF is sustainability in provisioning ecosystem services. Monitoring and evaluation in a participatory manner involving communities is included in the ESIRF and regular reviews need to be done to monitor the status of the ecosystem. Through the ESIRF, the study made recommendations to achieve a balance between humans and ecosystem needs.

Thusly, this framework supports the Constitution of Malawi (Government of Malawi, 2004), which states in section 13(c):

"To manage the environment responsibly in order to

i. prevent the degradation of the environment;
ii. provide a healthy living and working environment for the people of Malawi;
iii. accord full recognition to the rights of future generations by means of environmental protection and the sustainable development of natural resources; and
iv. conserve and enhance the biological diversity of Malawi."

Next, specific recommendations for policy makers, practitioners and the community were made while areas of further research were identified. Knowledge gaps that were filled or answered by this study were also highlighted.

6.2 RECOMMENDATIONS

In order to make an impact, scientific research findings need to be accessible and meaningful for policymakers, practitioners and communities. This section provides key recommendations derived from this study for each of these stakeholders.

6.2.1 Recommendations for Policymakers

1. In order to maintain provisioning ecosystem services, a holistic approach is required which addresses drivers, pressures, state and impacts of ecosystem change. Therefore, policymakers need to ensure that before conservation activities are undertaken, the causes of the problems are addressed, rather than just treating the symptoms.
2. A multi-sectoral approach integrating population, health and environment responses will help in addressing complex interconnected challenges in ecosystems. Therefore, policy makers need to allow for institutions to work together, pool budgets and overlap sectoral activities.
3. Ecosystem conservation using a bottom-up approach where ecosystem conservation needs are identified by communities and incorporated into Malawi's institutional framework can help achieve sustainability of provisioning ecosystem services.
4. Policies that guide ecosystem management, such as the Decentralized Environmental Management Guidelines need to be revised to include the participatory approach to ecosystem management as recommended in this study.
5. Conflicting policies such as Agriculture policy that promote use of treadle pumps which encourage river bank cultivation, as opposed to the Water Policy which promotes buffers along river banks, need to be resolved.
6. Policymakers in forestry should promote afforestation activities and curb deforestation as a matter of importance in the Likangala River catchment.
7. Decision making and policy formulation should be based on scientific evidence, thus more research should be encouraged in river catchments that focus on ecosystem services as they are important for human well-being.

6.2.2 Recommendations for Practitioners

1. In order to maintain provisioning ecosystem services, a holistic approach is required which addresses drivers, pressures, state and impacts of ecosystem change. Therefore practitioners working in relevant sectors need to come together, pool resources and jointly work towards achieving a holistic outcome of sustainable ecosystem and human needs.
2. A multi-sectoral approach integrating population, health and environment responses will help in addressing complex interconnected challenges in ecosystems. Practitioners need to understand these complexities and design programmes accordingly.
3. Ecosystem conservation using a bottom-up approach where ecosystem conservation needs are identified by communities and incorporated into Malawi's institutional framework can help achieve sustainability of provisioning ecosystem services. For this reason, practitioners need to involve communities and existing institutions to implement conservation programmes.
4. There is a need to provide civic education to communities in preventing open defecation and pollution of river water and to treat the water before consumption.
5. Simple and fast methods of water quality rating such as WQI are useful in identifying pollution hotspots in the river catchment and need to be used by practitioners for decision making.
6. River flows are good indicators of ecosystem health and have implications for ecosystem provisioning services. Therefore, river flow assessing and recording need to be done in the Likangala River.

6.2.3 Recommendations for Communities

1. In order to maintain provisioning ecosystem services, the users (communities) themselves have to be involved in their conservation through identifying hotspots of degradation that need remedial action and participate in conservation undertakings.
2. It is important to understand the connections between environment and health in order to appreciate that environmental degradation has negative human health impacts. For example, communities need civic education on how consumption of polluted water affects their health.

