Spatial and temporal dynamics of water quality in aquatic ecosystems. A review of physical, chemical and biological gnomes of some Rivers in Malawi

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Abstract

River ecosystems are among the most vulnerable aquatic systems in the face of increased, urbanization, land degradation, agricultural activities, and careless disposal of sewage and waste water. This paper presents a review on substantial parameters in water quality assessments for recreational purposes, domestic purposes and drinking. To attest good quality of water, multiple parameters have to be measured. Physical, chemical and biological gnomes are tested to ascertain the water quality. Water quality studies on some Malawian rivers evaluated various constituents such as phosphates, nitrates,pH, electrical conductivity (EC), total dissolved solids (TDs), heavy metals and faecal coliforms. The mean values among the rivers were: PH (6.1-7.8), Phosphates (0.1-4.4mg/L), nitrates (0.05-9.79mg/L), faecal coliforms (300-20408 cfu/100ml), Lead (0.05-0.74mg/L), Cadmium (0.004-0.14mg/L) and Manganese (0.4-1.8mg/L). The reviewed parameters exceeded World Health Organization (WHO) and Malawi Bureau of Standards (MBS) limits. This signifies that the studied rivers to some extent are polluted and probably pose threat to the ecosystem health as well as public wellbeing. Therefore, there is a need to intensify integrated management of water and land to curb further pollution of rivers.

Key words: *parameters, Malawian rivers, water quality, spatial, temporal*

1. INTRODUCTION

Rivers and streams are among lotic aquatic ecosystems which usually collect to form ponds and lakes (Chidya et al., 2011). Most catchments of perennial rivers are subject to various natural and human activities that have varying consequences on water quality (Pullanikkatil et al., 2015). Natural factors such as rainfall and weathering of underlying rock complex influence the identity and quantity of mineral nutrients in surface water (Kumwenda & Kambala, 2012). Anthropogenic activities such as industrialisation, urbanisation, agriculture and deforestation nevertheless, influence the physiognomies of surface water (Chidya et al., 2011).

Rivers provide readily available water for numerous uses in rural, peri-urban and urban areas apart from provision of other numerous ecosystem services, such as recharge of ground water, provision of habitats to aquatic life etc. However, despite their extensive roles, presently, degradation of water quality in rivers due to activities associated with urbanisation is increasing alarmingly (Kuyeli et al., 2009; Nyasulu, 2010; Chidya et al., 2011;). Increasing unselective dumping of solid and chemical wastes from households, industries and sewage works mainly in the urban areas result in increased pollution of water in rivers. These pollutants find their way into the river ecosystems mostly from city sewer systems, industrial wastewater discharges, and seasonal run-off from agricultural activities (Mumba et al., 2006; Chidya et al., 2011; Kumwenda & Kambala, 2012).

Earlier studies conducted on some river catchments reported increased clearance of vegetation, soil erosion, alteration of agricultural land to structure development, urban expansion, and intensification of agricultural activities in the river and stream banks (Mbano et al., 2009; Chimseu-Chipendo 2010; Nkhoma et al., 2020), which directly and indirectly influence the biological, chemical and physical characteristics of aquatic ecosystems. An assessment of water quality of some Malawian rivers revealed a fair and extreme pollution of water (Kuyeli et al., 2009; Kwanjana et al., 2009; Nyasulu, 2010; Chidya et al., 2011; Kumwenda & Kambala, 2012; Kambwiri et al., 2014).

Sustainable Development Goal # 6 of the United Nations that projects to the improvement of water quality through decreasing of pollution by 2030 can be achieved by among other interventions through gathering essential short and long term aquatic data and comparing water quality from different rivers (UN-Water, 2016). There is therefore, urgent need for a comprehensive assessment of the river systems to establish temporal and spatial dynamics of water quality locally. This paper aimed at reviewing the chemical, physical and biological gnomies of selected Malawian rivers in order to establish the water quality status.

