Building River Dialogue and Governance

STATE OF THE LAKE MALAWI/NYASA/NIASSA REPORT

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ACRONYMS

AfDB	African Development Bank
AVHRR	Advanced Very High Resolution Radiometer
BRIDGE	Building River Dialogue and Governance
CITES	Convention on International Trade in Endangered Species
DOC	Dissolved Organic Carbon
CDOM	Colour Dissolved Organic Matter
EGENCO	Electricity Generation Company
ESCOM	Electricity Supply Commission of Malawi
ENSO	El Nino and Southern Oscillation
ETo	Evapotranspiration
FAO	Food and Agriculture Organization
GCM	General Circulation Models
GEF	Global Environmental Facility
GHG	Green House Gases
GoM	Government of Malawi
IPCC	Intergovernmental Panel on Climate Change
IWRM&WEF	Integrated Water Resource Management and Water Efficiency Plan
IWRWM	Integrated Water Resource Management and Development
GDP	Gross Domestic Product
IUCN	International Union for the Conservation of Nature
ITCZ	Inter Tropical Convergence Zone
LLO	Large Lakes Observatory
LMNP	Lake Malawi National Park
LMNN	Lake Malawi/Nyasa/Niassa

LNB	Lake Nyasa Basin
LST	Lake Surface Temperature
LULC	Land Use Land Cover
MCA-M	Millennium Challenge Account Malawi
MCC	Millennium Challenge Compact
MODIS	Moderate Resolution Imaging Spectroradiometer
NAMA	Nationally Appropriate Mitigation Actions
NFP	National Fisheries Policy
NGO	Nongovernmental Organization
OID	Indian Ocean Dipole
NSO	National Statistical Office
PFM	Participatory Fisheries Management
PIAD	Presidential Initiative of Aquaculture Development
POC	Particulate Organic Carbon
RBO	River Basin Organization
RCMRD	Regional Centre for Mapping of Resources for Development
RWRA	Rapid Water Resources Assessment
SADC	Southern Development Community
SEA	South East Arm
SST	Sea Surface Temperature
SDC	Swiss Development Cooperation
SWAP	Sector Wide Approach
UK	United Kingdom
UNCCC	United Nation Convention on Climate Change
UNCBD	United Nation Convention on Biological Diversity

UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nation Environmental Programme
UNDP	United Nations Development Programme
UNESCO	United Nation Educational Scientific and Cultural Organization
WB	World Bank
ZAB	Zaire Air Boundary
ZAMCOM	Zambezi Water Commission

EXECUTIVE SUMMARY

The International Union for Conservation of Nature (IUCN) implemented the Building River Dialogue and Governance (BRIDGE) Programme in America, Africa, and Asia, which is funded by the Swiss Agency for Development and Cooperation. The goal of BRIDGE is "*Securing sustainable management of water resources for poverty reduction, nature conservation, economic growth and international cooperation through effective water governance*", (https://www.iucn.org/theme/water/our-work/current-projects/bridge). The programme supports capacity development for countries sharing rivers or lake basins to enhance effective water resources management through a shared vision, benefit-sharing, transparent, and coherent institutional frameworks. IUCN has been implementing BRIDGE activities in different shared basins. Lake Malawi/Niassa/Nyasa (LMNN) is one of the basins identified in BRIDGE.

This report is a synthesis of three national reports prepared by national consultants (Dr Geoffrey Chavula – Malawi, Mr Lucas Chairuca -Mozambique and Mr Faraji Faraji – Tanzania) under the guidance of the National Water Ministries in collaboration with the International Union for Conservation of Nature under BRIDGE. The report looks at responses from national, basin, and regional levels and is based on review of existing literature from governments and other sources. This report focuses on (i) the state of the LMNN ecosystem and (ii) highlights climate change issues of concern on the basin. The report intends to act as an important requisite for fostering transboundary dialogue and information exchange around the LMNN basin and create opportunities for capacity building and environmental diplomacy by building on existing initiatives in the basin. The report helps set the tone for future basin wide-planning, joint investments and developing mechanisms for transboundary cooperation for the management of the LMNN ecosystem between Malawi, Mozambique and Tanzania.

The LMNN contains the ninth largest and third deepest freshwater lake on the continent and is home to a greater diversity of fish and various other animal species than any other basin, the majority of which particularly the fish species are endemic to the basin. Therefore good water governance is essential in order to put in place policies, legal framework and agreements as well as institutions necessary to ensure sustainable development of water resources in the basin. The dominance of precipitation and evaporation in the lake's hydrologic cycle mean that the basin is susceptible to climate change with its observable potential impacts which flooding, drought, change in the frequency and distribution of rainfall, drying-up of rivers, receding of water bodies, cyclones amongst others. It is against this background that the IUCN with financial support from the Swiss Agency for Development and Cooperation (SDC) implemented the BRIDGE programme in the basin with the aim of improving water cooperation and increase water governance capacity from local to regional levels. During its implementation the BRIDGE programme engaged various stakeholders including the Southern Africa Development Community (SADC) Water Division, Zambezi Watercourse Commission (ZAMCOM) Secretariat, government institutions responsible for water resources management, civil society organizations and other to discuss and identify key areas in which the programme could potentially add value to ongoing initiatives and existing priorities in order to create opportunities for transboundary dialogue and information exchange and building capacity for negotiation and water diplomacy. The BRIDGE programme recognizes that the LMNN basin is faced with a number of threats and challenges including the following:

- Loss of biodiversity due to fishing and nearshore water quality impacts
- Overfishing in some areas (nearshore, especially southern end of the lake)
- Increased nutrient inputs and changes in phytoplankton composition
- High sedimentation loading
- Water level variability among others
- Unharmonized and slow policy implementation process
- High levels of deforestation in the basin
- Sub-optimal agricultural practices
- Biomass burning

As result of implementing the programme, a number of key lessons worth sharing have been learnt. Sustainable management of the LMNN requires an adoption of the ecosystem management approach, which requires the involvement of a number of different environmental sectors including fisheries, hydrology, agriculture, and forestry. Currently, there is no government agency in any of the three countries that is responsible for monitoring or management of water quality in LMNN. In each country there are departments that are responsible for overseeing water supply, but these agencies deal primarily with domestic water supply, and they are regularly monitoring water quality in the lake. The fact that no agencies are responsible for monitoring or managing water quality in the lake reflects the narrow focus of each of the natural resource management agencies.

Sustainable management of the LMNN basin require strong coordination and collaboration in research and management. Until recently, there was virtually no coordination among the three countries regarding research and management in the lake and its catchment. In recognition of the need for such coordination, a draft convention on the sustainable development of the lake and its basin was developed with support from FAO in 2003. However, the proposed LMNN Basin Commission never took shape

Most development projects related to LMNN have included some level of capacity building. In many cases, the capacity building takes the form of counterpart positions, in which one or more national trainees are assigned to work with an expert during the course of a project. And in other cases, it has taken the form of academic graduate education obtained from foreign institutions. Nevertheless, no community-based capacity building programmes have been successfully implemented and thus, limited local potential solutions to the basin's governance challenges have been offered to date.

Following the key lesson learnt from the BRIDGE programme a number of recommendations are being proposed including the following:

i. Given the recent climate extremes now being experienced in the region, there is an urgent need to establish an institutional mechanisms to nurture dialogue and foster co-operation in the management of the lake basin and its ecosystem
ii. An Memorandum of Understanding among the three riparian countries of Malawi, Mozambique and Tanzania will be an important first step to institutionalise collaborative efforts to manage the lake;
iii. Capacity building, especially of personnel tasked with the responsibility to manage the lake is essential, particularly in areas such as limnology, hydrometry, application of remote sensing technologies in lake monitoring, and negotiation skills; and
iv. There is need to install drifting and moored buoys on the lake to monitor processes such as wind speed, lake temperature, rainfall, humidity, chlorophyll concentration, waves movement and speed, sediment deposition, and water quality.
v. Capacity building will need to promote gender equity an youth empowerment, as these significant demographies constitute a large portion of the users of the lake basin resources
vi. The lake basin will benefit from a joint, transboundary initiative that focuses on the conservation of the ecosystem, climate risk reduction, sustainable water use and building of the capacity of local populations on ecosystem valuation and flood/drought early warning systems.

1.0 INTRODUCTION

Water security for communities and countries alike is increasingly affected by multiple demands on water resources from the household level to sectoral levels such as agriculture and energy. Water availability and water quality are furthermore influenced by ecosystem services, which are vital to health, food security and economic opportunities that enable communities to benefit from development. Coupled with the fact that water is distributed unequally between States, water insecurity can have far-reaching implications on the economic, social, and political fabric of countries and can potentially lead to conflict in the case of water resources that are shared across boundaries. Although these cross-cutting challenges influence the ability of States to effectively manage water resources, they can also create opportunities for cooperation and enhanced benefits. With most of the world's water resources shared across boundaries, improving water governance capacity at multiple levels, from local to transboundary levels, will enable States to better manage rising pressures on water resources and their effects.

Water governance refers to the policies, laws and institutions that govern and regulate the development and management of water resources within a State or in basins shared between States. The complexity and scope of water challenges has given rise to the need for harmonization of national and regional water frameworks, as well as the building of synergies between different scales of water management to ensure coherence and improved cooperation among multi-level stakeholders in water governance.

The Building River Dialogue and Governance (BRIDGE) programme has been working at the convergence of hydro-diplomacy and multilevel water governance to forge a new approach to the management of transboundary waters and strengthening of transboundary cooperation. By facilitating cooperation at multiple levels, BRIDGE complements and reinforces traditional high-level, inter-governmental diplomacy on water. It promotes agreements on water management as well as their implementation by water users. BRIDGE helps to create the dialogue spaces and cooperation mechanisms needed to operationalise water cooperation.

Over the first two phases of BRIDGE, between 2011 and 2015, global-level processes for water cooperation have shifted in three main ways: first, the entry of the United Nations Convention on Non-navigational Uses of International Watercourses, which constitutes a fundamental milestone for the global management of transboundary waters; second, the globalization of the UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes, which supplements the UN Watercourses Convention; and third, increasing attention in global discourse on how to promote and foster more effective hydro-diplomacy, including as support for implementation of the future Sustainable Development Goals. The adoption and coming into force of these global frameworks is deepening the need for effective means of operationalising water cooperation. The demands for approaches to facilitating water cooperation provided by BRIDGE are only likely to grow in the future.

In this context, BRIDGE aimed to address increasing efforts for cooperation and capacity building for transboundary water management among different stakeholders. Technical capacities at global, regional and transboundary levels have proved to be essential in supporting and promoting negotiations between governments leading to the creation of transboundary agreements. These capacities contribute to the formation of local, national and transboundary institutions needed to facilitate implementation of cooperative arrangements. BRIDGE adopted a tailored approach in each of the basins where it worked, in order to support and strengthen the management of transboundary waters according to the existing governance situation in each case. The programme channeled expertise through governance-related learning and practice, international water law, benefit sharing, and national governance, to foster dialogue and enhance stakeholders' technical capacities through training.

The approach of BRIDGE to hydro-diplomacy is premised on the idea that without effective water governance, planning for the management of shared water resources is impeded. Water-related vulnerabilities of marginalised people then go unaddressed, leading to weaker and less resilient livelihoods. Opportunities for economic growth are weakened and transboundary ecosystems are poorly managed. Moreover, experience from IUCN and elsewhere has shown that water governance capacity is built most effectively where stakeholders participate and it is coordinated from local to national and transboundary levels.

BRIDGE builds on the IUCN *'Strategy for Creating Water Governance Capacity,'* which aims to catalyze sustainable water resources development, including progress on safe water supply and sanitation, sustainable watershed management, biodiversity conservation and transboundary cooperation. The basic framework for this strategy comprises:

1. ***Demonstration*** **–** using demonstration and testing of how to make cooperation operational in a basin as the basis for confidence and trust building, shared learning and joint action on concrete steps in building national and transboundary water governance capacity;

2. ***Learning*** **–** using training and capacity building, for multiple stakeholders, including municipal and civil society actors as well as high-level national officials, in water governance, international water law and benefit sharing to improve understanding;

3. ***Dialogue for consensus building*** **–** using demonstration actions and learning events to catalyse new dialogues on technical, development and political matters;

4. ***Leadership Development*** **–** supporting the empowering of champions for transboundary water cooperation and better water governance, who can effectively advocate for mobilisation of water diplomacy;

5. ***Support facilities*** **–** providing advice on demand and technical assistance to governments and stakeholders on water governance, including on effective institutional and

legal frameworks, and communications to promote applications of lessons learned, advice and demonstration results in transboundary hot spots regionally and globally.

BRIDGE 3 applied this framework to promote hydro-diplomacy in nine transboundary basins which are the Andes, Mesoamerican and Mekong regions in phases 1 and 2 of the programme (BRIDGE-1 and BRIDGE-2, 2011-2015). An additional 5 transboundary basins in Africa were incorporated into the programme for 2014-2015 (BRIDGE-Africa). In all cases, tailored and adaptive activities at multiple levels achieved incremental steps in cooperation for water management. The Phase 3 of BRIDGE aimed to consolidate and strengthen institutional development fostered by BRIDGE in these basins. Operationalising cooperation to ensure improved water governance delivers benefits for stakeholders, the cooperation mechanisms developed by BRIDGE are sustainable in the long-term and adopted by other institutions into their strategies for water diplomacy.

2.0 OVERVIEW OF LAKE MALAWI/NYASA/NIASSA BASIN

2.1 Biophysical Features of the LMNN

The Lake Malawi/Nyasa/Niassa (LMNN) is a sub-basin of the Zambezi river system, (Boost and Hecky 2003). LMNN ranks amongst the world's largest lakes, being third deepest and ninth largest by surface area. The basin consists of a series of half-grabens (blocks of earth that have tilted and dropped during rifting). Some parts of the lakeshore are bordered by steep mountains, while the mountains that define the edges of the rift valley are separated from the lake by extensive lakeshore plains in other parts. Because of this nearshore topography it varies between gently sloping beaches and steep, rocky coastline. The lake itself is underlain by more than 4 km of sediment in its deepest regions, reflecting its great age, estimated at several million years (Boostma and Hecky, 2003) The catchment area of LMNN is 97,740 km^2, of which 64,373 km^2 (65.9%) lies in Malawi, 26,600 km^2 (27.2%) in Tanzania, and 6,768 km^2 (6.9%) in Mozambique (Department of Water/UNDP, 1986) (Fig. 1&2). The maximum length of the lake is approximately 570km, but it is comparatively narrow with an average width of about 48 km (Kanyika, 2000), but ranges from 25-75 km. LMNN has a mean depth of 260m and a maximum depth of 700 m, a surface area of 29,743 km^2, and a mean lake level of 474 m above sea level (Chavula, 2016) (Table 1). Nearly 52% of the river inflow into the lake is derived from catchments in Tanzania in particular Songwe and Ruhuhu Rivers. The northern two-thirds of the watershed are predominantly a mixture of woodlands (evergreen, Brachystegia) and agriculture. The southern third is woodland on the Mozambique coast, and almost completely cultivated land within the Malawi portion of the watershed, with the exception of the steep hillsides of the western side of the rift valley that are forest covered.

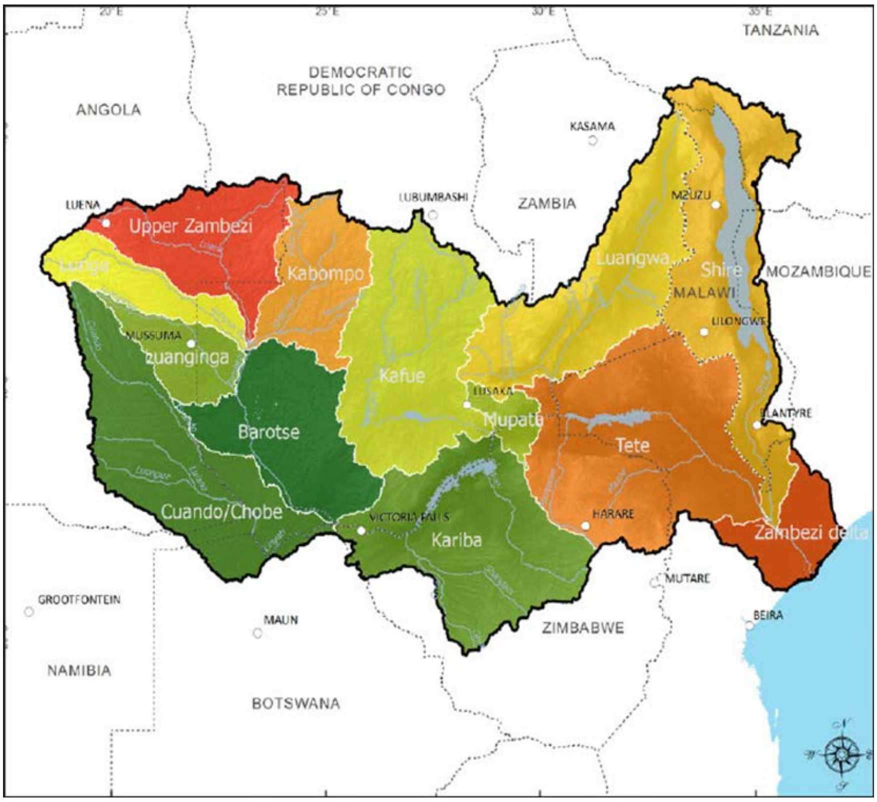

Figure 1. The 13 major sub-basins of the Zambezi River Basin. Map produced by J.-M. Mwenge Kahinda, CSIR-South Africa. (https://hub.globalccsinstitute.com/publications)