3. Population growth puts pressure on natural resources and therefore managing population growth through family planning is beneficial to communities who can then enjoy sustainable provisioning ecosystem services. Thus, communities need to understand the linkage between population growth and natural resource exploitation.
4. Conversion of forests and shrub-land into cultivated land impacts on biodiversity and availability of wild foods, therefore intensification of agriculture, promotion of agriculture that conserves biodiversity (such as fruit orchards) may be useful.
5. Communities need to diversify their livelihoods thereby reducing dependence on natural resources.
6. Planting on slopes, wetlands and river banks causes soil erosion, siltation and affects availability of medicinal plants and therefore, soil erosion control methods such as use of *vetiver* grass, terracing and providing buffers along river banks and wetlands need to be enforced.
7. Destructive activities such as creating bush fires to catch wild animals and insects need to be discouraged to conserve ecosystems.
8. Communities need to use fuel efficient technologies in order to reduce their dependence on fuelwood, thereby reducing deforestation.
9. Indigenous knowledge is useful in identifying hotspots for conservation which are rich in provisioning ecosystem services, and this calls for communities to be active partners working with existing institutional structures and providing their local knowledge for the betterment of all.

6.3 RESEARCH GAPS FILLED BY THE STUDY

This study fills research gaps found in global and country level literature. Globally, the need to carry out research and comprehend how people are benefiting from ecosystem services and in what manner they are being managed in different landscapes has been identified (MEA, 2003; Carpenter *et al.*, 2006; Carpenter *et al.*, 2009).

In Malawi, there has been ethno botanical studies (Morris, 1991) at country level, and one study at Chisi Island (Kalanda-Sabola, 2007), but none at the Likangala River catchment. This study provided information at catchment level on medicinal plants through an inventory and mapped the presence of provisioning ecosystem services using a participatory method.

Jamu *et al.* (2003) and Jamu *et al.* (2005) evaluated land use change in the Likangala River catchment, however, their land cover maps were limited to 1982 and 1995, and both derived from black and white aerial photographs. This study has used satellite images and mapped land cover for the years 1984, 1994, 2002 and 2013, thereby providing updated spatial information.

Limnological studies have been done in the study area in the past (Chidya *et al.*, 2011; Chavula and Mulwafu, 2007). Mulwafu and Nkhoma (2003) studied the use and management of water in Likangala Rice Irrigation Scheme, while Mulwafu (2000) reported on conflicts in water use; however, there have not been any studies that focussed on provisioning ecosystem services in the Likangala River catchment. This study fills this knowledge gap.

This study provides a novel method of managing provisioning ecosystem services using a holistic approach where drivers, pressures, states and impacts are addressed in an integrated manner using the PHE approach. The proposed ESIRF ensures community participation and involvement of relevant sectors to achieve sustainability of provisioning ecosystem services.

6.4 AREAS OF FURTHER RESEARCH

This study has identified the following areas of further research:

1. Regulating, supporting and cultural ecosystem services of the study area need to be researched, as they also have an impact on provisioning ecosystem services.

2. The extents and boundaries of different types of provisioning ecosystem services need to be mapped to study changes in scale and time.

3. Valuation of provisioning ecosystem services need to be done, in order to provide economic impetus for policy makers to promote their conservation.

4. Water flow studies in Likangala River catchment need to be done as it is an indicator of ecosystem health.

5. The impacts of climate change indicators and climate variability on ecosystem services need to be studied.

6.5 LIMITATIONS OF THE STUDY

The study has a number of limitations and its scope was confined by availability of resources to carry out the study and time limitations. The following were identified as key limitations:

1. Parts of the study used qualitative data, which is a powerful tool to bring out voices of communities. However, it is not possible to generalise the findings.

2. Water quality assessment did not cover parameters such as heavy metals, COD, BOD and dissolved oxygen due to limitations in resources and equipment availability;

3. Water quality results were only for one dry and one wet season in 2013 and therefore representative of the state of water quality at that time only and not for extended periods;

4. Boundaries and extents of provisioning ecosystem services have not been mapped in this study as some of the services are mobile (wild animals and birds).

Despite the limitations, this is a pioneering study that has captured multiple elements of ecosystem change in the particular study area. This study fills a number of knowledge gaps identified in international and national literature and provides recommendations at various levels from community to policy level. This study indicates that the human pressure on the environment is affecting the abundance of provisioning ecosystem services. Agriculture in the Likangala River catchment has grown at the expense of biodiversity and other land covers including woodlands, thereby affecting provisioning ecosystem services. Finally, this study agrees with Environmentalism-of-the-poor and pushes the move for rural communities to conserve ecosystems to defend and secure poor people's livelihoods, health and food security, because provisioning ecosystem services are most needed by them. The poor are considered the solution rather than the problem for sustainable ecosystem management.