2. DATA AND METHODS

The study reviewed various published works and reports for Malawi. A comprehensive online literature survey was therefore undertaken, with a focus on published papers on rivers in Malawi that analyzed key water quality parameters such as nitrates, total dissolved solids, turbidity, Phosphate, faecal coliforms, turbidity, Electrical conductivity, and heavy metals. These were compared with limits prescribed set by the Malawi Bureau of Standards (MBS) and the World Health Organisation (WHO).

3. RESULTS AND DISCUSSIONS

Tables 1A, B and C show the water quality parameters assessed in the reviewed studies while Table 2 shows the water quality standards by World Health Organisation (WHO) and Malawi Bureau of Standards (MBS) which were used as reference points for water quality standards in the review. The average pH was 8.3, 7.3, 6.8, 7.7 for Lilongwe River in 1980, 2005, 2009 and 2010 respectively, 6.1, 6,7.6 and 7.5 for Likangala in years 2006, 2011, 2015 and 2018. While Mudi River registered pH values of 7.6 in 2009 and 7.46 in 2012. 7.6, 7.4, 7.7, 7.8,6.1, 7.4, 7.1,6.7.6.64 for Mchesa, Ulongwe, Naperi, Limbe, Nasoro, Chirimba, Namiwawa, Lunyangwa and Ruo Rivers respectively.

Levels of turbidity were 247.9, 124.6, 220 NTU for Songani, Namiwawa and Lunyangwa Rivers correspondingly, Lilongwe registered 136.6 NTU in 2005, 123 NTU in 2010. Lilongwe, Songani and Namiwawa values were high than of Likangala and Mudi. 166 NTU, 97.65 NTU, 68.6 NTU, for Likangala in 2011, 2015 and 2018 respectively. While Mudi River registered 62.99 NTU in 2012. Electric conductivity ranged from 289.8 to 491Ω.cm for Lilongwe River, 197.9 to 444.4Ω.cm for Likangala. Mudi ranged from 4.7 to 4’28.69 Ω.cm while Napari registered the lowest value of 5Ω.cm in 2009.

The concentration of phosphate was 0.312, 0.5, 0.1mg/l for Lilongwe River in different years (see table 1A), 0.15,4.4,3.7mg/l for Likangala River, 2.9mg/l for Mudi, 2.9mg/l for Limbe River,3.8mg/l for Nasoro, 0.3646mg/l Ruo. Of all the rivers, Chirimba had a high concentration of 8.6mg/l Chirimba. The concentration of nitrates averaged 0.14mg/l for Lilongwe River and 8.66mg/l for Likangala River. Faecal coliforms count for Lilongwe River were 300,20408, 9369 and 3416 cfu/100ml in years 1980, 2005,2009 and 2010 respectively. Likangala registered 2000 in 2011 and 14738.79 cfu/100ml in 2015. Mudi River registered 1616.5 cfu/100ml in 2012. Ruo River had the lowest count of 167 cfu/100ml in 2014.

Table 1A: *Physical, Chemical and Biological parameters of water quality in studied rivers*

Year	River	Cu^{2+}	Cr^{3+}	$PO4^{3-}$	$SO4^{2-}$	$NO3^{-}$	Na^{+}	K^{+}	Pb^{2+}	Cd^{2+}	Mn^{2+}
2005	Lilongwe	*Na	Na	0.312	17	0.09	Na	Na	Na	Na	Na
2009	Lilongwe	Na	Na	0.5	0.16	0.05	18.77	1.89	0.74	0.004	Na
2010	Lilongwe	Na	Na	0.1	Na	0.18	24.3	Na	0.07	0.14	Na
2006	Likangala	Na	Na	0.15	Na	0.24	Na	Na	Na	Na	Na
2011	Likangala	Bl	0.18	4.4	10.9	15.7	17.4	4.9	0.71	0.05	1.8
2015	Likangala	0.03	0.05	3.7	7.1	1.7	13.3	3.1	0.06	Na	0.4
2018	Likangala	0.03	0.051	3.7	7.2	1.66	13.2	3.12	0.05	Na	0.4
2009	Mudi	Na	Na	2.9	17.5	5.8	Na	Na	Na	Na	Na
2012	Mudi	0.08	0.28	Na	Na	9.79	Na	Na	0.57	0.01	Na