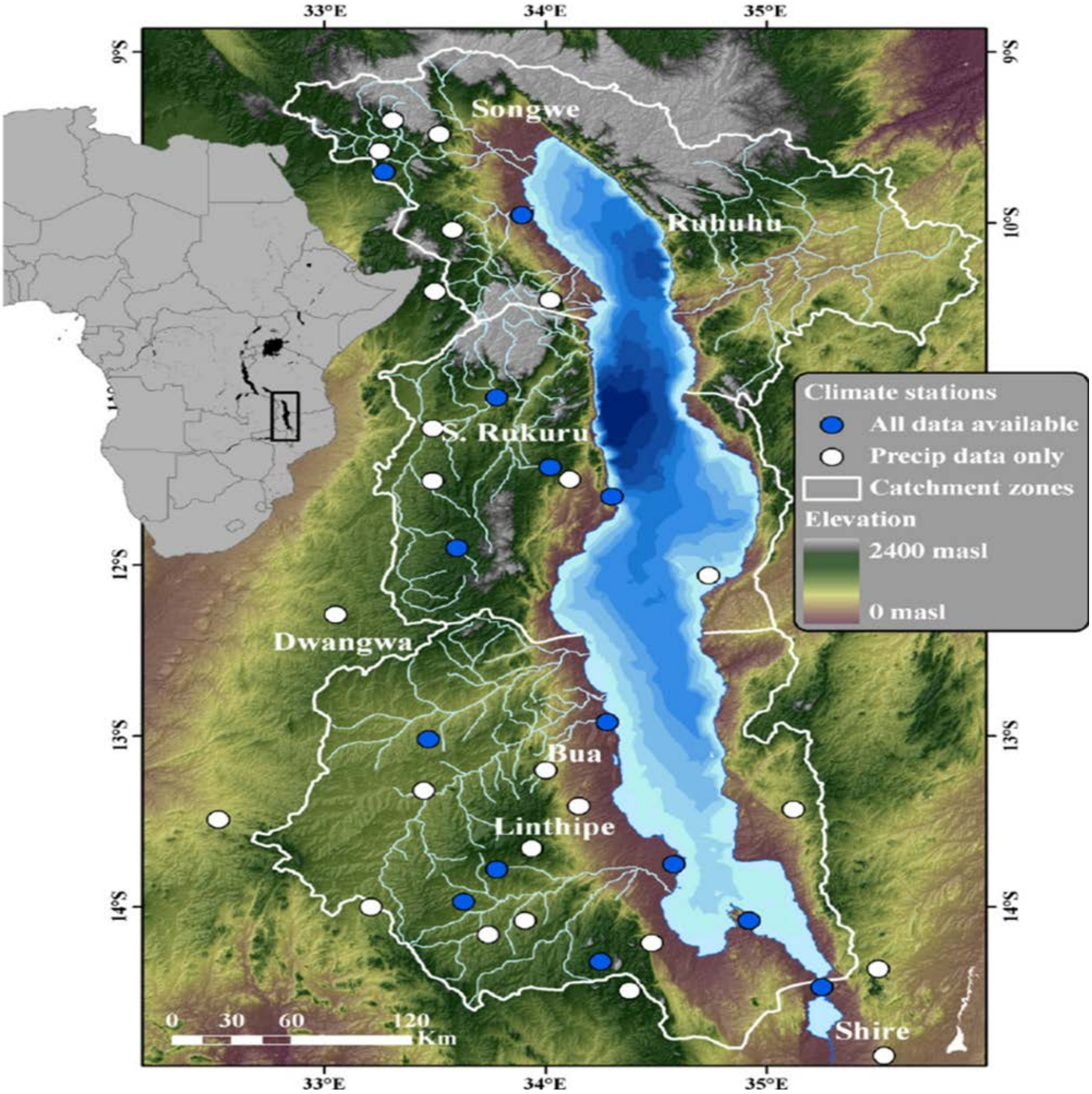

Figure 2. Map of LMNN Basin [Lyons *et al*, *2011*]

According to Bootsma and Jorgensen (2006), the lake may generally be classified as oligotrophic, i.e. low productivity. Basins with infertile soils release relatively little nitrogen and phosphorus leading to less productive lakes, classified as oligotrophic or mesotrophic. Watersheds with rich organic soils, or agricultural regions enriched with fertilizers, yield much higher nutrient loads, resulting in more productive, eutrophic (even hyper-eutrophic) lakes. In spite of its oligotrophic character, the lake is renowned for its rich biological diversity. It contains the largest number of freshwater fish species in the world, serving as a habitat to about 1000 fish species, most of which are endemic and dominated by cichlids (Kanyika, 2000). In recognition of its unique biologic diversity, the LMNN was in 1984 declared a World Heritage Site by UNESCO.

Table 1. Physical characteristics of Lake Malawi/Nyasa/Niassa (Hecky *et al.* 2006)

Feature	**Measure**
Length (km)	560
Maximum width (km)	75
Surface area (km^2)	28,000
Volume (km^3)	8,400
Maximum depth (m)	700
Mean depth (m)	292
Water level	regulated
Shoreline length (km)	1,500
Catchment area (km^2)	100,500
River inflow (I) (km^3/year)	29
River Outflow (O) (km^3/year)	11
Precipitation (P) (km^3/year)	39
Evaporation (E) (km3/year)	55
Flushing time (V/O) (year)	750
Residence time (V/(P+1))/year	140
Altitude (meters above sea level)	474

Boostma and Jorgensen (2014), highlight that of all the waters that enter into the lake only about 16% flows out the Shire River with the remainder being evaporated directly from the lake surface. Its long flushing time has ramifications on the lakes water quality since nutrients or other chemicals entering the lake become trapped in the lake and can only be removed by burial in the sediments, loss to the atmosphere, or very slow process of water outflow through the Shire River. The highest population density of the LMNN is in the southern Malawi portion, although it is also relatively high at the northern end, in Songwe and Kiwira River catchments.

2.2 Physical Characteristics of the LMNN

2.2.1 Physiography

In Malawi, four major physiographic zones are identified, namely: the high land areas, plateau areas, rift valley escarpment and rift valley plains (Water Department/UNDP, 1986). The plateau areas occupy approximately 75% of the land surface and range from 750 - 1300 meters in altitude while the rift valley plains comprise the flat land along LMNN and range from 450 - 600 meters in altitude. Except for the flood plains bordering the lake, in Tanzania, the Basin is generally hilly and mountainous up to an altitude of almost 3,000 m above mean sea level (m a.s.l), with the Rungwe, and Kipengere Mountains being the highest. The lowest area is around the Lake at about 470 m a.s.l. The peak of the Rungwe Mountain (Fig. 3) has an altitude of 2,960 m above sea level. The LMNN Basin in Mozambique ranges in altitude from about 500m to close to 1000m a.s.l.

Figure 3: Rungwe Mountain, view from Tukuyu (April 2013)

2.2.2. Climate of the LMNN Basin

The LMNN Basin experiences a tropical-continental climate with two distinct season's namely wet season from November to April and dry season from May to October (Chavula, 2008). The dry season is characterized by strong southeasterly trade winds that blow over the lake while, during the wet season the winds are generally weaker northeasterly winds. The Inter Tropical Convergence Zone (ITCZ), the Zaire Air Boundary (ZAB) and tropical cyclones are the three large scale synoptic systems that bring rainfall to the basin. The average annual rainfall over the LMNN basin and the lake itself is 996 mm and 1410 mm respectively (Shela, 2000) with an estimated annual lake evaporation of 1,610 mm (Kanyika, 2000). The climate of the LMNN basin is strongly influenced by the seasonal migration of the ITCZ over east Africa (McHugh and Rogers, 2001). The regional climate is also affected by the southeastern Africa convergence zone which is formed by three surface airstreams namely: southeast trades coming off the Indian Ocean, the northeasterly monsoon and the Atlantic air mass derived from the west (Rogers, 2001). Rainfall variability associated with this convergence in the southern parts of East Africa has been attributed to sea surface temperature (SST) characteristics in the South Atlantic Ocean, the equatorial pacific and the Indian Ocean as well as to the North Atlantic Oscillation (McHugh and Rogers, 2001). But the dominant pattern of influence appears to be a dipole structure in the Indian Ocean SST field; when the western (eastern) Indian Ocean is warm (cool), the Indian Ocean Dipole (IOD) is considered to be positive, easterly winds are enhanced across the equatorial Indian Ocean, and East Africa generally experiences high rainfall. The IOD is essentially the Indian Ocean version of the Pacific Ocean warming, which during a negative phase, causes warmer wetter conditions in the eastern Indian Ocean and cooler, drier conditions in the western region (Boostma and Jorgensen 2014; Chavula, 2016).

According to Chavula (2016), while the outlook for stable or rising lake levels may be promising, given some climate model predictions for increased precipitation during the coming decades, this may be offset by increasing human demand for water due to increasing population in the basin and by the increase in evaporation caused by rising temperature. LMNN could drop in level to the point where it becomes a closed-basin lake with no outflow down the Shire River. If the levels of the lakes drop significantly, the impact on society could be severe. Since the LMNN basin lies close to the boundary of the African rainfall dipole, it makes climate prediction for the region somewhat tenuous. Lake level fluctuations in the region as indicated in Fig. 4 show that the LMNN appears to be responding as a tropical East African system at present, but it may be vulnerable to shifting into the southern African sector of rainfall as climate evolves over the coming decades.

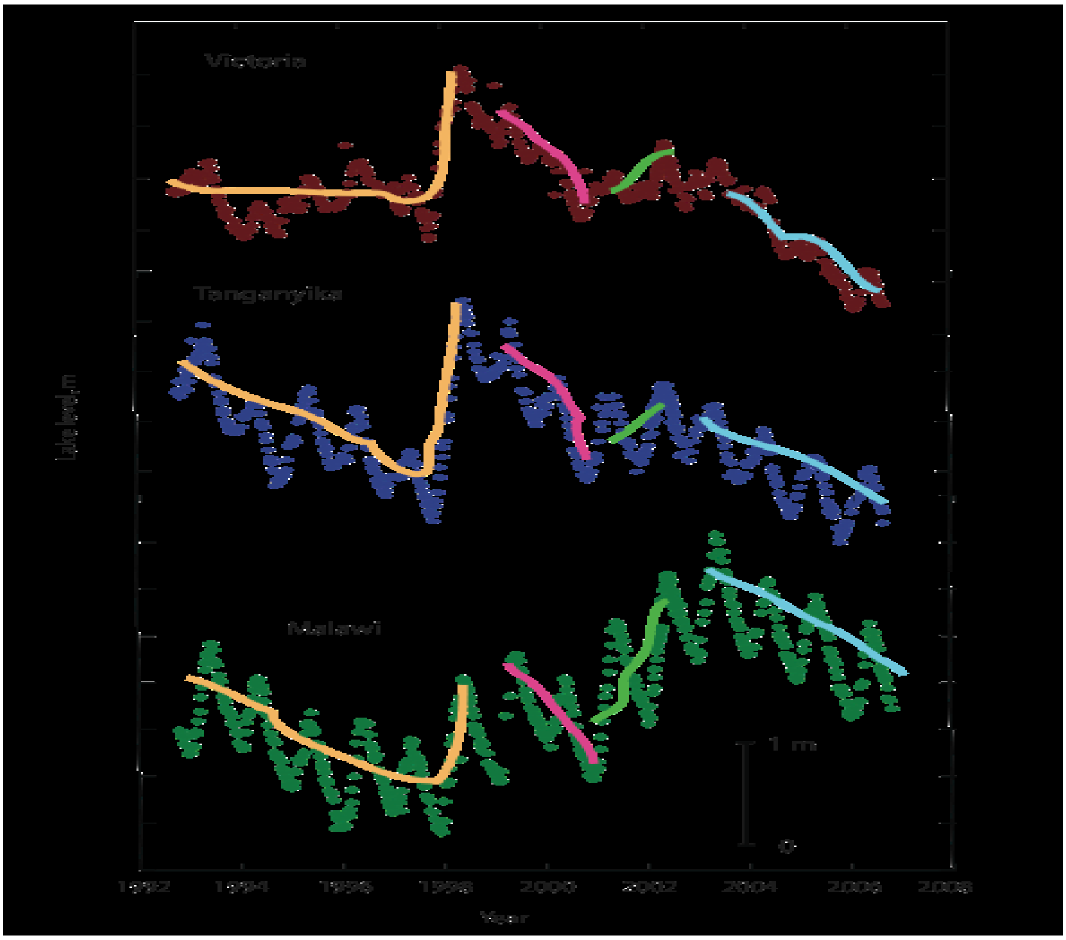

Figure 4: Satellite radar altimetry of lake levels in East Africa, 1993 – 1997 from TOPEX and Jason.

Nicholson *et al.*, (2013) divided Malawi into four homogeneous rainfall regions as depicted by Figure 5. It is clear from Figure 4 that LMNN mostly falls in Zone 1, with its southern part falling in Zone 3.

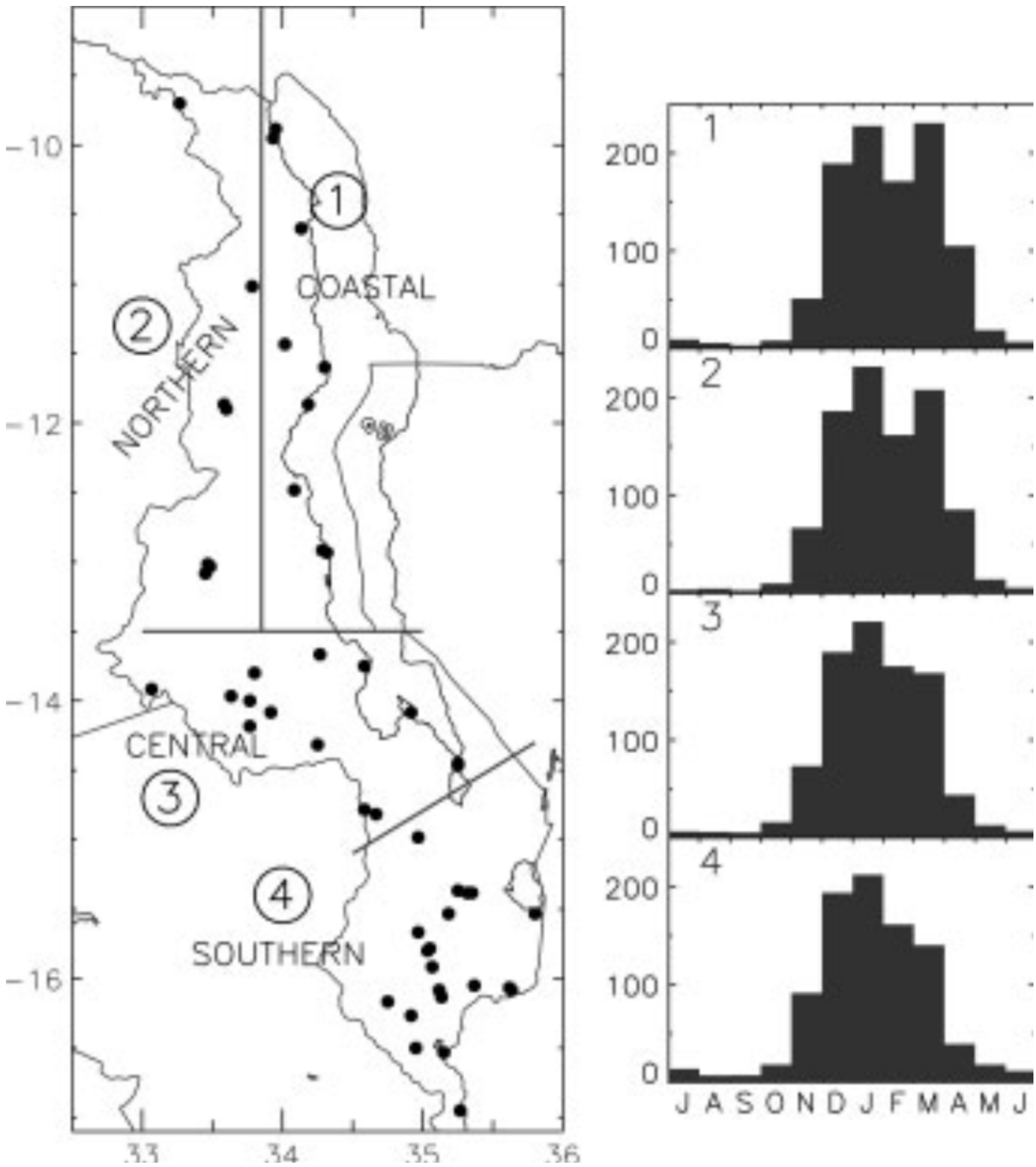

Fig 5: Four homogeneous rainfall regions of Malawi and the stations within them. Right: The typical seasonal cycle of rainfall (mm per month) in each region (Source: Nicholson *et al*, 2013).

According to Jin and Feng, (2013) the volume variations of water stored within Lakes and reservoirs are the indicator of the combined impact of climate change and water cycle. The overall lake water volume depends on the balance between the water inputs and outputs. The inputs are the sum of direct rainfall over the lake surface runoff from the drainage basin area, and underground seepage (which can be neglected). The outputs are the sum of direct evaporation from the lake, river outflow, and groundwater seepage. Groundwater seepage is usually a minor component of the water budget and can be neglected or defined as a constant value in the water budget equation (Cretaux and Birkett, 2006). Some of these components can be remotely sensed (e.g. rainfall, lake level), while others can be estimated from global and regional hydrological models (e.g. evapotranspiration). The great lakes of East African Rift Valley, which include the LMNN, are unique natural resources that are heavily utilized by their bordering countries for water supply (drinking, agriculture, industry, and hydropower production), transportation, fish production, waste disposal, recreation, and tourism. The population density is high and heavily concentrated near the lakes (Cohen et al., 1996). However monitoring of water storage variations in the LMNN is difficult because of the lack of a comprehensive global monitoring network that is costly and demands strong labour intensity. The satellite gravimetry, particularly the Gravity Recovery and Climate Experiment (GRACE) mission, provides a unique opportunity to detect continental water storage variations (Jin et al., 2010, 2012).