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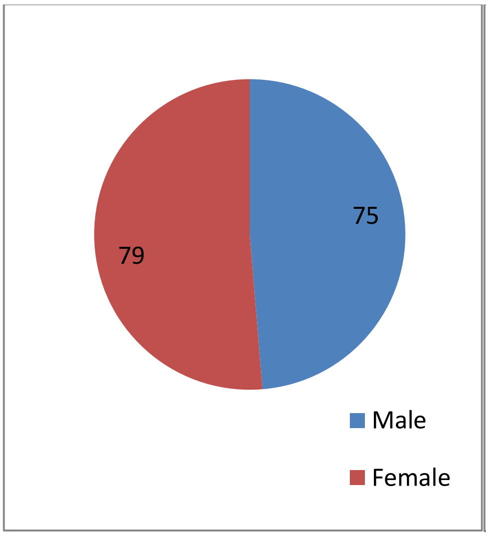
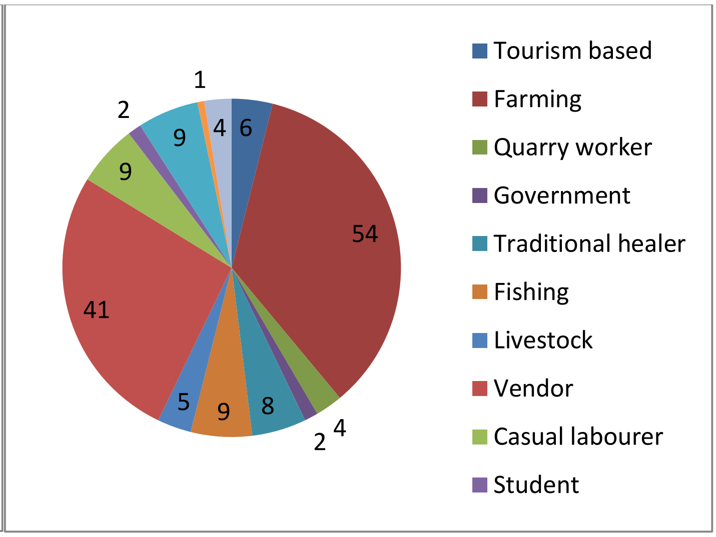
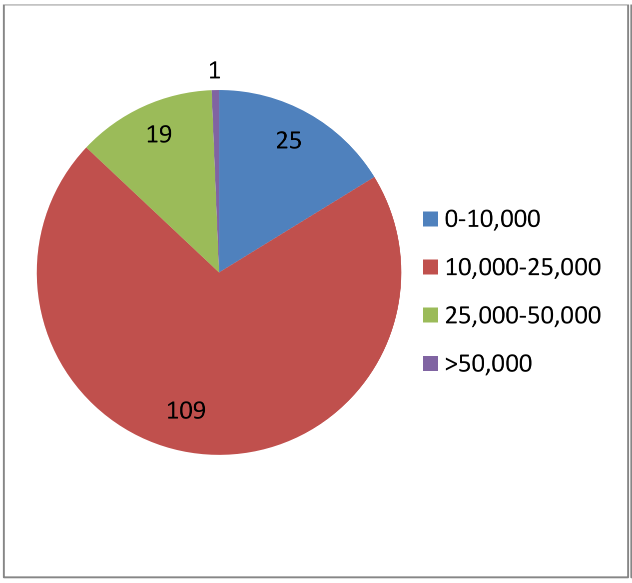
APPENDIX I

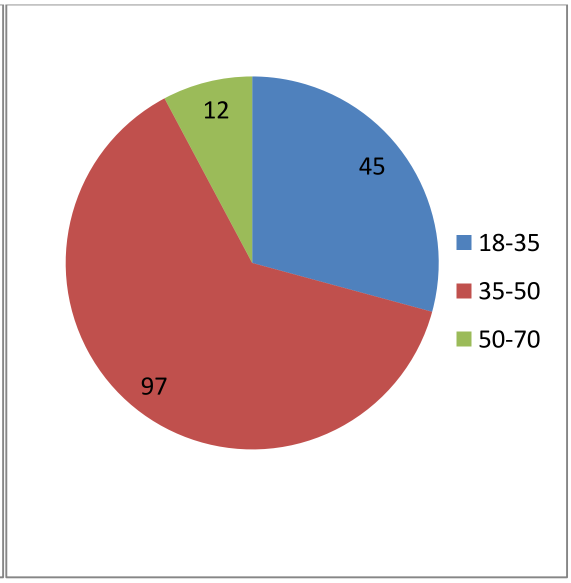
Socio Economic information of communities interviewed and those who participated in mapping exercise





Gender and occupations of community members





Income in Malawian Kwacha (approx 380 to 1US$). *Ages of participants*

APPENDIX II

Guiding questions for Focus Group Discussions and PGIS

Location of FGD:………………………………… Date:…………….................…………..