*Na= Data Not Available

Table 1B: *Physical, Chemical and Biological parameters of water quality in studied rivers*

Year	**River**	**BOD**	**SS**	**DO**	**pH**	**TDS**	**TURB**	**Faecal Coli**	**EC**
1980	Lilongwe	20	Na	7.65	8.3	Na	Na	300	Na
2005	Lilongwe	Na	Na	4.9	7.3	185.1	136.6	20408	289.8
2009	Lilongwe	27.6	Na	6.12	6.8	357	Na	9369	491
2010	Lilongwe	18.5	80.75	5.5	7.7	177	123	3416	316
2006	Likangala	Na	Na	Na	6.1	Na	Na	Na	Na
2011	Likangala	Na	Na	Na	6	301	166	2000	444.4
2015	Likangala	Na	265.3	Na	7.6	307	97.65	14738.79	359
2018	Likangala	Na	Na	Na	7.5	98.88	68.6	Na	197.9
2009	Mudi	133.4	30.3	Na	7.6	29.8	Na	Na	4.7
2012	Mudi	77.35	Na	Na	7.46	211.43	62.99	1616.5	428.69

Table 1C: *Physical, Chemical and Biological parameters of water quality in studied rivers*

Year	**River**	**EC**	**K^+**	**CaCO3**	**pH**	**DO**	**TDS**	**TURB**	**Faecal Coli**	**$PO4^{3-}$**	**$SO4^{2-}$**	**$NO3^-$**
2011	Mchesa	105.6	Na	Na	7.6	3.6	312.8	Na	Na	Na	Na	Na
2002	Ulongwe	Na	5.3	123.5	7.4	Na	19	Na	Na	Na	Na	Na
2008	Mulunguzi	Na	Na	Na	Na	7.78	Na	Na	Na	Na	Na	Na
2009	Naperi	5	Na	Na	7.7	Na	20.01	Na	Na	Na	18.09	28.98
2009	Limbe	7.5	Na	Na	7.8	Na	14.4	Na	Na	2.9	12.5	42.6
2009	Nasoro	25.2	Na	Na	6.1	Na	23.5	Na	Na	3.8	19.14	59.8
2009	Chirimba	73.6	Na	Na	7.4	Na	73.6	Na	Na	8.6	60.4	54.5
2010	Songani	133.7	Na	121.58	7.1	6.97	Na	247.9	Na	Na	Na	Na
2010	Namiwawa	99.2	Na	<200	7.1	6.6	Na	124.6	Na	Na	Na	Na
2014	Lunyangwa	350	Na	Na	6.68	Na	120	220	>1000	Na	Na	Na
2014	Ruo	7.8	14.4	Na	6.64	9.077	3.211	Na	167	0.346	9.407	0.462

Table 2: *Malawi Bureau of Standards (MBS, 2005) and World Health Organisation (WHO, 2021) Guidelines on water quality*

Determinant	**Upper limit and ranges**	
	MBS	**WHO**
EC	70-150mS/m	Not of health concern
pH	5.0-9.5	6.5-8.5
Calcium	80-150mg/L	No data
Chloride	100-200mg/L	5mg/L
Nitrate	6.0-10.0mg/L	50mg/L
Potassium	25-50mg/L	Occurs at a low concentration below health concern
Sodium	100-200mg/L	50mg/L
Copper	0.500-1.000mg/L	2mg/L
Cadmium	0.003-0.005mg/L	0.003mg/L
Lead	0.01-0.05mg/L	0.01mg/L
DO	>5.0mg/L	Not of health concern
Manganese	0.05-1.00mg/L	0.05mg/L
Turbidity	5 NTU	<5 NTU
Chromium	No data	0.05 mg/L
TDS	1000mg/L	1000mg/L
F. coli form	0cfu/100m	0cfu/100ml
Phosphate	0.5mg/L	0.5mg/L