2.2.3 Soils and Rock Types of the Basin

Geologically, most of the area in the LMNN Basin is underlain by crystalline metamorphic and igneous rocks of Pre-Cambrian to Lower Palaeozoic age commonly referred to as the Pre-Cambrian Basement Complex (Figure 6). These rocks are overlain uncomfortably by younger sedimentary and volcanic rocks. Along the shore of the lake, the bedrock is covered by unconsolidated Quaternary alluvium. The basement complex rocks have been subjected to several phases of deformation and metamorphism affecting large tracts of Africa. Biotite and hornblende gneisses are most commonly encountered, although other rock types are often interbanded with them.

The soil type in the LMNN basin determines the nutrient concentration of the LMNN, which is considered low, phytoplankton concentration is also low (Figure 7). Boostma and Jorgensen (2014) revealed that the surface water concentrations of dissolved nitrogen and phosphorus typically are below 0.4 µmol/L and 0.1 µmol/L respectively, and the chlorophyll-a concentrations (used as an index of phytoplankton abundance) are below 1 µg/L. According to Boostma and Jorgensen (2014) the nutrient concentration is a poor indicator of the rate at which nutrients are delivered to a lake, primarily because nutrients are rapidly assimilated by phytoplankton. Thus, their concentration may remain low even when nutrient delivery rates have increased. While there is insufficient historic data on nutrient inputs from rivers to determine if inputs to the lake have increased, analysis of sediments in the lake provides an alternative method of examining the lake’s history. Recent sediment cores suggest that phosphorus inputs to the southern half of the LMNN have steadily increased compared to the northern half of the LMNN over the past half century (Hecky et al.1999). According to Guildford et.al. (2003) phosphorus appears to be an important nutrient controlling phytoplankton production in the lake and increased inputs of this nutrient might be expected to produce increased phytoplankton abundance. A comparison of phytoplankton species composition in sediment cores, suggests there has been a shift in species dominance particularly in the southern part of the LMNN where the previously common Planktolyngbya nyassensis has been replaced by Planktolyngbya tallingi, a species more commonly seen under conditions of higher nutrient concentrations and lower light availability (Hecky et al. 1999). In addition, the potentially toxic species Cylindrospermopsis raciborski was recently reported. Understanding of the lower food web structure in the

LMNN is insufficient to determine whether or not such changes may affect the zooplankton and fish production.

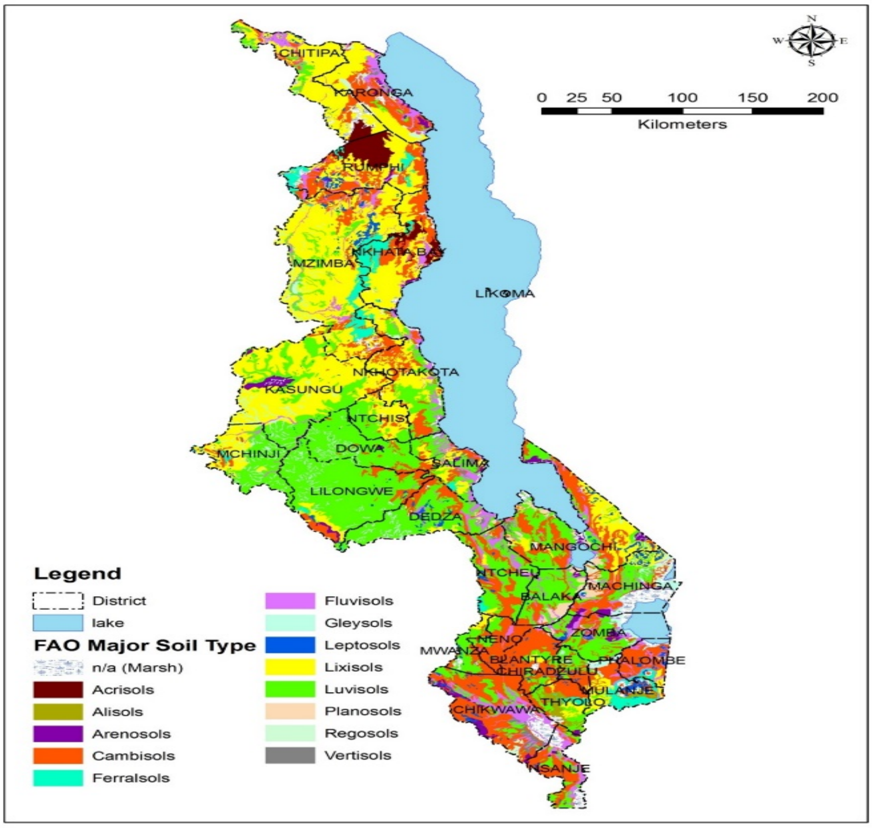

Figure 6: Soil Types (Source: GoM, 2015)

It is apparent that land use changes and erosion of phosphorus-containing soils have been the most likely cause of increase in phosphorus input to the lake particularly in Malawi where the large population relies directly on subsistence agriculture for food. High population density is resulting in the expansion of subsistence agriculture to marginal lands, including wetlands and steep hill slopes. An indication of the extent of erosion in the LMNN basin is provided by a comparison of dissolved organic carbon: (DOC) and particulate organic carbon (POC) concentrations in tributary rivers. In undisturbed rivers, the DOC concentration is generally about 10 times the POC concentration. In contrast, in many LMNN tributaries, the POC concentration is much higher than the DOC concentration (Ramlal et al. 2003), suggesting exceptionally high erosion rates within the basin. Not only do these erosion rates result in accelerated nutrient inputs to the lake, the high suspended sediment loads in rivers increase the turbidity of near-shore waters. Data collected by Duponchelle et al. (2000) indicates that greater turbidity leads to decreased body condition in rock-dwelling cichlids in LMNN.

In addition to catchment erosion, a large proportion of the nitrogen and phosphorus entering the lake originates from the atmosphere due to large biomass burning that occurs in the LMNN, and increased exposure of soil to wind erosion, promoted by burning, deforestation and overgrazing of the land. Changes in land use not only affect erosion and nutrient inputs to the LMNN, they also appear to have had a significant effect on the hydrology within the basin.

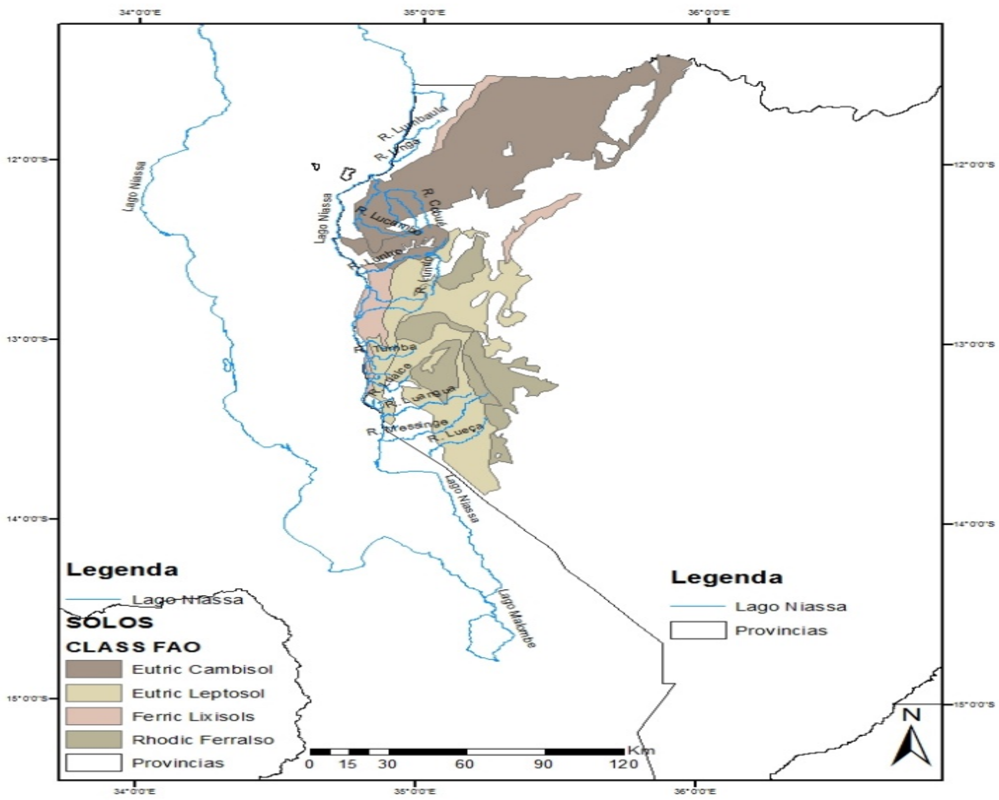

Figure 7. Soil Map of Lake Malawi/Nyasa/Niassa Area (Mozambique)

2.2.4 Vegetation Cover and Land Use

The natural vegetation cover over most of the LMNN basin is “miombo” (Brachystegia) deciduous woodland, but this wood resource is under severe pressure for domestic uses because of the population increase (Figures 8, 9 and 10). Larger areas of forest remain in the northern (and mountainous) catchments of the basin. All rural households in the basin use wood for cooking while 90% of urban households use charcoal. The twin catchment pressures of agriculture and biomass for energy have led to high rates of forest loss with substantial consequences for the water quality and quantity as well as increasingly erratic river flows (Hecky et al 2003). In order to avert the situation the governments of the riparian countries will inevitably need to promote economic diversification in order to lessen the direct dependence on land access, although current emphasis is on maximizing agricultural production.

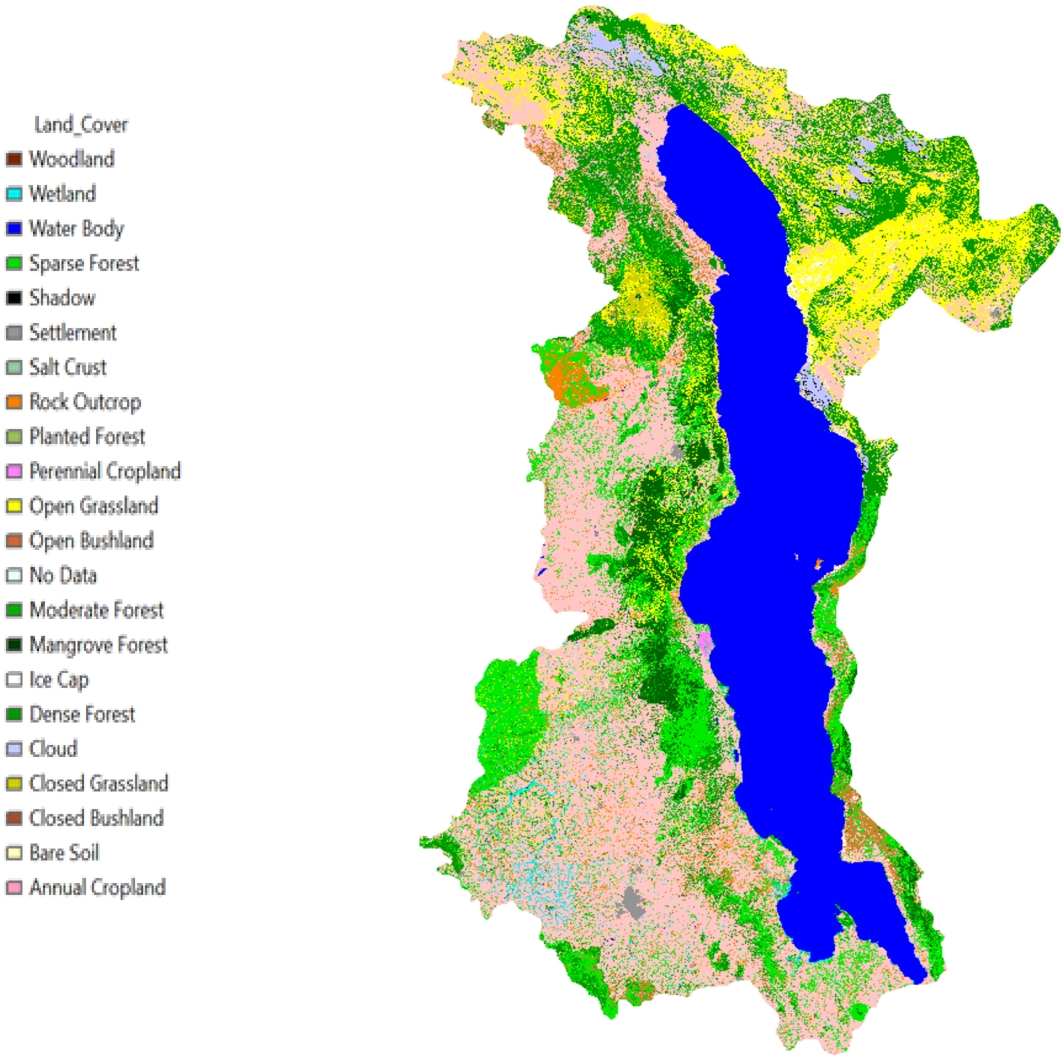

Figure 8: Land Cover Map for 2010 (Source: RCMRD)

Figure 9: A typical Thrush and Burn field (Chitipa District)

Figure 10: Newly burnt Thrush and Burn field (Chitipa District)

2.2.5 Evaporation and Evapotranspiration (ETo)

Evaporation is usually measured using evaporation pans, or estimated from data usually collected at meteorological stations. It is generally accepted that the well-known Penman method is the most accurate method to estimate open water evaporation, ETO. The main use of meteorological data other than rainfall in Basin hydrology is to estimate potential evapotranspiration. Most often this is done using the Penman – Monteith method in the form proposed by FAO (1998) to estimate the so-called crop reference evapotranspiration (ETo).

Figure 11 shows estimates of ETo values collected by the SMEC from three stations at the border of the Basin or just outside the basin at Mbeya, Njombe and Songea and Karonga.

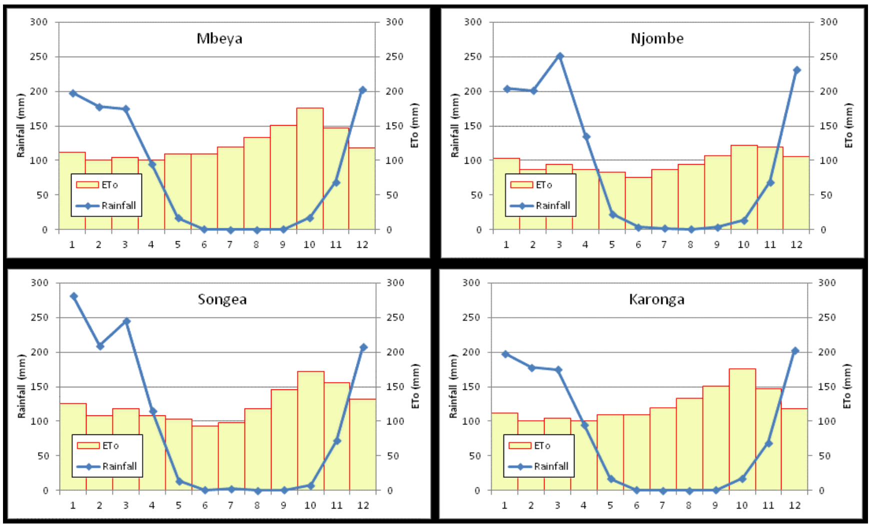

Fig. 11. ETo values for four stations

The annual mean rainfall and mean ETo data determined from these stations is summarized in Table 2, below:

Table 2: The annual mean rainfall and mean ETo in mm/year for four stations

Station	**Altitude m (a.s.l)**	**Latitude (deg)**	**Longitude (deg)**	**Mean rainfall (mm/year)**	**Mean ETo (mm/year)**
Mbeya	1,701	-8.93	33.46	955	1,479
Njombe	1,890	-9.41	34.75	1,140	1,166
Songea	1,067	-10.64	36.68	1,157	1,478
Karonga	529	-9.95	33.88	799	1,687

2.5.6 Actual Evapotranspiration

SMEC have shown that in a climate with a pronounced dry season such as in the Basin, the actual evapotranspiration usually falls short of the potential evapotranspiration. For selected catchments in the Basin average annual rainfall, runoff, and evapotranspiration values are given in Table 3.

Table 3: Average annual water balance

River	Catchment	Rainfall	Runoff	Evapo-transpiration
	(km^2)	mm/year	mm/year	mm/year
Songwe	3103	1747	440	1307
Kiwira	187	2064	930	1134
Kiwira	709	2134	920	1214
Rumakali	400	1977	878	1099
Ruhuhu	1979	1409	516	893
Kitewaka	2135	1268	478	790
Rutakira	5557	1286	246	1039
Ruhuhu	14331	1268	330	938

At all the stations, ETo exceeds runoff by as much as 4x while rainfall exceeds ETo. The lowest ETo loss of water as ETo is 55% of rainfall at Kiwira and the highest is 80% of rainfall at New Bridge on the Rutakira river. In the north and north-east of the basin, there is net gain of water as runoff into the rivers that flow into the lake. Percentage runoff range from 20% to 45% of rainfall. The areas with high percentage runoff are also prone to floods.

3.0 CLIMATE CHANGE AND VARIABILITY

Climate change has been defined by the Intergovernmental Panel on Climate Change, IPCC (2001) as statistically significant variations in climate that persist for an extended period, typically decades or longer. It includes shifts in the frequency and magnitude of sporadic weather events as well as the slow continuous rise in global mean surface temperature. Climate, water resources, biophysical and socioeconomic systems are interconnected in complex ways, so a change in any one of these induces a change in another. Anthropogenic climate change adds a major pressure to nations that are already confronting the issue of sustainable water resource use, such as in the LMNN basin and the African continent as whole.

3.1 Climate Conditions of the LMNN Basin

The basin is characterised by a warm temperate climate with dry winters and warm to hot summers. There are large elevation differences across the basin, and as such temperatures vary significantly. Most rainfall occurs in the northern parts of the basin.

The dominance of precipitation and evaporation in the lake's hydrologic cycle mean that it is very susceptible to changes in climate. Flooding is a recurring phenomenon in the Kyela Floodplain on the north side of the lake as well as the southern end of the lake in Salima and Mangochi, where agriculture is the predominant economic activity. The frequency of extreme climate events such as drought and flood has been increasing within the basin in recent years, with the severity of drought events more pronounced in semi-arid areas. The lake is particularly prone to unevenly distributed rainfall and periods of drought (Boostma and Jorgensen, 2014).