Greetings! I am undertaking a study on the natural resources that communities benefit from in the Likangala River Catchment. The results from this study will be used in a PhD thesis and will be published. The Zomba City Assembly has provided permission for this research. May I please ask you a few questions and record the answers?

1. Socio economic characteristics of respondents

Name	Gender	Occupation	Age	Income (preferably monthly)

2. What medicinal plants do you derive from this catchment? Please list them, their uses and where they are located.

Medicinal Plant (Chichewa name)	Uses	Location found (Wetland, river bank, forest?)

3. What wild foods do you extract from the catchment? This can include wild animals, birds, wild fruits and where are they located.

Wild foods (Chichewa name)	Location found (Wetland, river bank, forest?)
Wild animals	
Wild fruits	
Birds (edible only)	
Fungus (mushroom)	
Fish/ river crabs	
Insects	
Others (wild honey)	

4. What non-food natural resources do you extract and where are they found?

Non-food natural resources	Location found (Wetland, river bank, forest?)
Stones	
Sand	
Reeds	
Ornamental stones	
Ornamental flowers	
Others…?	

5. How have the availability of natural resources changed over the years and what are the reasons?

Natural resources	Declining?	Increasing?	Reason

6. For what purposes do you use the water in Likangala River?

Tick those applicable

☐ Drinking

☐ Washing

☐ Bathing

☐ Irrigation

7. How has water quality in Likangala River changed over the years? How does this affect natural resources such as availability of fish?

…………………………………………………………………………………………………
…………………………………………

8. How have the forests and woodlands changed in the catchment?

…………………………………………………………………………………………………
…………………………………………

9. How has wetlands changed in the catchment?

…………………………………………………………………………………………………
…………………………………………

10. What are the major causes of change in Likangala Catchment?

…………………………………………………………………………………………………
…………………………………………

Participatory Geographic Information System (PGIS) mapping of provisioning ecosystem service

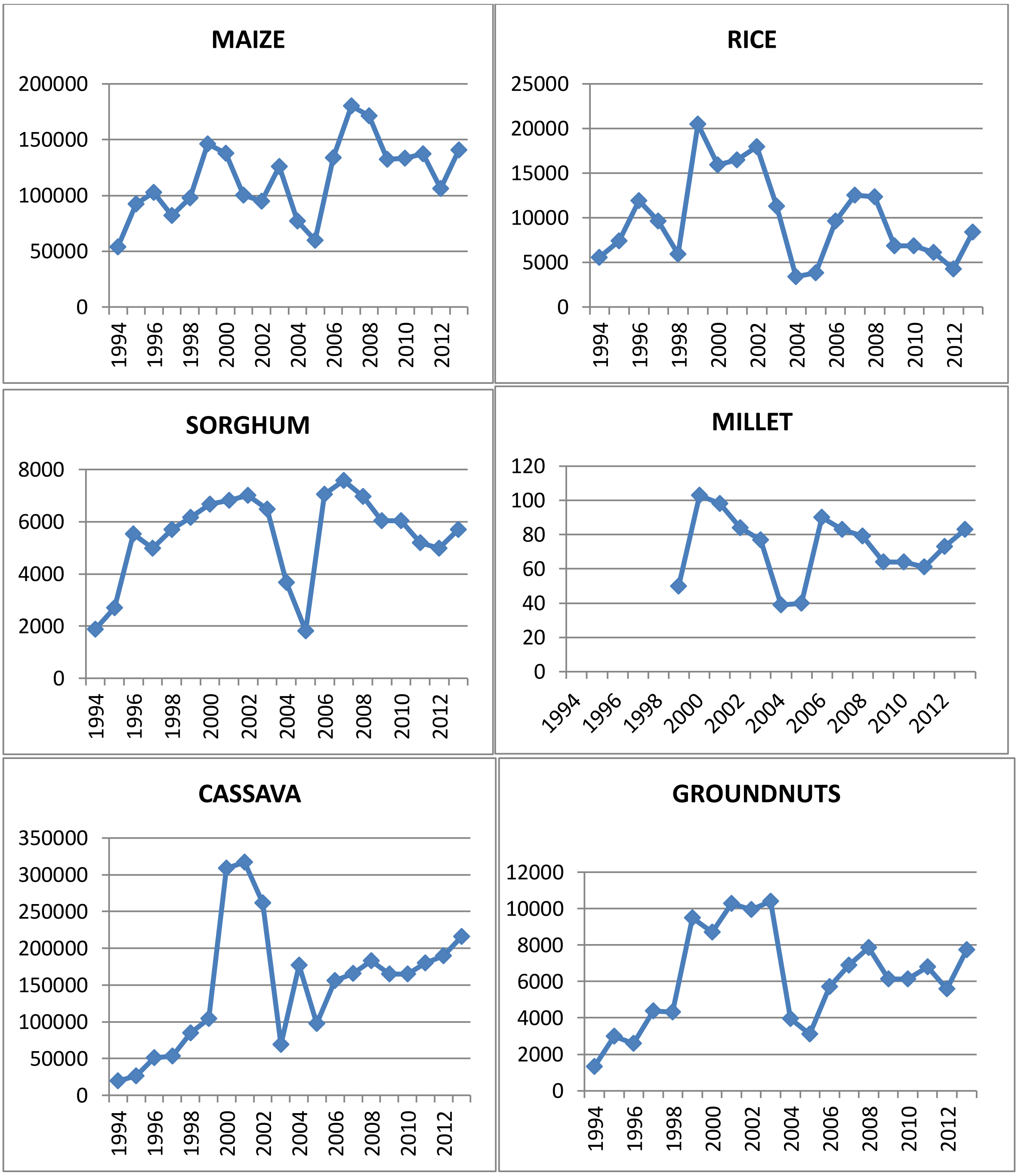
In groups of men and women (separately) request community members to draw their village and surrounds on a flip chart. Indicate Likangala River and major landmarks around their village. Then ask the groups to locate the places where they derive ten categories of natural resources:

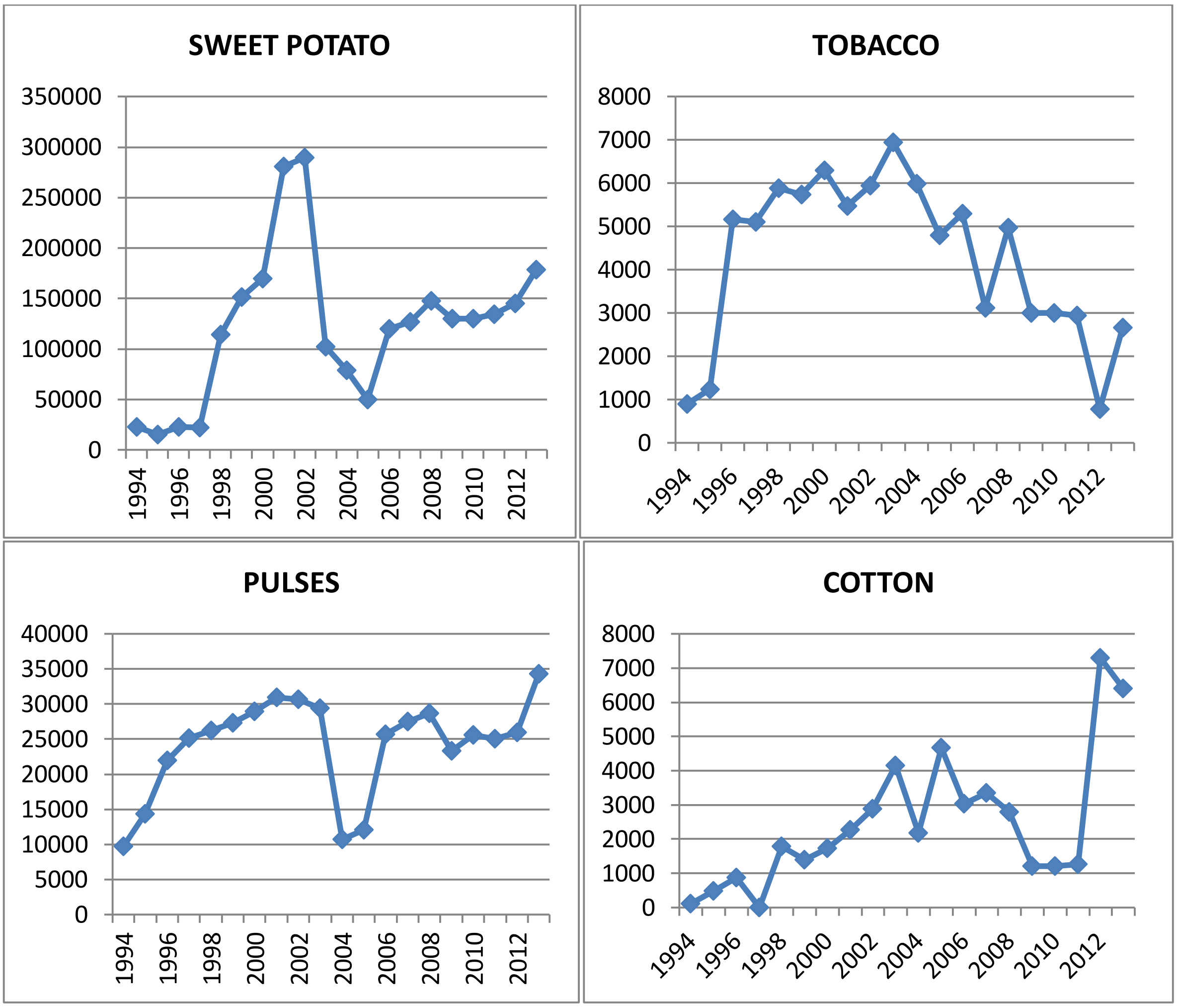
1. Wood
2. Wild Animals
3. Birds
4. Sand
5. Stones
6. Reeds
7. Wild Fruits
8. Medicinal Plants
9. Ornamental Flowers
10. Fish.