3.1 General water quality status of the studied rivers

Water quality assessment entails the overall process of evaluation of the physical, chemical and biological nature of water in relation to natural quality, human effects and intended uses, particularly uses which may affect human health and the health of the aquatic ecosystem itself (Chapman, 1996). Water quality analysis of rivers and streams is directly linked to monitoring of the health and sustainable utilization of these aquatic ecosystems and is also essential for conservation of aquatic flora and fauna (Kumwenda & Kambala, 2012). Generally, assessment of the mean values of faecal coliform in the reviewed rivers in Malawi, reveals significant contamination exemplified by above standards findings. For instance, Lilongwe River's faecal coliforms changed from 300 cfu/100ml to 20408 cfu/100ml in 1980 and 2005 respectively. Likangala River also had the same trend; it registered mean value of faecal coliform of 2000 cfu/100ml in 2011 and 14739 cfu/100ml in 2015 above allowable value of 0cfu/100 ml by WHO and MBS.

3.2 Spatial influence on surface water quality

Spatial difference in terms of distribution of activities and physical conditions influence the chemical, physical and biological characteristics of surface water bodies. Rivers that pass through urban areas are highly vulnerable to pollution due to urban and industrial wastes while rivers that pass through rural areas their source of contaminants tend to be non-point source of agricultural activities. Higher mean values (> MBS but < WHO) of nitrates were recorded in Naperi and Limbe Rivers while, Nasoro and Chirimba registered values more than WHO standards. However, Likangala and Mudi Rivers showed levels of nitrates below MBS except in 2011 when Likangala recorded 15.7mg/L, which was still below WHO standards. Some of the lowest levels of nitrates were recorded in Lilongwe, Likangala and Ruo Rivers. The lower nitrate levels in Ruo River (0.462 mg/L) were attributed to highly vegetated catchment of the Ruo by Kambwiri et al. (2014), since, trees and grasses inhibit the transfer of nitrates into rivers and stream. Phosphates which share similar agricultural and urban sources like nitrates, generally were below both standard in all rivers except in Likangala (4.4mg/L; 2011) and Chirimba (8.7mg/L; 2009) rivers which had more than standard values. Such readings could be due to broken sewers along Likangala River and industrial waste water disposal in Chirimba industrial area. Other parameters like DO and TDS were always below both standards where measured while turbidity was always above standards probably reflecting the state of land degradation which has resulted in more siltation. A study by Kuyeli et al. (2009) correlated the impairment of water quality in a stream to the type of industry in its vicinity. For instance, Shire Valley abattoir are partially contributing to the pollution of Mchesa River in Blantyre (Kosamu et al., 2011). Similar study, done in Lunyangwa River found that water degradation is due to intensification of land use in the catchment area and in the river banks (Nyasulu, 2010; Kuyeli et al., 2009; Wanda et al., 2014; Pullanikkatil et al., 2015). Son et al. (2020) argued that nutrient concentration differs due to geographical location, in their study they found varied nutrient concentration in upper, middle and lower parts of Cau River in Vietnam.

3.3 Temporal trends in some water quality parameters in selected river

Some rivers as Lilongwe, Likangala and Mudi had more than one water quality assessment studies hence it was possible to compare trends of some parameter over some years as follows:

i. pH

The mean values of pH of the selected rivers ranged between 6 and 8.3, which is within the recommended limits by WHO and MBS (Table 2). A temporal trend showed a general decrease of mean pH for Lilongwe River (Figure 1). A study done on Lilongwe River in 1980 found an average pH of 8.3. Work done in 2009 and 2010 on the same river reported average pH of 6.8 and 7.7 respectively. This shows that the river may be turning more acidic though towards the neutral state on the pH scale. This corresponds with the outlined principle stated by Chiras (1998) that a river tends to be more acidic when aging (Kwanjana, 2009; Nyasulu, 2010; Kumwenda & Kambala, 2012). In the case of Lilongwe River, the aging process is expedited by increased input from both point and non-point sources of pollution resulting mainly from anthropogenic activities.