Recent climate trends within the basin show a temperature increase of 0.9°C between 1960 and 2006 (McSweeney *et al*., 2008). The increase in temperature has been most rapid in December-January-February. Climate Change Studies undertaken by the Government of Malawi and presented in the Initial and Second National Communication reports revealed the following conclusions resulting from climate change in the country (GoM, 2002; GoM, 2011b):

a) Temperatures would rise by between 1ºC and 3ºC under climate change scenario;

b) Rainfall would increase by between 5% and 22%, or decrease by between 1 per cent and 16 per cent, depending on the model used and location; and

c) Rivers in Malawi are very sensitive to changes in rainfall, hence generally the frequency and magnitude of heavy storms and droughts would increase resulting in severe floods and devastating droughts.

3.2 Impacts of Climate Change in the Basin

Observable and potential effects of climate change on water resources in Africa include: flooding, drought, change in the frequency and distribution of rainfall, drying-up of rivers, receding of water bodies, landslides, and cyclones among others (Urama and Ozor, 2010). The impact of climate change on water resources of the LMNN through the hydrological cycle increase floods and droughts and these have huge social and economic impacts on the three riparian states of the LMNN. The prospect of climate change brings a new element of uncertainty to the management and development of water resources in the LMNN.

General Circulation Models (GCMs) were used to establish future climate scenarios in the basin. Seasonal rainfall projections tend to decrease for the dry season, and increase in the wet season rainfall, although there are variances across the basin and models indicated disagreements in projected changes in the amplitude of future El Niño events. Deep tropical lakes are also experiencing reduced algal abundance and declines in productivity because stronger stratification reduces upwelling of nutrient-rich deep water. Recent declines in fish abundance in the East African lakes (30% in Lake Tanganyika) have been linked with climatic impacts on the lake ecosystems[1].Climate affects a wide range of the environmental resources that are key

[1] Climate Change Report: Preparation of an Integrated Water Resources Management and Development Plan for the Lake Nyasa Basin May 2013 (Final May 2015)

attractions for tourism, such as wildlife productivity and biodiversity, water levels and quality. Climate also has an important influence on environmental conditions that can deter tourists, including infectious disease, wildfires, insect or waterborne pests, and extreme events such as cyclones.

The adverse effects of climate change, such as increased incidence of drought, will aggravate the impacts of increased demand and deteriorating water quality. In places like Ruaha National Park ecosystem, droughts have significant impacts on wildlife and hence tourism (URT, 2002). Other impacts of climate change are already evident for example, Tanzania has witnessed occurrence of extreme weather events, with impacts on the agriculture, energy and business sectors, as well as environmental and ecological impacts. The droughts that have affected the LMNN over the years are all associated with the El Niño Southern Oscillation phenomenon (ENSO). Climatologists have established a highly significant relationship between ENSO and inter-annual variations in rainfall in Southern Africa. But it is not a simple canonical relationship: not every El Niño event brings low rainfall; and in some years extremely low annual rainfall is not clearly linked to El Niño events (WB, 2003). Much less well-understood oceanic -atmospheric interactions in the Indian Ocean and Southern Atlantic are now recognized as important influences on rainfall patterns in the LMNN basin. Drought has been commonly seen as the main climate issue in the LMNN. Given this scenario, climate forecasting and Early Warning Systems need to give more attention to potentially extremely high rainfall events and that localized monitoring and agro-meteorological interpretation of data is needed to reflect the significant variations between and within countries in the basin in order to inform critical decisions.

Table 4: Impacts of climate change by sector and effect (source, Chavula 2016 and Faraji, 2016)

Sector	Effects of higher temperatures	Effects of increased drought episodes	Increased rainfall & shift in seasonality	Effects of rise is sea level	Impacts
Human health	Shifts in disease vector habitats / incidence of malaria; respiratory problems	Increased risk of water related disease; food shortage; water conflict; famine. 2 Million affected by food shortages in 2006/7 in the Basin	Increased risk of waterborne disease; flood/ landslide risk	Inundation in low lying coastal areas; possible elevated salinization of coastal aquifers	Conflict; health burdens and risks; economic costs; poverty; inequity
Agriculture and food security	Shift s in the viable area for coffee and cash crops; reduced maize output; higher evapotranspiration losses	Crop failure; reduction in grazing lands and stock loss	Elevated erosion, land degradation crop loss; change in crop yields/disease	Limited to potential impacts on marine coastal fisheries	Food insecurity; economic shocks; loss of incomes and livelihood options; poverty

Sector	Effects of higher temperatures	Effects of increased drought episodes	Increased rainfall & shift in seasonality	Effects of rise is sea level	Impacts
Infrastructure and settlements	evaporative losses; damage to roads; cooling costs	Significant implications for HEP; water shortage	Flood damage to infrastructure, transport, communications and Settlements. Only 3% of roads are sealed	Coastal inundation and modification to port facilities	Economic loss and growth volatility; reduced reliability of HEP; migration
Environment and biodiversity	Biodiversity loss as niches are closed out; changing ecosystem dynamics and production	Additional pressure on natural resource use (forests and fisheries)	Shift in habitats and growing seasons	Potential impacts on marine coastal ecosystems	Impacts on biodiversity and agro-ecological systems; fishery productivity deforestation

3.3 Responses to Climate Change Impacts: Mitigation and Adaptation

There are usually challenges when making decisions on what to do in order to respond to climate change impacts. Some of the challenges include the sheer magnitude of the changes required to mitigate and/or adapt successfully to climate change, and the global free riding problem that impedes consensus on who should pay for those changes (Henderson et.al. 2018) The general consensus is to limit global warming to 2°C (3.6°F) above pre-industrial levels by the end of the 21st century in order to avoid potentially dangerous impacts. However, this requires atmospheric concentrations of CO2eq to remain below 450 ppm. Many scientists argue that reducing emissions requires greatly increasing the efficiency with which energy is used; “decarbonizing” the world’s energy system using renewable energy or carbon capture; and changing land use and management. Responses to climate change impacts in the LMNN basin requires implementation of both mitigation and adaptation strategies such as

a) The implementation of actions intended to reduce the magnitude of anthropogenic GHG emissions and enhance sinks;

b) Technological change and substitution that reduces resource inputs and emissions per unit of output;

c) The implementation of policies to reduce greenhouse gas emissions and enhance sinks; and

d) Actions that result in the reduction of net greenhouse gas emissions, including increasing energy efficiency, reducing energy consumption (e.g., through public transportation, the design cities and buildings), reducing emissions from known sources, and increasing the rate at which carbon is removed from the atmosphere (i.e., carbon sequestration through afforestation and reforestation programmes).

The three riparian countries have each developed the National Adaptation Programme of Actions (NAPA), 2006 for Malawi and 2007 for Tanzania and Mozambique respectively, which provide a process for identification of priority activities that respond to the countries' urgent and immediate needs to adapt to climate change. These NAPAs were submitted to the Conference of Parties (COP 21) held in Paris in December 2015. Priority actions in the NAPAs are summarised in the table 5 below:

Table 5: Prioritized Actions for the NAPAs for Malawi, Tanzania and Mozambique

Country	**Prioritized actions**
Malawi	• Sustaining life and livelihoods for the most vulnerable communities, • Enhancing food security and developing community based storage systems for seed and food, • Improving crop production through the use of appropriate technologies, • Increasing resilience of food production systems to erratic rains by promoting sustainable dimba production of maize and vegetables in dambos, wetlands and along river valleys, • Targeting afforestation and re-afforestation programmes to control siltation and the provision of fuel wood, and for their benefits, such as sources of alternative cash income, • Improving energy access and security in rural areas (e.g., through extension of the rural electrification programme, energy-efficient stoves and development of ethanol-based stoves), • Improving nutrition among rural communities (e.g., through the promotion of fish farming, rearing of small ruminants and nutritional supplements for children and the sick), • Disseminating bed nets in high incidence malaria areas, • Developing food and water reserves for disaster preparedness and response, 10) Developing community based wildlife ranching and a breeding programme for Nyala, • Developing and implementing strategies for drought preparedness, flood zoning and mitigation works, • Developing technologies to mitigate climate change, • Providing standby power generation facilities, • Managing forest fires in collaboration with communities, • Developing small dams, and other storage facilities, to mitigate flooding, to harvest water and to initiate community based fish farming and breeding.
Tanzania	• Increase irrigation by using appropriate water efficient technologies to boost crop production in all areas • Alternative farming systems and relocation of water sources including wells along the low lying coastal areas • Develop water harvesting and storage programmes for rural communities particularly those in drylands • Community based catchments conservation and management programmes • Explore and invest in alternative clean energy sources e.g. Wind, Solar, bio-diesel, etc. • promotion of application of cogeneration in the industry sector • A forestation programmes in degraded lands using more adaptive and fast growing tree species • Develop community forest fire prevention plans and programmes • Establishing and Strengthening community awareness programmes on preventable major health hazards • Implement sustainable tourism activities • Enhance wildlife extension services and assistance to rural communities in managing wildlife resources • Water harvesting and recycling • Construction of artificial structures, e.g., sea walls, artificially placing sand on the beaches and coastal drain beach management system • Establish good land tenure system and facilitate sustainable human settlements

Mozambique	• Strengthening of an early warning system • Strengthening capacities of agricultural producers to cope with climate change • Reduction of climate change impacts in coastal zones • Management of water resources under climate change

Source: Malawi NAPA, (2006), Tanzania NAPA, (2007) and Mozambique NAPA, 2007

4. WATER RESOURCES

4.1 Hydrology of the LMNN

A detailed discussion on the hydrology of the LMNN was given by Shela (2000) and Kumambala and Ervine (2010) (Table 6). On the Malawi side, the drainage system of the Basin comprises the following rivers: Linthipe, Bua, Dwangwa, Dwambazi, South and North Rukuru, Lufira, and these cover a total catchment area of 38,341 km2, representing 39.2 percent of the catchment of the lake (Figure 12) (Kumambala and Ervine, 2010). That being the case, the inflows from these rivers have a significant impact on the water level in the lake (Shela, 2000). Other rivers flowing into the lake include Songwe and Ruhuhu River from Tanzania. The only outlet of LMNN is the Shire River, the main source of hydropower generation in Malawi. As pointed out in the preceding discussion, the rainy season in the basin commences in October-November, and ends in April the following year. Both the land catchment and the lake rainfall peak up in March, with monthly totals of about 220 and 300 mm, respectively (Shela, 2000). Records of tributary flows show that they respond to the trends of the rainfall pattern. The inflows average about 910 m3/s or 1,000 mm depth over the lake per year and are the highest in April, with an average monthly flow of 2,080 m3/s, equivalent to a total monthly depth of 7.8 mm. Tributaries from Tanzania discharge about 52 % of the total inflow into the lake.

Water levels of the LMNN have been observed since 1896. However, the archiving of daily records commenced in 1915, with hydrometric stations located at Chilumba and Nkhata Bay in the northern region, and Monkey Bay in the southern region. The lake level is an average of the daily readings from the three stations. It is worth noting that there are insignificant seasonal differences of a few centimeters between the three stations throughout the year, most likely resulting from wind effects by south-eateries and monsoons. Thus, lake levels are dependent on rainfall over the lake, inflows from rivers draining into the lake, evaporation losses from the lake-surface and outflow from the lake through the Shire River.

One other hydrological aspect that has not been covered in the preceding discussion is the Environmental Flow Requirement for the LMNN Basin. Environmental flows describe the quantity, quality and timing of water-flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and wellbeing that depend on these ecosystems (The Brisbane Declaration of 2007). The purpose of an Environmental Flow Assessment (EFA) is to investigate and describe the environmental consequences of modified flow regimes in different parts of a river system, so that the required water quantities can be negotiated along with the required quantities for consumptive uses such as agriculture, livestock, fisheries, wildlife, industry, energy, recreation and other social and economic activities. Sound understanding of freshwater systems and human uses of water; clear policies and strong legislation that recognize the environment as a user of fresh water; and capable institutions to guide the management process are necessary in determining credible environmental flows. For all rivers in Malawi, a minimum dry and wet season flows of 15% and 24% of the natural annual flow respectively is mandatory (Atkins, 2013 WRIS).

Outflows from LMNN are controlled by Kamuzu Barrage at Liwonde, constructed in 1965 and recently reconstructed in 2019. The barrage consists of 14 radial gates. The justification for constructing a control gate at Liwonde is to mitigate the possibilities of failure to maintain the design flow of 170 m3/sec for hydropower generation in the middle reach of the Shire River. The physical operation of the barrage is done by Electricity Generation Company (EGENCO) on advice by the Hydrology Section of the Ministry of Agriculture, Irrigation and Water Development based on water levels in LMNN and the corresponding outflow records.

Table 6. Net Water Storage of Lake Malawi (Kumambala and Ervine, 2010)

Researcher	**Kidd (1983) [4]**	**Neuland (1984) [2]**	**Drayton (1984) [13]**
Data period	1954 – 1979	1954-1979	1953-1974
Rainfall over the lake (mm)	1414	1374	1350
Inflow into the lake (mm)	1000	693	693
Lake Evaporation (mm)	1872	1605	1610
Outflow from the lake (mm)	418	404	334
Change in storage (mm)	+112	+58	+59

The hydrological budget of LMNN is dominated by precipitation falling directly on the lake (1350 mm/y) and evaporation (1610 mm/y), with river inflow and storm runoff accounting for 650 mm/y and river outflow just 390 mm/y (Spigel and Coulter, 1996).

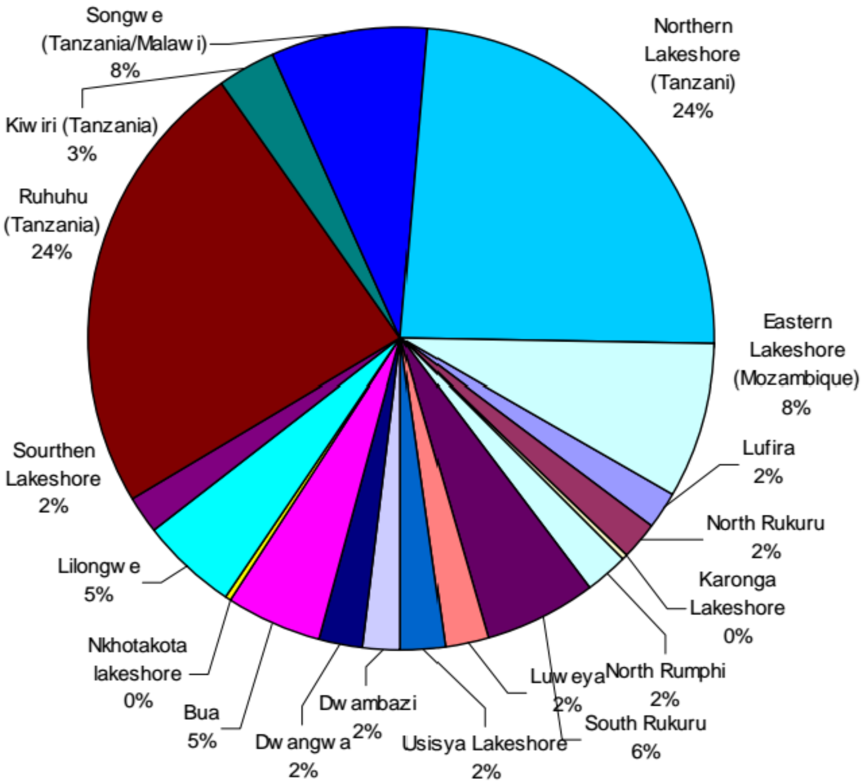

Figure 12. Lake Malawi inflow contribution from different catchments (Kumambala & Ervine, 2010)

The drainage system of the Basin comprises the following rivers:

(i) Linthipe, Bua, Dwangwa, Dwambazi, South and North Rukuru, Lufira (Malawi) and these cover a total catchment area of 38,341 km^2, representing 39.2 percent of the catchment of the lake (Kumambala and Ervine, 2010).

(ii) Songwe, Kiwira, Mbaka, Lufirio, Rumakali, Lumbira, Nkiwe, Mchuchuma, Ruhuhu and Mbawa (Tanzania). These rivers from Tanzania contribute 52% of all river inflows into the lake. This represents some 45% of the total inflow into Lake Malawi/Nyasa/Niassa.

(iii) Unga, Cobue, Lundo, Lunho, Umba and Uaice (Mozambique). There are no gauge stations on these rivers, so there is no estimate of inflow through them.

During the early years of the last century, the lowest level of 469.94 m a.s.l was reached in December 1915 and the outflow from the Lake ceased from 1915 till 1935 (Shela, 2000). In May 1980 a maximum level was observed of 477.16 m a.s.l. Thus the observed range in water levels is as large as 7.22 m. Figure 13 shows the observed levels at Mamba Bay and Figure 14 shows the water level projections up to 2050.