The communities may map these natural resources using their own key clearly indicated on the flip chart. After the map is drawn take a photograph of the flip chart for records.

APPENDIX III

Crop production in Zomba District (1994-2012)





Major crop estimates in Metric tons for Zomba District (1994-2013)
Source: Zomba District Agricultural Office, 2014

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Email Ethics@nwu.ac.za
2013/07/01

ETHICS APPROVAL OF PROJECT

This is to certify that the next project was approved by the NWU Ethics Committee:

Project title. Mapping of Provisioning Ecosystems Services in Likangala River Catchment, Zomba, Southern Malawi

Project leader: Dr Palamuleni
NWU Ethics approval no: NWU-00036-13-A9

The Ethics Committee would like to remain at your service as scientist and researcher, and wishes you well with your project. Please do not hesitate to contact the Ethics Committee for any further enquiries or requests for assistance.

Yours sincerely

Me.Marietjie Halgryn
NWU Ethics Secretariate

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Academic Administration (Mafikeng Campus)
SOLEMN DECLARATION (for Masters and Doctoral Candidates)
Solemn declaration by student

I ____-declare herewith that the thesis entitled,
-____
-____

which I herewith submit to the North-West University as completion/~~partial~~ ~~completion~~ of the requirements set for the ____________degree, is my own work and has not already been submitted to any other university.
I understand and accept that the copies that are submitted for examination are the property of the University.

Signature of candidate________________University-number________________________

Signed at________________this_________day of _____________2014__.

Declared before me on this _________day of____________________200__

Commissioner of Oaths:_________________ _________________________
Declaration by supervisor/promotor
The undersigned declares:

- that the candidate attended an approved module of study for the relevant qualification and that the work for the course has been completed or that work approved by the Senate has been done
- the candidate is hereby granted permission to submit his/her mini-dissertation/dissertation or thesis
- that registration/change of the title has been approved;
- that the appointment/change of examiners has been finalised and
- that all the procedures have been followed according to the Manual for post graduate studies.

Signature of Supervisor:_____________________________Date:____________________

Signature of School Director:________________________Date:_____________________

Signature of Dean:___ _______________________________Date:__________________

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Date: 02nd December, 2014

Re: Student Number **23881356**

This serves to confirm that I have read and edited Ms Deepa Pullanikkatil's PhD thesis titled:

'Mapping of Provisioning Ecosystems Services in Likangala River Catchment, Zomba, Southern Malawi'

The candidate corrected all language errors identified.

The document presentation is of an acceptable academic and linguistic standard.

Thank you,

....

D.T. Kawadza
Faculty of Agriculture, Science and Technology