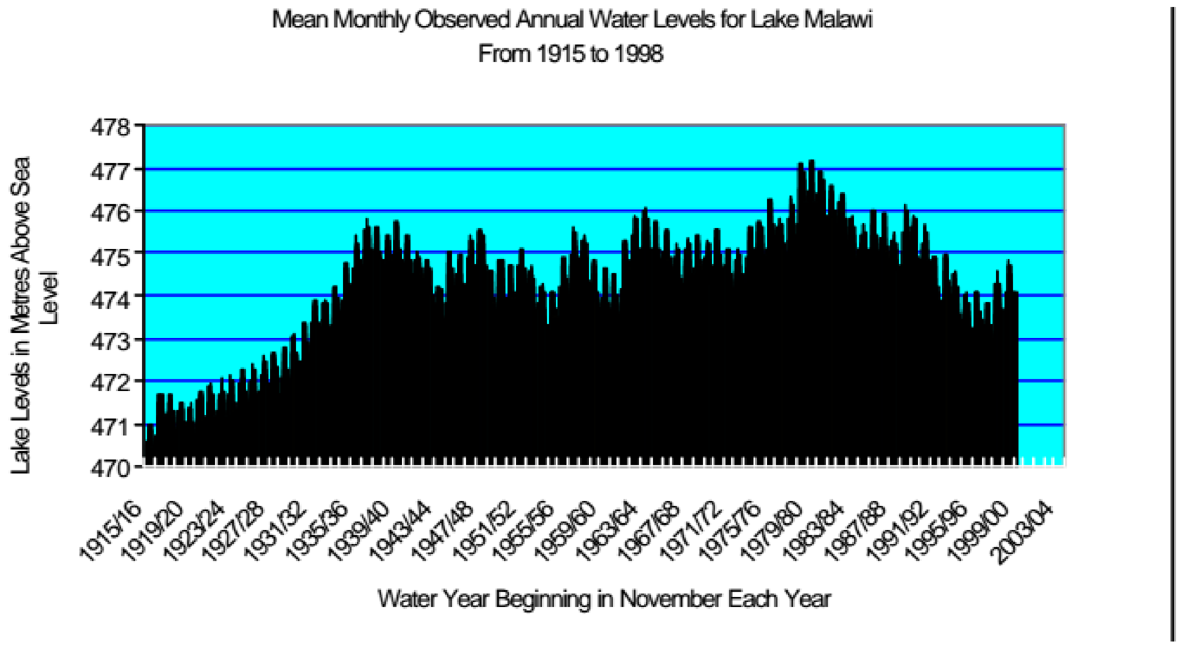

Figure 13. Lake Level Fluctuations (Shela, 2000)

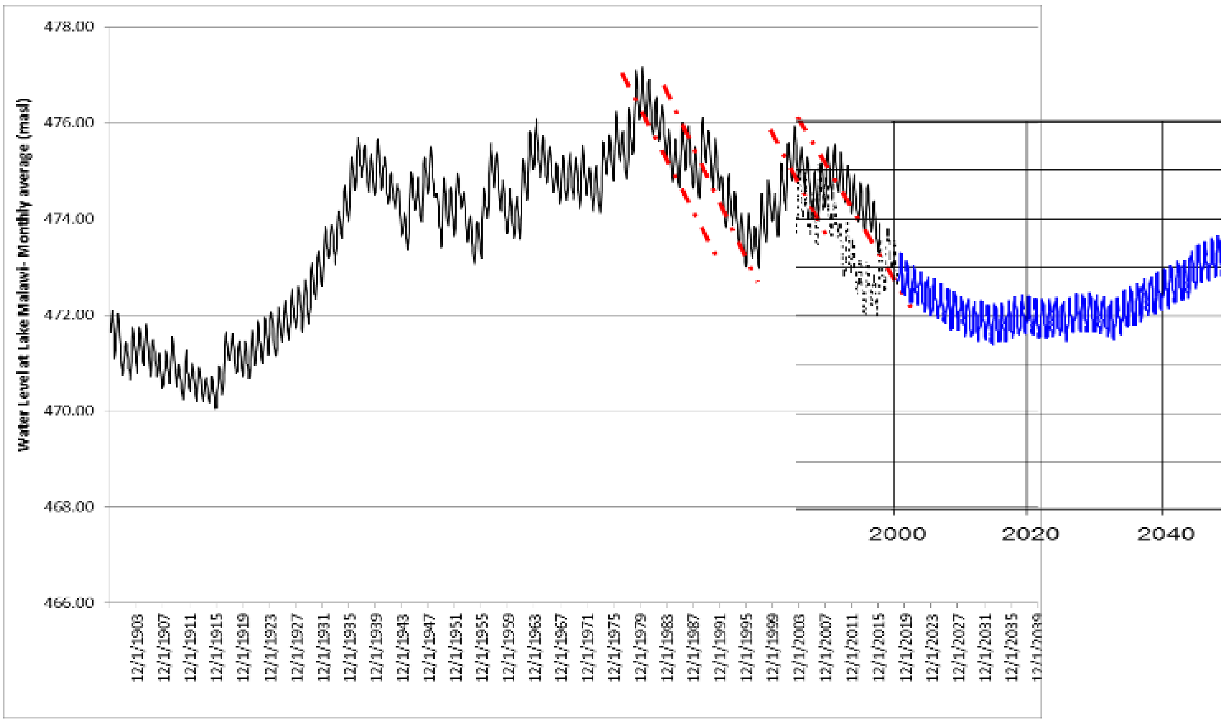

Figure 14: Water levels of Lake Malawi/Nyasa/Niassa – showing projections to 2050 (Source, Chavula, 2016)

Figure 15 (below) shows long-term monthly average water levels. The highest levels are observed between February and July while the lowest levels are observed from October to January. This follows the pattern of the rainy season.

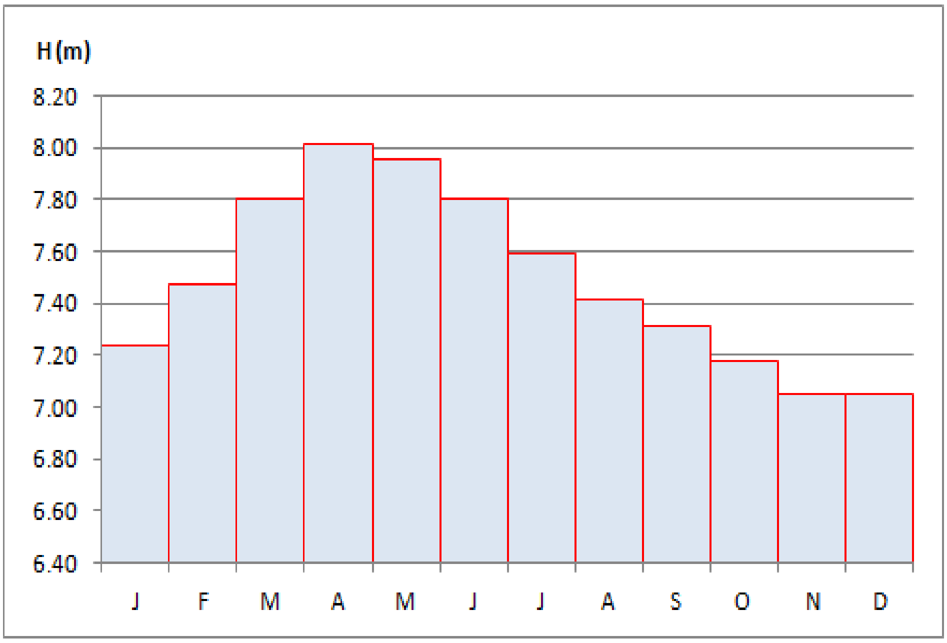

Figure 15: Average Monthly Water Levels at Lake Malawi/Nyasa/Niassa (1973 - 2012) (Source, Chavula. 2016)

4.2 Ground Water Resource Availability

The occurrence of groundwater within the basin is influenced by geology/geomorphology, followed by topography and rainfall, all of which influence recharge and discharge from the aquifer systems. However, development of groundwater within the basin is mostly influenced by topography and associated drainage patterns (Nears, 2016). Groundwater quality is generally acceptable for human consumption (Figure 16). Groundwater resources in the basement complex aquifer are characterized by the dominance of alkaline earths in the cation group, and by carbonates in the anion group. Borehole yields, defined as the volume of water that can be abstracted from a borehole, in the basin vary from nil or negligible to as high as 43 l/s or 1.35 million m3/year. Data from 2086 boreholes from a master database of borehole logs developed by Atkins (2011), and provided by the Ministry of Agriculture, Irrigation and Water Development were used to generate a spatial distribution of borehole yields in the Malawi part of the basin. Borehole yields are highly dependent on aquifer type. The highest yielding aquifers are the quaternary alluvium (QA) and weathered basement (WB) with average yields of 0.53 l/s and 0.73 l/s. The Karoo sedimentaries (KS) is a minor aquifer located in the western part of the area with lower average yields of 0.27 l/s and small maximum yields. Yields will vary considerably within the same aquifer depending on weathering, fracturing and the location of fault zones. Atkins (2011) notes that the mean yields for the three aquifers are very similar, which, given the different hydrogeological properties, is unusual.

Figure 16. Groundwater source for community in Meponda village, Mozambique [Chaeruca]

It is thought that the recorded yields are largely a function of borehole equipment and the nature of the yield testing procedure. Due to this observation potential yields for each aquifer were estimated from experience and from single aquifer tests, mainly in the alluvial aquifers in the Shire valley. The database of boreholes used in the analysis is by no means a complete dataset of all abstraction wells, which means that this is not a representation of present groundwater abstraction. Total yield for the catchment for the wells as a whole is approximately 40 million m3/year, which is somewhat lower than total estimated rural demands of around 50 million m3/year. Recharge to the aquifers is small in Basin and occurs mainly during February to March during the late part of the rainy season, when the topsoil is saturated and water is available for infiltration. Base flow is seasonal and occurs mainly during March to July as a result of the recharge to the groundwater storage. However, due to depletion of the vegetative cover of the catchments, surface runoff (resulting from rainfall events) occurs more rapidly than under natural conditions. This means that less water infiltrates to recharge the aquifers. The vulnerability of groundwater users to drought is increasing. Nears (2016) has estimated the relative vulnerability of groundwater with respect to availability (based on recharge) across the basin. There is need for long term monitoring of groundwater levels and extraction within the basin. It is therefore not possible to assess the current impact of extraction on the various aquifer systems. For example, in Tanzania, estimates for groundwater resources in the LMNN Basin have been attempted (Table 7).

Table 7 Estimated Safe Yield and groundwater usage for each Catchment (Source, Faraji, 2016)

Catchment	Recharge Volume (1,000 m³) for 2015	10% Recharge (= ASY; 1,000 m³)	% of ASY Used	Groundwater Available for Other Uses (1,000 m³)
Kiwira	78,745	7,875	46.3	4,226
Lufirio	47,134	4,713	35.2	3,056
Lumbira	86,265	8,627	9.5	7,810
Mbaka	30,993	3,099	5.1	2,940
Mbawa	81,521	8,152	18.9	6,613
Mchuchuma	31,413	3,141	7.4	2,909
Nkiwe	73,723	7,372	7.8	6,796
Ruhuhu	509,090	50,909	12.8	44,418
Rumakali	30,614	3,061	7.9	2,818
Songwe	100,530	10,053	36.4	6,394
Total	**1,070,028**	**107,003**	**18**	**87,979**

4.3 Water Demand Access and Use

There is a large proportion of the basin's population without access to potable water supply and sanitation services, exposing many to health risks such as water related diseases (Figures 17 and 18). Water service coverage would be higher if fewer systems were non-operational, malfunctioning or dried up because of extended drought events, as found in many areas (GoM, 2006).

Figure 17: Drawing water directly from the lake in Mozambique (Chaeruca)

Figure 18: People using Lake Malawi water, in Malawi (Photo: Hans Hillewaert)

The major water demand sectors in the LMNN Basin include:

(i) Domestic Water supply (including rural and urban water supplies);

(ii) Agricultural sector (mainly irrigation);

(iii) Livestock;

(iv) Hydropower sector;

(v) Industrial and mining and

(vi) Environment (related to river flows and lakes).

The agricultural sector is the largest water consumer in the basin, which also happen to be the significant contributor to all countries' GDP and employment. Major crops grown include sugar, rice, maize, and tobacco. Investment into irrigation schemes in the basin has been increasing, in an effort to boost agricultural productivity, such as seen through the Greenbelt Initiative in Malawi, and the Lower Songwe Irrigation Development project on the border of Malawi and Tanzania. The latter involves the construction of a dam and hydropower house in the districts of Kyela and Ileje, and the design of a gravity-fed irrigation scheme.

4.4 Water and Energy

In addition the LMNN is source of other economic benefits to Malawi which include electricity, transportation, tourism, as well as ornamental fish trade. The electricity produced in Malawi mostly comes from hydroelectric plants on the Shire River which drains from the LMNN. The fluctuations in the river discharge which is controlled by the LMNN water levels make the power generation on the Shire River precarious considering that the level of the LMNN is very sensitive to climatic changes. To avert the situation, the Malawi and Mozambique Government have signed a power sharing agreement to enable the two government to interconnect electrical power from Matombo power station in Mozambique's north western Tete province to the southern region of Malawi. With support from the Millennium Challenge Compact (MCC) through the Millennium Challenge Account-Malawi (MCA-M), the Malawi government has managed to upgrade the power transmission lines as well as the generation plants in order to prepare for the interconnection as well as promote independent power producers to generate power from various sources and sell to the power utility company Electricity Supply Commission of Malawi (ESCOM).

4.5 Water Quality and Pollution

Altkins (2011) reveals that surface water quality in the basin reflects upstream Lake Outflows with their contaminant inputs, in addition to 'within-catchment' flows and pollutant sources. The quality of Lake Malawi's water upstream has deteriorated over the last three decades, due to the point-source discharge of sewage as well as run-off from the agricultural sector becoming more diffuse. Both of these contain significant nutrient quantities. This has given rise to the proliferation of both native and alien invasive species in particular in the Shire Catchment, with the hippo grass *Vossia cuspidata* and the water hyacinth *Eichhornia crassipes* being of particular note. Floating mats of vegetation have created significant problems at all of the hydropower sites in the basin. Although more than 80% of the urban population have access to water supplied through pipelines from water treatment plants, more than 80% of the rural population do not, and instead have to rely on raw water for drinking, from sources such as boreholes, shallow dug wells, and intakes from rivers (gravity fed schemes). The quality of untreated water is easily degraded by environmental changes. The number of victims of water related diarrhoea increases every rainy season because river floodwaters are contaminated, and the overflow from latrine pollutes groundwater in boreholes and wells. In urban areas, sewage treatment plants tend to be abandoned due to lack of financial sources. Hence, sewage effluent overflows into the nearest river or stream from broken conduits and degrades the water. In addition, illegal waste disposal to rivers is widespread, though its impact and extent is unknown. Heavy industry, factories and mining activities release toxic substances such as mercury, cadmium, lead, radioactive substances, and so on, into the aquatic environment and may cause significant health problems to people and ecosystems, in the same way as developed countries have experienced. However, there is also evidence of water-borne diseases posing a serious public health concern throughout the basin, with the highest rates of occurrence in unplanned urban settlements and rural areas (Chavula, 2016). The extent to which this is the case in the entire LMNN basin is not known due to lack of monitoring data required to assess this issue.

5.0 ECOLOGY OF THE LAKE

5.1 Fish and Fisheries

The LMNN is the most species-rich lake in the world, and nearly 1000 of the fish species are endemic. Fisheries is the main economic use of the lake, providing about 70% of animal uptake by the citizenry. However, overfishing has caused catches of important species to decline but more importantly in the most economically valuable species such as the Chambo (*tilapia*). This has been exacerbated by the degradation of river and nearshore habitats partlu due to nutrient deposits. Nutrient increase is significant due to a combination of factors, including the low flushing rate of the lake; soil erosion due to deforestation; and atmospheric deposition from biomass burning and wind erosion. The northern part of the lake, including the Songwe and Ruhuhu rivers, is the focus of a significant number of planned mining developments. The Mozambican part of the lake is a National Park and Ramsar site; in Malawi, Lake Malawi National Park (LMNP) in the southern part of the lake is also a World Heritage site.

Fish resources from LMNN provide numerous economic and nutritional benefits to the local communities. The 2015 frame survey estimated that approximately 60,600 people are directly employed in the fishing industry (GoM 2016) and over 300,000 in related activities such as processing and marketing. The LMNN is not only unique because of its size but also for the fact that it is regarded as a global treasure for biodiversity (Ribbink 2001a). It is estimated that the lake harbors between 500 and 1,000 fish species (Snoeks, 2000) and approximately 99% are endemic (only found in this lake) to the lake. Considering the age of the lake, such a huge number of ichthyofauna represents one of the fastest and largest adaptive radiation and explosive speciation in human history (Owen et al. 1990). Out of the 500 to 1000 species inhabiting the lake, only a third are described formally or catalogued by a cheironym (Ribbink et al. 1983) and the number of describe species keeps on increasing with each taxonomic survey. A total of eleven families exist within the lake basin and is dominated by the Cichlidae family in terms of species richness, diversity and abundance. The cichlids within the basin comprise mostly of two major Meta populations, the Tilapiine and the Haplochromine. The Haplochromine comprise of 39 general and over 700 species. Several evolutionary biologists and molecular ecologists have attempted to provide reasons for the large number of species within the Cichlidae family and allopatric speciation, sympatric speciation, as well as speciation enhanced due to emergent colour morphs that play a very significant role in sexual selection are some of them.

Fish introductions in LMNN are rare apart from the relocation of some ornamental fish from their natural habitats. The rocky-shore, plankton-feeding cichlid fish *Cynotilapia afra* is endemic to LMNN, but in the 1960s, the species was relocated to the southern areas of the lake, presumably because of the aquarium fish trade (Figure 21). Since then, the species has established itself on a number of rocky habitats within the Lake Malawi National Park. The establishment and spread of *C. afra* is partly due to its ability to occupy a vacant ecological niche, and its enhanced genetic diversity (Zidana et al. 2009).

Although fish kills are a rare occurrence in LMNN, a massive fish kill took place from late September to November in 1999 (Bootsma and Jorgensen, 2004). It was alleged by the Ministry of Natural Resources and Environmental Affairs that upwelling triggered by prolonged winds over the lake during the stated period led to the extrusion of hydrogen sulfide from the anoxic hypolimnion zone to the epilimnion, in the process killing a wide spectrum of fish species occupying different ecological niches. Bootsma and Jorgensen (2004) suggested that toxic algae may have been one of the causes of the fish kill. The incident raises concerns that Lake Malawi/Nyasa/Niassa could experience more frequent fish kills in future should the basin be degraded to the conditions found in the catchment of Lake Victoria (Balirwa *et al*., 2003) and due to adverse impacts of climate change. Recent lake wide fish kills in Malawi occurred over the periods 2005-2006, 2010-2011, August 2014, and December 2014.

5.2 Phytoplankton

The first reports on the algae of the LMNN were those of Schmidle in the 1900s. More studies were conducted in the 1950s, 1980s and major contributions have come from Bootsma (1993), the UK/SADC Project (Patterson and Kachinjika 1995) and the SADC/GEF Project in the 1990's (Ngochera, 2016). Phytoplankton studies are very relevant in the limnological section due to their key role in primary production, as indicators of water quality and their impact on light distribution. Biomass and taxonomic composition of planktonic autotrophs and protozooplankton fluctuate throughout the year with a *Chroococcus* bloom in December and a preceding large increase of the diatom *Aulacoseira* between October and December (Bootsma 1993). The *Chroococcus* bloom coincided with a period of increased photosynthetic rate and Bootsma (1993) attributed that to an increased upward mixing of nutrients into the relatively shallow surface mixed layer. *Stephanodiscus* sp., are the most dominant phytoplankton species group in the lake (Patterson and Kachinjika 1995). Their importance increases into the mixed season, May to September when nutrient-rich hypolimnetic waters mix with surface waters. Cyanobacteria or blue-green algae are dominated by *Oscillatoria sp*. and *Microsystis aerugenosa* but the heterocystous *Anabaena flos-aquae* are most important during the stratified season. *Staurastratum leptocladium* and *Ankistrodesmus sp*. are the dominant green algae but their contribution to the overall phytoplankton biomass is very minor. The previously common *Planktolyngbya nyassensis* has been replaced by *Planktolyngbya tallingi*, a species that is more common under conditions of higher nutrient concentrations and lower light availability (Higgins et al. 2001). The potentially toxic *Cylindrospermopsis raciborski* has recently been reported. Although these changes seem to have occurred, our understanding of the lower food web structure in the lake is insufficient to determine whether such changes may affect zooplankton and fish production. Phytoplankton biomass is dominated by picoplankton, which contributes more than 60% (Ngochera, 2016). Chlorophyll *a* is lowest during the stratified season and increases into the mixing season with concentrations that range between 1.0 and 1.4µg/L. A comparative analysis of the autotroph biomass variability between the Great Lakes of Africa and those from North America indicate that variability is not lower in the tropical lakes than in the temperate lakes than previously thought, which provides evidence that nutrient availability is an important factor controlling seasonality.

It is worth noting that chlorophyll concentration is a common indicator of phytoplankton biomass and is the most important light absorbing compound present in algal cells. As demonstrated by Chavula (2008), the linear relationship obtained between *in situ* chlorophyll concentration and the ratio of normalized reflectance R443/R551 appears to be useful in estimating chlorophyll-*a* concentrations from MODIS/AQUA satellite imagery. This relationship may be coded into an equation to compute chlorophyll concentrations using SeaDAS, and the results can be presented in chlorophyll maps. Such maps could be valuable to watershed managers in designing and implementing appropriate best management practices (BMPs) in the catchment area (Chavula, 2008).

5.3 Zooplankton

Like many tropical freshwater systems, the zooplankton community of the LMNN is species poor (Ngochera, 2016). It comprises two species of calanoid (*Tropodiaptomus cunningtoni* and *Thermodiaptomus mixtus*), two species of cyclopoids (*Mesocyclops aequatorialis* and *Thermocyclops neglectus*), two species of cladocera (*Diaphanosoma excisum* and *Bosmina longirostris*), and the midge *Chaoborus edulis* (Hecky 1991, Irvine 1995). While zooplankton species are observed throughout the year, short term fluctuations in abundance and population sizes are observed in the South East Arm (SEA) of LMNN (Twombly 1983). Zooplankton biomass range between 16 and 46 mg m-3 with an average of 24 mg m-3 (Figure 19)

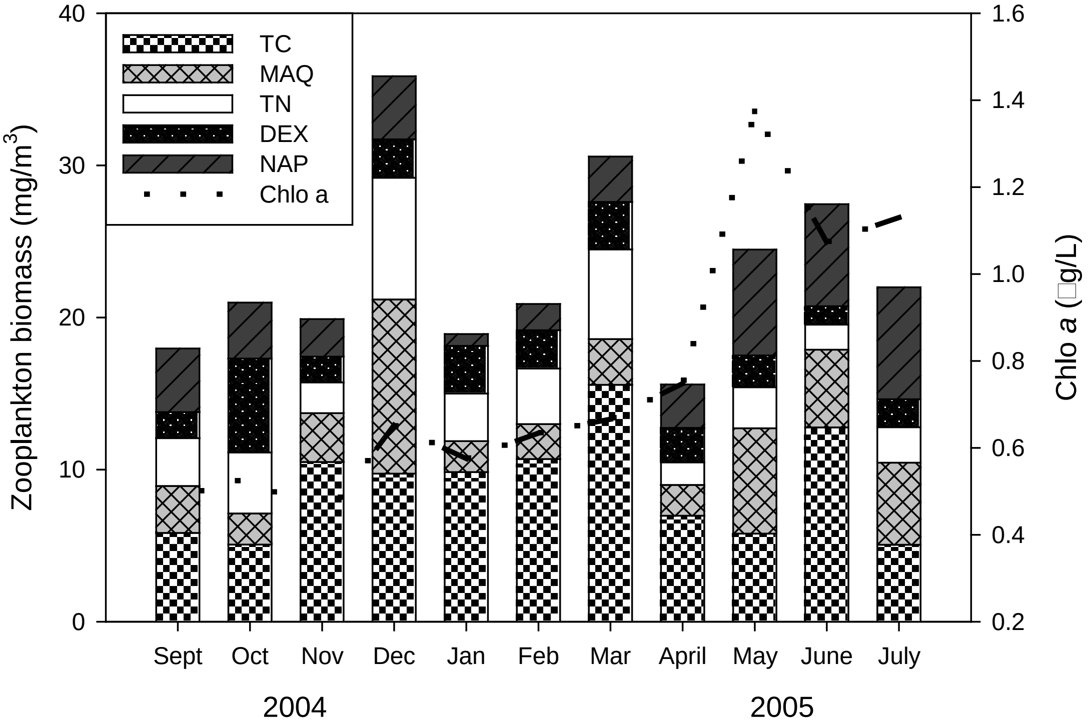

Figure 19. Zooplankton and Chlorophyll *a* biomass at a standard station in the SEA of Lake Malawi/Nyasa/Niassa. (TC = *T. cunningtoni*, MAQ = *M. aequatorialis*, TN = *T. neglectus*, DEX = *D. excisum*, NAP = nauplii

The zooplankton community is dominated by copepods contributing over 70% of the total zooplankton biomass (Twombly 1983, Irvine and Waya 1995). Nauplii dominate the numerical crustacean zooplankton composition (contributing over 50%). However, the post-naupliar, *T. cunningtoni* dominates the total zooplankton biomass with an average of 42%. *M. a. aequatorialis* becomes the second most important while *D. excisum* is the most abundant cladoceran. *B. longirostris* is generally rare and contributes less than 5% (Irvine and Waya 1995, Ngochera 2006). Similarly, *T. mixtus* is not important in the lake. Zooplankton feeding preferences change with season; and adult zooplankton utilize forms of food other than phytoplankton during other periods, such as nauplii or protozoans (Ngochera and Bootsma 2011). This extra step in the food web, and the trophic positions of large zooplankton species, may alter estimates of food web efficiency and potential fish production for LMNN

5.4 Macrophytes

The abundance and distribution of macrophytes around the lake is poorly understood, but they are particularly vulnerable to removal by seine netting, agriculture and shoreline development (Ngochera, 2016). These weed-beds provide physical, structural and biological habitat for invertebrates, act as nursery grounds and refuge for fish. It is clear from the number of fish (and perhaps other organisms too) that show close anatomical, behavioral and ecological adaptations to these vegetated areas that they represent the products of a long co-evolutionary association. The evolutionary association also reflects tight ecological interrelationships, suggesting that the vegetated areas represent a complex, but dynamic web of intricate activities. Macrophytes are confined to shallow areas along the shore, including rivers and swamps (Ngochera, 2016). They include the *Phragmites mauritianus* and *Phragmites australis* (reeds), *Typha domingensis* (bulrush), *Cyperus papyrus* (papyrus) and *Vossia cuspidata* (hippo-grass) stands. Rooted emergent macrophytes (reeds, bulrushes, papyrus and hippo-grass) develop and propagate rapidly resulting in dense, monospecific stands as other plants have no opportunity to survive. The relationship between these rooted emergent macrophytes and other plants to the physical environment can be useful in understanding biodiversity. A number of aquatic plant species are of conservation interest because of the threat they pose to natural ecosystems and other species. Amongst the most significant to the aquatic environment are: *Azolla nilotica* (Azollaceae); *Eichhornia crassipes* (Pontederiaceae); *Myriophyllum aquaticaum* (Haloragidaceae); *Salvinia molesta* (Salviniaceae) and *Pistia stratiotes* (Araceae). Annual fluctuations in water levels coupled with wave action weakens these plants and are seen floating in big masses within the lake and towards the Shire River where they affect power generation in the country.

5.5 Invertebrates

Invertebrate species of special social and economic interest are the most commonly recorded in the Basin, including agricultural pests (army worm), parasitic or vectors of diseases (mosquitoes, tsetse flies), edible (*amacimbi/madora*) and charismatic insects (butterflies, dragonflies). The full number of existing species is unknown but is most likely to be in the thousands. Invertebrates are responsible for much of the nutrient cycling in aquatic ecosystems and form the basis for complex food chain systems that fish and other larger aquatic species depend on (Timberlake and Childes 2004).

5. 6 Ecological Threats

5.6.1 Sedimentation

Although over-fishing is the major cause for the low catches in the LMNN, fisheries are also under intense pressure from impacts of sedimentation and siltation emanating from its catchment (Bootsma and Hecky 1993, Munthali 1997). According to Kingdon et al. (1999) an estimated 4.97 t ha-1 yr-1 of suspended sediments are discharged into LMNN. While the fate of such loaded material depends on a number of processes, the nature of the loaded material, prevailing physico-chemical conditions and flushing rates are the dominant factors (Bootsma and Hecky 1993). The flushing time for the lake is huge, estimated at about some 750 years (Bootsma and Hecky 1993), and hence sediments continue to accumulate before they are removed by the Shire River, the only outlet for LMNN.

As a result of deforestation, biomass burning, destruction of wetlands in the catchments for agricultural purposes and the cultivation of marginal areas such as steep slopes of hills, massive quantities of sediment eroded from clear-cut watersheds are discharged into the rivers and eventually in the lake (Bootsma and Hecky 1993). The negative impact of excess sedimentation and water turbidity on the diversity and ecology of aquatic communities has been reported for other Great Lakes. In Lake Tanganyika, species richness of crustacean ostracods was 40 to 62% reduced at highly disturbed sites than less disturbed sites. A similar pattern was also observed for fish species richness (Cohen et al. 1993). Similarly, in Lake Victoria, low fish diversity was reported in areas that had become turbid as a result of eutrophication (Seehausen et al. 1997).

The impact of sediment discharge on LMNN is not yet apparent and remains associated with the rainy season where river plumes can be seen entering the lake following heavy downpours. Increased sediment load has the potential to increase water turbidity resulting in the following: reduction of light penetration and hence affecting photosynthetic rates (Bootsma and Hecky 1999a); a reduction in habitat complexity (Munthali 1997), affecting fish sexual mate choice; and destruction of spawning grounds (Lévêque 1995). Therefore, sediment impacts on fish habitats provides a basis for concern about the sustainability of biodiversity in the lake (Mkanda 2000). Observations made within three days following a strong rain event in February 1998 in the Linthipe River showed that about 700,000 tons of suspended sediment were delivered into LMNN (McCullough 1999). Much of the suspended river load was made of sand and coarse silt which settled quickly. For the littoral rocky shore, whose food web is based on benthic algae growing on rocks, the blanketing of benthic algae by deposited sediments primarily affects the specialized aufwuchs eaters (Munthali 1997). The LMNN rock-dwelling *Mbuna*, whose communities directly rely on the algal carpet covering the rocks and whose mobility and migration capacity are very restricted and are chiefly impacted by the increasing sediment discharges (Ribbink 1994). This would cause the fish to move upwards to the shallows to compensate for the shortage of food and suitable habitat in the deeper waters, rendering them vulnerable (Higgins et al. 2001). The *Mbuna* comprise over 50% of the total fish species in LMNN (Munthali 1997). Evidence is abound of the decline or extinction of some of the most popular riverine fish species within the LMNN Basin. For example, species of *Opsaridium microlepis*, *Opsaridium microcephalus*, *Barbus johnstoni*, *Barbus eurystomus*, and *Barbus litamba* have declined in catches while the potamodromous species *Labeo mesops* is completely missing in the fishermen's catches (Mkanda 2000). The decline is associated primarily with the degradation of catchments of tributary rivers and the subsequent alterations in river flow regimes and sedimentation (Skelton et al. 1991). The massive amount of silt that is washed down into the lake from cultivated steep marginal lands and catchment areas following heavy rains have destroyed habitats of especially gravel spawners (Tweddle 1995).

5.6.2 Plant invasion

Water hyacinth, *Eichhornia crassipes*, invaded Lake Victoria in 1988, with high rates of infestation in shallow waters and bays, which also happen to be breeding and nursery grounds for most fish species (Ogutu-ohwayo et al. 1997). Catches of Nile perch decreased following the infestation of water hyacinth, while those of Nile tilapia, lung fish (*Protopterus aethiopicus*) and mud fish (*Clarias gariepinus*) increased. In Malawi, water hyacinth was first introduced in the 1960s, and it is now present in the lake especially in sheltered bays and many of the tributaries in the SEA. Within LMNN the plant is not abundant, probably due to the low nutrient concentrations in the lake (Bootsma and Hecky 1999b). However, there is potential for water hyacinth to become a problem especially in the SEA which has relatively higher nutrient concentrations than the other parts of the lake. This may have serious implications for biodiversity, since the lake's richest fish communities are found in the nearshore zone. Currently, most of the water hyacinth found in the lake originates in tributaries, and dies out in the lake (Phiri et al. 2001). Water hyacinth is abundant in the out-flowing Shire River, and results in problems at the Kamuzu Barrage at Liwonde and at hydro-power generating plants in the middle reach of the Shire River. The Department of Fisheries initiated a water hyacinth biological control program in 1995 using the weevil *Neochetina* spp. and had its rearing tanks at the Fisheries Office in Mangochi. Over one million weevils were bred and transferred to heavily infested problem areas. Together with manual removal of the weed, this effort was a success (Phiri et al. 2001). However, water hyacinth remains a problem since the program was discontinued.

6.0 SOCIO-ECONOMIC CHARACTERISTICS

6.1 Population and Poverty

According to the National Statistical Office (NSO, 2019), the population of Malawi is 17.5 million representing a 35% increase from the 2008 National Population Census. As already mentioned above the population density of the LMNN is greatest in Southern part of the basin in Malawi. The population on the Tanzania and Mozambican parts of the basin is relatively smaller compared to Malawi. Tanzania has about 1.4 million people living in the basin while Mozambique has just over a hundred thousand. However, Malawi is one of the least developed countries in the world with a per capital income US$317 compared to US$413 and US$950 for Mozambique and Tanzania respectively, according to the SADC Selected Indicators of 2016 as approved by the SADC Statistics Committee (2017).

The high levels of poverty in Malawi are caused by the low agricultural productivity, low non-farm income, low education and poor health (GoM, 2018). The implication of the low income is that the majority of the farmers in LMNN are unable to purchase inputs to improve their agronomic practices. Secondly it means during growing seasons, farmers have to work as casual labourers on commercial farms at the expense of managing their own lands in an optimal manner. Thirdly, the majority of the people are engaged in unsustainable forest harvesting such as charcoal burning in the fragile steep slopes of the LMNN basin causing heavy deforestation which result into serious soil erosion and siltation of major rivers and stream flow into the LMNN. The heavy deforestation in the LMNN basin particularly on the Malawi side has caused heavy siltation, which seriously affected the breeding grounds for fish.

The portion of the basin that is in Mozambique is small and lies in the Niassa Province. Niassa has fertile land but it is the country’s most sparsely populated province with a total population of less than one million. In an effort to help populate the province in 1996, the Mozambique and South Africa governments signed an agreement to make land within the Niassa province available to South African farmers. It should be noted that since the end of the civil war, Mozambique’s economy has greatly improved. According to the SADC (2017), the country’s average annual inflation decreased from 47% to 2% between 1996 and 2000 and GDP grew by almost 10% per year. In 2002 the economic growth was 12% the best in the SADC and Africa continent. Although little of this development has extended to the Niassa Province, there has been recent rapid expansion of tobacco growing and curing in the province. About 95% of the cultivated land comprises traditional, family-run farms with an average size of about 2 ha. The tourism sector in the province has also started picking up with the construction of some tourism facilities within the province.

The Tanzania side of the basin contains four regions; Mbeya, Songwe, Njombe and Ruvuma; with a total of fourteen districts and a population density of about 50.8 persons/km^2 (Faraji, 2016). In Mozambique, the LMNN basin is part of the Lago Niassa District/Niassa Province which has a population of 80166 according to the official population census of 2007 (Chaeruca, *unpubl*.) compared to a population of 55892 in 1997. Assuming the same growth over the period 1997 to 2017, the current population would be about 115 000. If the same trend continues, the population of the Lago District would rise to about 380 000 by 2050. It is estimated that that by 2050, the population of the LMNN shall comprise about 49.2 million, the majority being on the Malawian side of the basin. The National Statistical Offices of the three countries reveal some interesting trends. About 46.6% of the current population of Malawi is under the age of 14, while about 67% is under 24 years of age (http://www.indexmundi.com/malawi). In Mozambique, about 45% of the national population is under 14 while 66.1% is under 24. In Tanzania, 44% of the national population is under 14 while 63.77 is under 24. National fertility rates are at 5.5 (Malawi), 5.2 (Mozambique) and 4.8 (Tanzania). Combined, these demographics indicate that the basin states have very young and growing populations which are going to have serious implications of the natural resources in the LMNN basin.

6.2 Livelihoods

The majority of the people in the LMNN basin derive their livelihoods from agriculture and fishing. Agriculture is the main stay of the Malawi's economy, accounting half of the GDP and for almost all expert revenues. Within Malawi, the fishing industry contributes between 2% and 4% to the GDP, employing almost 300,000 people either directly or indirectly (GoM, 2018). Agriculture accounts for half of the GDP in Tanzania, and about 35% of the GDP in Mozambique. Within Malawi, fish provide 70% of the animal dietary protein with the majority of the fish coming from the LMNN.

A study by SMEC delineate LMNN communities with high dependency on water and aquatic ecosystems into four as follows:

i. River communities: those communities who are living along the rivers and use river water for small scale irrigation of their (vegetable) gardens, commonly cultivated in the riparian buffer zones. Irrigation is by hand fetched river water using buckets or eureka cans for small scale irrigation (e.g. tomatoes, onions, okra, and green vegetable). In addition these communities plant crops in the dry riverbed (mostly in the upper reaches) during the dry season and rely on residual moisture.

ii. Lake shore communities: those communities who live along the shoreline of Lake Malawi/Nyasa/Niassa and are largely dependent on fisheries for their livelihood (Figure 20)

iii. Communities who depend on floodwater for irrigation. Those who are living in flood prone areas and cultivate rice with floodwaters.

iv. Communities that make their living with gold panning in the upper reaches of the Ruhuhu River and in the proximity with Mbinga district. They use the river water for washing of the gold rich alluvial deposits. Some communities derive their livelihoods from small wetlands which are enclosed by valleys (5-6 ha maximum). Agriculture in these areas is practiced as well and contributes about 15% of household food and 55 - 95% of household income annually (Munishi et al 2011).

Figure 20: Chambo and Usipa fish on the Market (Source: Sousa, G., Beck, J., 2013)

6.3 Land and Agriculture

Land-use in the LMNN Basin is largely small-scale cultivation of cassava, rice, groundnuts and other crops. Plantation crops include tea, coffee, rubber and cocoa. Much of the basin agricultural activities area rain-fed with few irrigation activities mainly for tea and sugarcane growing. The agricultural activity impacts sediment loads into the rivers that flow into the Lake.

Over the last few decades, population growth in the area and expansion of areas under agriculture has led to deforestation within the basin and these activities have increased sediment loads into the rivers and the lake itself. Over-cultivation and overgrazing have caused significant land degradation in this densely-populated region. Deforestation for fuel-wood and land clearance for agriculture coupled with dry season bush fires has accelerated rate of soil loss in the basin.

6.4 Aquaculture Potential of the Basin

FAO, 2014, reveals that aquaculture in the LMNN consists of two sub-sectors, namely a long established ‘low input-low output’ rural aquaculture, and a nascent commercial sector, which ensures the bulk of production. The development of rural aquaculture was supported with the establishment of the Ruhila Aquaculture Center in Tanzania and Domasi Experimental Fish Farm for the breeding and distribution of Tilapia rendalli and Oreochromis shiranus. In Malawi between 1970s and 1980s the sub-sector received support from several donors and NGOs, promoting the wide adoption of fish farming. A typical small-holder fish farmer has one or two small ponds of about 200 m^2 or less, usually located in close proximity to a seasonal wetland. It is estimated that there are currently about 6,000 fish farmers in Malawi working on about

10,000 ponds. Fish production from rural aquaculture has steadily increased from 800 MT in 2003 to 1,200 MT in 2008. The production is mostly composed of Tilapia and to a lesser extent, Catfish.

Commercial aquaculture began in 2004 with the establishment of two large-scale production units in Malawi. One is a large-scale cage culture operation (MALDECO Aquaculture), which produces around 1,000 MT per year of Oreochromis karongae (Chambo) in circular floating cages in Lake Malawi (Mangochi area). MALDECO also built its own feed mill, complete with a pellitiser, for easy access to commercial quality feed (Litvinoff, 2009). The other is a medium-scale pond culture operation (GK Aquafarms) in the Lower Shire Valley at Kasinthula, which produces Oreochromis mossambicus and Common Carp (Cyprinus carpio). GK Aquafarms was allowed by the government to raise Common Carp as the Lower Shire is outside the LMNN basin. It should be noted that in Malawi the development of commercial aquaculture was supported by a Presidential Initiative on Aquaculture Development (PIAD) that was launched early in 2006. Current total fish production from aquaculture in Malawi is estimated at 2,600 MT per year. According to Commonwealth/GTZ (2007), there is considerable potential for the development of aquaculture in Malawi due to the good availability of perennial water and the warm climate that favours fast fish growth. However this potential is constrained by three key challenges, which include the common use of slow growing indigenous species due to the ban on the use of exotic fish species in the catchment of Lake Malawi; access to good quality commercial feeds; and the low participation of private investors in aquaculture in the LMNN basin. Figure 21 below shows the fishing practices around the lake.

Figure 21: Aquaculture in the LMNN (Source: Lucas Chairuca)

7.0 POLICIES, LEGISLATION AND INSTITUTIONS

7.1 Policies and legislation

A number of water resources management policies and legislations have been enacted in all the LMNN Basin States with a view to promoting conservation, equitable allocation, and protection of water resources against pollution, over-exploitation, and physical degradation; and to establish water supply and sanitation delivery services or other water dependent services. The LMNN Basin States are also party to several bilateral, regional, pan African and global agreements, treaties and/or conventions. At the global level various policy pronouncements and multilateral agreements have been signed by the LMNN Sub basin Member States that demonstrate the commitment of the three countries to ensure that the health of the lake and its catchment area are maintained. For example Sustainable Development Goal 6 targets include:

- achieving universal and equitable access to safe and affordable drinking water for all by 2030;
- improving water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally by 2030;
- protecting and restoring water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes among other goals that will contribute to maintaining the ecological integrity of the river systems;
- expanding international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies by 2030

Zambezi River Basin riparian states are also party to multilateral environmental agreements which are relevant for the management of the LMNN sub basin and its associated ecosystems. Some of such multilateral environmental agreements include the UN Watercourse Convention; the UN Convention on Biological Diversity (CBD); the Aichi Biodiversity Targets; the UN Convention to Combat Desertification (CCD); the Framework Convention on Climate Change and the Ramsar Convention. All the LMNN Sub basin States are contracting parties to the Convention on Biological Diversity. Further, all the LMNN Sub basin States are signatories to the Ramsar Convention. Six Ramsar sites in the LMNN basin collectively cover an area of about 7.0 million ha. The three states have all ratified or acceded to the Convention on International Trade in Endangered Species (CITES), have signed or ratified the Cartagena Protocol on Biosafety and have ratified or accepted the World Heritage Convention. The three countries in the LMNN basin have a Memoranda of Understanding related to the Convention on Migratory Species (the Bonn Convention): Malawi, Mozambique and Tanzania. These Memoranda relate variously to marine turtles, dugongs, migratory water birds, birds of prey, seabirds and gorillas.

At regional level, the SADC instruments for water cooperation include the SADC Treaty and its protocols such as Revised Protocol on Shared Watercourses, the Regional Water Policy, adopted in 2005; the Regional Water Strategy adopted in 2006 and Regional Strategic Action Plan on Integrated Water Resources and Development Management. These instruments promote the management and protection of the ecological integrity of river basins and include relevant articles on water quality, aquatic weeds, and protection of fragile ecosystems among others. For example Article 3.4 of the Revised Protocol calls for State parties to maintain a proper balance between resource development for a higher standard of living for their people and conservation and enhancement of the environment to promote sustainable development. Article 3.6 calls for State parties to exchange available information and data regarding water quality and environmental conditions of shared watercourses.

The SADC Regional Water Policy recognises the environment as a resource base and a legitimate user of water and thus requires Member States to allocate sufficient water to maintain ecosystem integrity and biodiversity including marine and estuarine life. The water quality policy statements focus on harmonisation and upholding minimum standards, prevention, and control of pollution and environmental impact assessments. Control of alien invasive species with the ultimate aim of total eradication of those, which are non-economical, is also included as a policy statement.

The Water Sector led regional instruments of cooperation are complimented by other SADC Sector instruments such as the SADC Forestry Protocol and the SADC Fisheries Protocol, Regional Biodiversity Strategy, Regional Biodiversity Action Plan, the Sub-regional Action Programme to Combat Desertification among others which are also sector specific but contain articles that are relevant to the management and protection of aquatic ecosystems and improving river health.

River Basin Organisations (RBO's) have been established on shared watercourses in the SADC region to advise and coordinate the sustainable development and equitable utilisation of the associated water resources for mutual benefit and integration. The river basin agreements clarify the institutional set up, objectives and mandates of the RBO's concerning various aspects of water resources management including protection of the water resources.

All the LMNN Sub basin states have signed and ratified the Agreement on the Establishment of the Zambezi Water Commission (2004). The Zambezi Watercourse Commission (ZAMCOM) is a river basin organization set up by countries that share the Zambezi River Basin, as stipulated in the 2004 ZAMCOM Agreement and in accordance with the revised SADC Protocol on Shared Watercourses of 2000. The Riparian States to the Zambezi River Basin are *the Republic of Angola, the Republic of Botswana, the Republic of Malawi, the Republic of Mozambique, the Republic of Namibia, the Republic of Tanzania, the Republic of Zambia, and the Republic of Zimbabwe.*

ZAMCOM's objective is "to promote the equitable and reasonable utilization of the water resources of the Zambezi Watercourse as well as the efficient management and sustainable development thereof".

As outlined in the Agreement, ZAMCOM functions include:

- Collecting, evaluating and disseminating all data and information on the Zambezi Watercourse for implementation of the Agreement;
- Promoting, supporting, coordinating and harmonizing the management and development of the water resources of the Zambezi Watercourse;
- Advising Member States on the planning, management, utilization, development, protection and conservation of the Zambezi Watercourse as well as on the role and position of the Public with regard to such activities and the possible impact thereof on social and cultural heritage matters;
- Advising Member States on measures necessary for the avoidance of disputes and assist in the resolution of conflicts among Member States with regard to the planning, management, utilization, development, protection and conservation of the Zambezi Watercourse;
- Fostering greater awareness among the inhabitants of the Zambezi Watercourse of the equitable and reasonable utilization and the efficient management and sustainable development of the resources of the Zambezi Watercourse;
- Cooperating with the institutions of SADC as well as other international and national organizations where necessary;
- Promoting and assisting in the harmonization of national water policies and legislative measures;
- Promoting the application and development of the ZAMCOM Agreement according to its objective and the principles.

At national level a number of environment and water resources management policies and legislations have been enacted in Malawi, Mozambique, and Tanzania to promote conservation, equitable allocation, and protection of the environment and water resources against pollution, over-exploitation, and physical degradation; and to establish water supply and sanitation delivery services or other water dependent services as summarised Table 8 below.

Table 8: Summary of existing legislations and policies Malawi, Tanzania, and Mozambique

Country	Environmental component	Responsible agency	Title and date of legislation
Malawi	Water resources (use of)	Ministry of Irrigation and Water Development: Water Resources Board Water Abstraction Control Subcommittee	Water Resources Act, CAP 72.03 (1969)
			Water Works Act, CAP 72.01 (1995)
			National Water Policy, 2005
	Effluent (disposal)	Ministry of Irrigation and Water Development: Pollution Control Subcommittee Malawi Bureau of Standards	Water Resources (Water Pollution Control) Regulations

	Air		Environmental Management Act, (2004)
	Waste	Ministry of Natural Resources, Energy and Environment	Environmental Management Act, 2004
	Planning and zoning	District Officers	Environmental Management Act, 2004
	Forestry	Ministry of Natural Resources, Energy and Environment: Forestry Department	National Forestry Policy (1996)
			Forestry Act, 2007
	Mining and mineral resources	Ministry of Natural Resources, Energy and Environment: Mines Department Title and date of legislation	Mines and Minerals Act, CAP 61.01 and Regulations
			Explosives Act, CAP 14.09 and Regulations
			Petroleum (Applications) Regulations, CAP 61.01
	Wildlife and natural resources	Ministry of Natural Resources, Energy and Environment: Department of National Parks and Wildlife	National Parks and Wildlife Act, CAP 66.07 (1992), as amended, and Regulations
			Game Act, CAP 66.03
	Plants	Ministry of Agriculture, Irrigation and Water Development	Plant Protection Act, CAP 64.01
			Noxious Weeds Act, CAP 64.02
			Council for National Herbarium and Botanic Gardens of Malawi Act, CAP 41
	Agriculture	Ministry of Agriculture, Irrigation and Water Development	Special Crops Act, CAP 65.01
			Tobacco Act, CAP 65.02
			Cotton Act, CAP 65.04
	Land	Ministry of Lands, Housing and Urban Development	Land Act, (2016)
			Customary Land Act (2016)
			Registered Amendment Land Act (2016)
			National Lands Policy (2002
	Fisheries	Ministry of Agriculture, Irrigation and Water Development	Fisheries Conservation and Management Act, CAP 66.05 (1997) Regulations (2002)
			National Fisheries and Aquaculture Policy (2001)
	Industrial infrastructure and urban development	Various	Industrial Development Act, CAP 51.01
			Electricity Act, CAP 73.01
			Public Roads Act, CAP 69.02
	Health	Ministry of Health	Public Health Act, CAP 34.01
	Historic monuments	Department of Antiquities	Monuments Act, CAP 29.01

Mozambique	Water resources	Ministry of Public Works and Housing	National Water Policy, 1995, amended in October 2007 1990 Constitution Act and Water Law (Law 16/91) Southern African Development Community (SADC) Protocol on Shared Watercourses is important. National Water Resource Management Strategy, 2007
	Air	MICOA	Dec 18/2004, New Regulations on Environmental Quality and Effluent Discharge Decree No. 24/2008, Regulations on the Management of Substances that Deplete the Ozone Layer
	Noise	Department of Labour	Legislative Diploma No. 48/73, General Regulations on Hygiene and Safety on Industrial Plant
	Waste – liquid effluents	MICOA	Decree No. 18/2004, Regulations on the Parameters for Air Quality and Effluent Emissions
	Waste	Each municipality (i.e. only urban)	Municipality Law No. 2/97
	Planning and zoning	Ministry of Planning and Development	Legislation in preparation
	Land use planning and development	National Land Cadastre, Ministry of Agriculture, Council of Ministers	Land Law No. 19/97 Decree No. 66/98, Land Law Regulations
	Mining and mineral resources	Ministry of Mineral Resources and National Petroleum Institute (Institute Nacional de Petroleum (INP))	Petroleum Law, No. 3 of 2001 Petroleum Operations Regulations, No. 24 of 2004 Decree No. 26, 2004, provides environmental regulation for mining activities
	Conservation	Ministry of Tourism: National Directorate for Conservation Areas	Conservation Policy and Implementation Strategy, 2009 Regulation for Control of Alien Invasive Species, 2008
	Wildlife and natural resources (including forestry)	Ministry of Agriculture National Directorate of Forestry and Wildlife	Forestry and Wildlife Law, No. 10 of 1999
	Agricultural and land	Ministry of Agriculture	Land Law, No. 19 of 1997, and Regulations (Law 66/98) and Technical Annex (29–A of 2000
	Fauna and flora	Ministry of Agriculture	Decree No. 12/2002, Regulation for Flora Resources Protection
	Fisheries	Ministry of Fisheries	Fisheries Law, No. 3 of 1990
	Transmission (electricity)	Ministry of Energy	Electricity Law, No. 21/97
	Human resettlement, compensation and rehabilitation	Ministry of Gender and Social Affairs	

	Archaeological, historical and cultural	Ministry of Culture (Department of Monuments)	National Heritage Protection Law, No. 10/88 of 22 December 1988 Decree No. 27/94, Regulations on the Protection of Archaeological Heritage Property
Tanzania	Environment	The National Environmental Policy of 1997	The Environmental Management Act of 2004
			The Environmental Impact Assessment and Audit Regulations of 2005
			Strategic Environmental Assessment Regulations of 2008
	Water	National Water policy of 2002	Water Resources Management Act, 2009
			Water Supply and Sanitation Act, 2009
	Energy	The National Energy Policy of 2003	Electricity Act of 2008
	Transport	The National Transport Policy of 2003	The Road Act, 2007
			Railway Act, 1973
			Tanzania Civil Aviation Act, 1977
	Land	National Land Policy of 1995	Land Act of 1999
			Land Regulations
			Village Land Act of 1999
			Land Use Planning Act, 2007
			Rural Farmlands Act Chapter 22
			Local Government District Authorities Act of1982
			Protected Places and Areas Act of 1969
	Mineral	Mineral Policy of Tanzania, 2009	Mineral Act, 2010
	Agriculture	Agricultural and Livestock Policy of 1997	Pesticide Control Regulation 1984
			Industrial and Consumer Chemicals (management and Control) Act 2003
		Irrigation Policy, 2010	Protection of New Plant Varieties (Plant Breeders' Rights) Act, 2002
			Irrigation Act, 2013 *(Bill)*
	Livestock	Livestock Policy of 2006	Grazing Land and Animal Feed Resources Act of 2010
			The Diary Industry Act, 2004
	Natural Resources and Tourism	National Forests Policy of 1988	Plant Protection Act, 1997
			Forest Act 2002
		Wildlife Policy of 1998	National parks Act 1992
			Wildlife Conservation Act of 2009
	International Relations	Foreign Policy of United Republic of Tanzania, 2001	Diplomatic and Consular Immunities and Privileges Act, 1986
	Crosscutting Issues	National HIV/AIDS Policy, 2001	The HIV and AIDS (Prevention and Control) Act, 2008 (Act No. 28/08)
		Policy on Women in Development in Tanzania, 1992	National Strategy For Gender Development

7.2 Coordination of Basin Development Activities

Recent experiences from Tanzania reveal that the majority of sectoral water users such as irrigated agriculture and hydropower generation, have independently been implementing parallel targeted development programmes. This therefore requires a coordination mechanism of implementing projects. Boostma and Jorgensen (2014) revealed that the country's development programmes have emphasized only water supply and have not considered water resource management aspects as an integral component. As part of the development of water resources management capability, Tanzania has been divided into nine basins and new water resources management initiatives are being developed using these newly divided basins for management units. After a ranking of issues in order of importance for each basin it was apparent that the basins within LMNN basin are not currently prioritized. Moreover, the responsible government department is currently only able to provide resources for developing two of the basins, based on the presence of hydropower or irrigation infrastructure.

Experience also shows that fragmented planning and management, lack of integrated sectoral approaches to development and conflicting sectoral policies are the main causes of water use conflicts in the LMNN. These conflicts highlight the need to manage the available water resources in a comprehensive manner, taking into consideration integrated plans in cross-sectoral uses of water, land use, pollution control, environmental and public health considerations on a basin-wide approach (WB, 2010). For example as part of the sector-wide review, a comprehensive Rapid Water Resources Assessment (RWRA) based on existing information was completed in Tanzania. The issues specifically identified for the Songwe and Ruhuhu basins include water pollution, impacts of fisheries, conservation of sensitive ecosystems (in particular wetlands on the Songwe River System) and intensive cattle grazing in the catchment.

8.0 KEY CHALLENGES AND LESSONS LEARNT

8.1 Key Results and Challenges

Implementation of Phase 3 of the BRIDGE programme has contributed towards initiating transboundary engagement for the three LMNN member states even though the effects are generally not straightforward to measure. While several reports have revealed that convening the cooperation and engagement between Malawi. Tanzania and Mozambique on matters related to the management of the Lake has been a challenge in the past, the BRIDGE programme managed to convene LMNN regional meetings successfully where the three countries jointly discussed and agreed on the work programme to assist further transboundary engagement. Through the BRIDGE programme the government and its stakeholders showed genuine willingness to begin working together on transboundary water cooperation within the Lake Malawi/Nyasa/Niassa. Some of the agreements include the technical study on the environmental state of the Lake, the

Memorandum of understanding, and capacity building in various components of transboundary water governance.

However the BRIDGE programme in the LMNN suffered a number of uncertainty factors and high risks including the following:

a) The contentious historical matters around the Lake boundary between Malawi and Tanzania have erupted during the life of the project thereby posing risk of disengagement by Malawi

b) There has also been poor ownership on the part of government stakeholders within which BRIDGE was anchored:

   i) The changes in the Ministerial leadership (i.e. Government reshuffling of Permanent Secretaries) in both the Water and Foreign Affairs Ministries especially in Malawi coupled with inadequate communication between the two Ministries has to some extend been a factor to delays in the implementation of BRIDGE in LMNN.

   ii) Failure to appreciate the implications of slow or non-delivery of project outputs has been a clear indication of poor ownership of the programme to the intended recipient countries. Cancelation of the two LMNN Regional Meetings at the very last minute while all logistics have been concluded both by Malawi and Tanzania is a good example to this.

These factors militated against effective delivery of the main and most important project expected output, which is the Memorandum of Understanding (MOU) between the three countries. The estimated costs and timelines of several activities for the LMNN component are difficult to predict due to the uncertainty related to firm commitment from the Government of Malawi.

Even though the BRIDGE programme encouraged and promoted the participation of all genders in its activities, women participation has not been very successful.

8.2 Lessons Learnt

- Engagement of transboundary stakeholders requires development of mechanisms that avails data and open up communication to various stakeholders. There is a need to have a transparent communication and information sharing across the countries so that the need for water for applying environment flow management is effectively considered.

- Over and above the necessary ingredients of transboundary water cooperation that are trust and confidence building, there is need for established commitment amongst stakeholders within the countries. Transboundary water cooperation cuts across a number of sectoral issues and stakeholder engagement across sectors is key.

- Transboundary water governance requires both technical and political buy in and engagement. There is need therefore to provide for time to allow for the necessary trust and confidence building processes which may not necessarily align with the project timelines.

9.0. CONCLUSIONS AND RECOMMENDATIONS

The LMNN is endowed with various natural resources and the majority of the people in the basin derive their livelihoods from agriculture. However the LMNN is prone to climate change and realizing this challenge the three riparian countries have developed the NAPAs which have identified priority activation to be implemented. Moreover, effective implementation of the priority activities is hampered by among other factors the lack of coordination between various sectors/institutions involved in the utilization of the natural resources of the LMNN. Implementation of the BRIDGE programme in the LMNN has been highly political and sensitive requiring patience and slow incremental steps. It is recognised however that the three riparian countries already have enabling policy and legal frameworks for sustainable management of the LMNN basin. Following the lessons learnt during the implementation of the BRIDGE-3 programme the following recommendations are being made:

i. Considering that trans-boundary water governance requires both technical and political buy in and engagement, it is of utmost importance to work closely with the governments of Malawi and Tanzania to ensure the border disputes between the two countries are amicably resolved in order to ensure full engagement and commitment
ii. It is important to establish an institutional mechanisms to foster cooperation in the management of the lake and its basin water resources, and the current wave of climate extremes (cyclones and prolonged droughts) obtaining in the region bring an urgency to this issue
iii. An Memorandum of Understanding among the three riparian countries of Malawi, Mozambique and Tanzania, on collaborative efforts to manage the lake basin and surrounding ecosystem, will be an important first step towards sustainable cooperation that will support livelihoods for the local people
iv. There is need to continue building the capacity of personnel tasked with the responsibility to manage the lake, particularly in areas such as limnology, hydrometry, application of remote sensing technologies in lake monitoring, and as well as negotiation skills
v. Capacity building will need to promote gender equity an youth empowerment, as these significant demographies constitute a large portion of the users of the lake basin resources
vi. The lake basin will benefit from a joint, transboundary initiative that focuses on the conservation of the ecosystem, climate risk reduction, sustainable water use and building of the capacity of local populations on ecosystem valuation and flood/drought early warning systems.

References

1. Arttu, P (2014). Carbon stocks for six different land use classes in Niassa province, Mozambique. (Unpubl. Masters Thesis, Univ of Helsinki, Finland)
2. Beilfuss R. (2012) A Risky Climate for Southern African Hydro ASSESSING HYDROLOGICAL RISKS AND CONSEQUENCES FOR ZAMBEZI RIVER BASIN DAMS. Int. Rivers
3. Chavula, G. M, S (2016). State of the Environment and Outlook Report for Lake Malawi/Nyasa/Niassa. Malawi Country Report. BRIDGE Programme
4. DNGA, (2005). As Tres Convenções do Rio e os Respectivos Protocolos, MICOA ,GoM
5. INGC, (2005). Plano Director de Prevenção e Mitigação das Calamidades Naturais. Maputo. Mozambique.
6. Bambaige, A., (2007). National Adaptation Strategies to Climate Change Impacts – Case Study in Mozambique –Occasional Paper – Human Development Report – UNDP
7. Balirwa, J.S., C.A. Chapman, L.J. Chapman, K. Geheb, L. Kaufman, R.H. Lowe-McConnell, O. Seehausen, J.H. Wanink, R.L. Welcomme, and F. Witte. (2003), Biodiversity and Fisheries Sustainability in the Lake Victoria Basin: An Unexpected Marriage? Bioscience 53:703-715.
8. Bootsma, H.A., Hecky, R.E. 2003, A Comparative Introduction to the Biology and Limnology of the African Great Lakes. J. Great Lakes Res. 29 (Supplement 2):3–18 Internat. Assoc. Great Lakes Res., 2003
9. Bootsma H. and Jorgensen S.E., (2004), Lake Malawi / Nyasa, 36 pp. In Nakamura M. (ed.), Managing Lake Basins; Practical Approaches for Sustainable Use.
10. Bootsma H.A. and Jorgensen S.E., (2006), Lake Malawi / Nyasa: Experience and lessons learned brief
11. E. Hecky, editors. Water Quality Report. Lake Malawi/Nyasa Biodiversity Conservation
12. Bootsma, H. A. and R. E. Hecky. 2003. A comparative introduction to the biology and limnology of the African Great Lakes. J. Great Lakes Res. 29 (Supp. 2):3-18.
13. Halafo, J.S., (2013. Habitates Aquáticos, Diversidade Biológica Aquática, Pescas e propostas de Medidas de Gestão no Lago Niassa, Relatório Interno de Investigação Pesqueira No 17
14. Global Water Partnership, 2000, Integrated water resources management, Denmark;
15. GoM. (2010). Malawi State of Environment and Outlook Report: Environment for Suitable Economic Growth. Lilongwe: Ministry of Natural Resources, Energy and Environment.
16. GoM. (2013). National Disaster Risk Management Policy. Lilongwe: Department of Disaster Preparedness and Management.
17. Government of Malawi (2010). Malawi State of Environment and Outlook Report: Environment for Sustainable Economic Growth, Ministry of Natural Resources, Energy and Environment, Lilongwe, Malawi.
18. Government of Malawi, 2011, Malawi Growth and Development Strategy: From Poverty to Prosperity 2011-2016, Ministry of Finance, Lilongwe, Malawi
19. Government of Malawi, 2013, National Disaster Risk Management Communication Strategy 2014-2018, Malawi
20. Government of Malawi, 2015, National Disaster Risk Management Policy of Malawi, Malawi
21. Guildford S.J. and Hecky R.E., (2000), Total nitrogen, total phosphorus and nutrient limitation in lakes and oceans: Is there a common relationship? Limnol. Oceanogr. 45:1213-1223.
22. Guildford S.J., Bootsma H.A., Fee E.J., Heckey R.E., and Patterson G., (2000), Phytoplankton nutrient status and mean water column light intensity in Lakes Malawi and Superior, J. Aquatic Ecosystem Health and Management 3:35-45
23. Guildford S.J., Hecky R.E., Taylor W.D., Mugidde R., and Bootsma H.A., (2003), Nutrient enrichment experiments in tropical Great Lakes Malawi / Nyasa and Victoria, Journal of Great Lakes Research, Vol. 29, Supplent 2, 2003.

24. Hecky R.E., Bootsma H.A., and Kingdon M.L., (2003), Impact of land use on sediment and nutrient yields to Lake Malawi / Nyasa (Africa), Journal of Great Lakes Research, Vol. 29, Supplent 2, 2003.
25. Hecky R.E., Bootsma H.A., and Kingdon M.L., (2003), Impact of land use on sediment and nutrient yields to Lake Malawi / Nyasa (Africa), Journal of Great Lakes Research, Vol. 29, Supplent 2, 2003.
26. Higgins, S. N., R. E. Hecky, and W. D. Taylor. 2001. Epilithic nitrogen fixation in the rocky littoral zones of Lake Malawi, Africa. Limnol. Oceanogr 46:976 - 982.
27. IGAD Climate Prediction and Applications Centre (ICPAC), (2007). Climate change and human development in Africa: Assessing the risks and vulnerabilities of climate change in Kenya, Malawi and Ethiopia. United Nations Development Programme
28. IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan ISBN 4-88788-032-4
29. IPCC, 2001, Climate Change 2001 – The Scientific Basis, Cambridge University Press, UK
30. IPCC, 2007, Fourth Assessment Report (AR4), UNFCCC;
31. IUCN, (2015), BRIDGE Lake Malawi/Nyasa/Niassa Stakeholder Consultations Report (draft) of 4th May 2015
32. Johnson T.C. and Nga'ng'a P., (1990), Reflections on a Rift Lake, in Lacustrine Basin Exploration – case studies and modern analogs (edt. Katz B. J.), The American Association of Petroleum Geologists, Oklahoma, USA.
33. Kainja S., (2000), Forestry outlook study for Malawi, a report submitted to the World Bank.
34. Kimaro,T.A., Maddyngwe,I. and Norbert, T., (2007). Quantifying Changes in Lake Nyasa Surface Area Using Remotely Sensed data. Water Resources Engineering Department, University of Dar Es Salam
35. Kumambala, P.G., Ervine, A., (2010). Water Balance Model of Lake Malawi and its Sensitivity to Climate Change .The Open Hydrology Journal, 2010, 4, 152 – 1162
36. Kalff J., (2002), Limnology, Prentice-Hall, Inc, Upper Saddle River, New Jersey.
37. Kumambala, P.G., Ervine, A (2010). Water Balance Model Lake Malawi and it's Sensitivity to Climate Change. The Open Hydrology Journal, 4: 152 – 162)

38. Kanyika G. Y., (2000), Water balance model for Lake Malawi, M.Sc. Thesis, University of Dar es Salaam, Tanzania.
39. Lyons, R.P., Kroll, C.N., Scholz C.A. (2011). An energy-balance hydrologic model for the Lake Malawi Rift Basin, East Africa (Global and Planetary Change, 75:83-97)
40. McSweeney, C., New, M. and Lizcano, G., 2008, UNDP Climate Change Country Profiles: Malawi, Oxford University, UK.
41. Mkanda F.X., (2002), Contribution by farmer's survival strategies to soil erosion strategies in the Linthipe River catchment: implications for biodiversity conservation in Lake Malawi /Nyasa, Biodiversity and conservation 11: 1327-1359.
42. Ngochera, M. J. 2006. Phytoplankton and zooplankton interactions in tropical Lake Malawi. Masters Thesis. University of Wisconsin – Milwaukee, USA, Milwaukee.

43. Ngochera, M. J. and H. A. Bootsma. 2011. Temporal trends of phytoplankton and zooplankton stable isotope composition in tropical Lake Malawi. J. of Great Lakes Res. 37:45 - 53.

44. Ngochera, M.J., 2016, Physical and hydrological characteristics of Lake Malawi, a paper contributed towards the compilation of the country report on State of the Environment and Outlook Report for LMNN

45. Nicholson S.E., Klotter D., Chavula G., (2013), A detailed rainfall climatology for Malawi, Southern Africa, International Journal of Climatology (2013);
46. Nicholson SE, Yin X., 2002, Mesoscale patterns of rainfall, cloudiness and evaporation over the Great Lakes of Africa. In The East African Great Lakes: Limnology, Palaeolimnology and Biodiversity, Odada EO, Olago DO (eds). Kluwer Academic Publishers: Dordrecht, Holland. 93–119. Nicholson SE, Dezfuli
47. Phiri, P. M., R. K. Day, S. Chimatiro, M. P. Hill, M. J. W. Cock, M. G. Hill, and E. Nyando. 2001. Progress with biological control of water hyacinth in Malawi. Pages 47 - 52 in M. H. Julien, M. P. Hill, T. D. Center, and D. Jianqing, editors. Biological and integrated control of water hyacinth, Eichornia crassipes. ACIAR Proceedings 102.
48. Ribbink, A. J. 2001a. Lake Malawi/Niassa/Nyasa Ecoregion: Biophysical Reconnaissance. WWF Southern African Programme Office, Harare.

49. Ribbink, A. J. 2001b. Lake Malawi/Niassa/Nyasa ecoregion: biophysical reconnaissance. WWF – SARPO, Harare, Zimbabwe.

50. Ruddick K.G., Gons H.J., Rijkerboer M., and Tilstone G., (2001), Optical remote sensing of chlorophyll a in case 2 waters by use of an adaptive two-band algorithm with optical error properties, Applied Optics, 20th July 2001/Vol. 40, No. 21
51. SADC, (2000). Revised Protocol on Shared Water CoursesSouthern African Development Community, 2000, State of the Environment Zambeze Basin
52. SADC, (2001). Protocol on Fisheries
53. SADC- WD/ZRA, SIDA/DANIDA/NorwegianEmbassyLusaka, (2008). “Integrated Water Resources Management Strategy and Implementation Plan for the Zambezi River Basin”
54. SADC- WD/ZRA, SIDA/DANIDA/NorwegianEmbassyLusaka, (2008). “Integrated Water Resources Management Strategy and Implementation Plan for the Zambezi River Basin”

55. SADC, (2003). Joint Water Commission Between Mozambique and Malawi Southern African Development Community,2002, Environmental Sustainability in Water resources Management in Southern Africa
56. SADC, (2012). Zambezi River Basin Atlas of the Changing Environment
57. Saidi A. Faraji (2016). State of the Environment and Outlook Report for Lake Malawi/Nyasa/Niassa. Tanzania Country Report. BRIDGE Programme
58. Sangea, H., Upton, K. & Ó Dochartaigh, B.É. 2016. Africa Groundwater Atlas: Hydrogeology of Tanzania. British Geological Survey.
59. S. E. Nicholson, D. Klotter and G. Chavula, 2013, A detailed rainfall climatology for Malawi, Southern Africa, International Journal of Climatology, int. j. climatol. (2013)
60. Shela O. N., (2000), Naturalization of Lake Malawi levels and Shire River flows: challenges of water resources research and sustainable utilization on the Lake Malawi – Shire River system. Paper presented at the Water Net Symposium on Sustainable Use of Water Resources held in Maputo 1-2 November, 2000.
61. Snoeks, J. 2000. How well known is the ichthyodiversity of the large East African lakes? Adv. Ecol. Res. 31:17 - 38.
62. Thornton, W (2015). Western Tanzania: Lake Rukwa and Lake Nyasa Rifts. Exploration Africa
63. UNEP, 2012, Climate Early Warning Systems Feasibility Report: Early Warning Systems and Hazard Prediction, Oxford University, UK.
64. Vollmer, M., R. Weiss, and H. Bootsma. (2002). Ventilation of Lake Malawi/Nyasa.
65. Wooster M, Patterson G., Loftie R., and Sear C., (2001), Derivation and validation of the seasonal thermal structure of Lake Malawi using multi-satellite AVHRR observations, INT. J. Remote Sensing, 2001, Vol. 22, NO. 15, 2953-2972.
66. Zidana, H., G. F. Turner, C. Van Oosterhout, and B. Hänfling. 2009. Elevated mtDNA Diversity in introduced populations of Cynotilapia afra (Günther 1894) in Lake Malawi National Park is evidence for multiple source populations and hybridization. Molecular Ecology 18:4380 - 4389.
67. ZAMCOM, (2015). Zambezi Environment Outlook