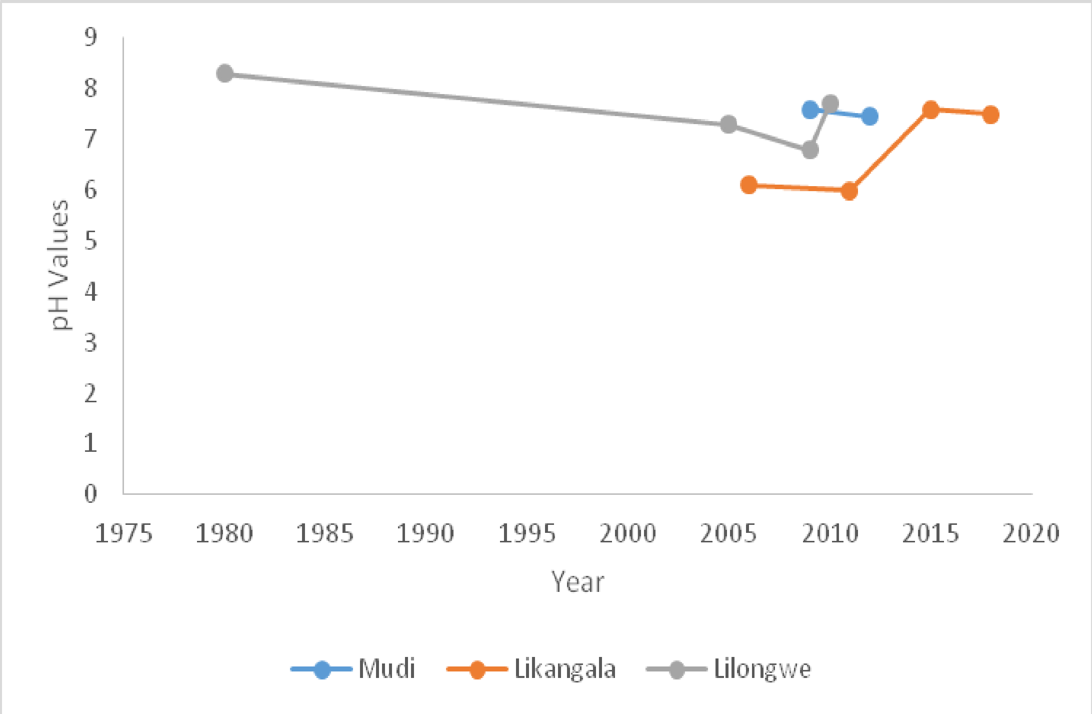

Figure 1: *Temporal variation in pH*

ii. Electrical conductivity (EC)

Electrical conductivity is proxy for concentration of ions and total dissolved solids in water. In a normal situation, water has low electric conductivity of 75ms/m or less (Mara, 2003). Therefore, an abrupt increase or decrease in conductivity in water body can indicate pollution. The electrical conductivity of Lilongwe, Mudi, Likangala, Lunyangwa Rivers were above the Malawi Bureau of Standards limits of 70-150mS/m indicative of pollution of the rivers with dissolved ions. Increasing EC has varying negative effects on aquatic life as it may cause death of aquatic life (Nyasulu, 2010; Chidya et al., 2011; Pullanikkatil et al., 2015). Figure 2 reveals an increasing trend of EC in all the three rivers particularly between 2005 and 2010, thereafter EC decreases specifically in rivers Lilongwe and Likangala. The decrease in conductivity could be attributed to addition of organic compounds that do not disintegrate into ions in water and heavy rainfall that dilutes salinity concentration (Shrestha et al., 2017).

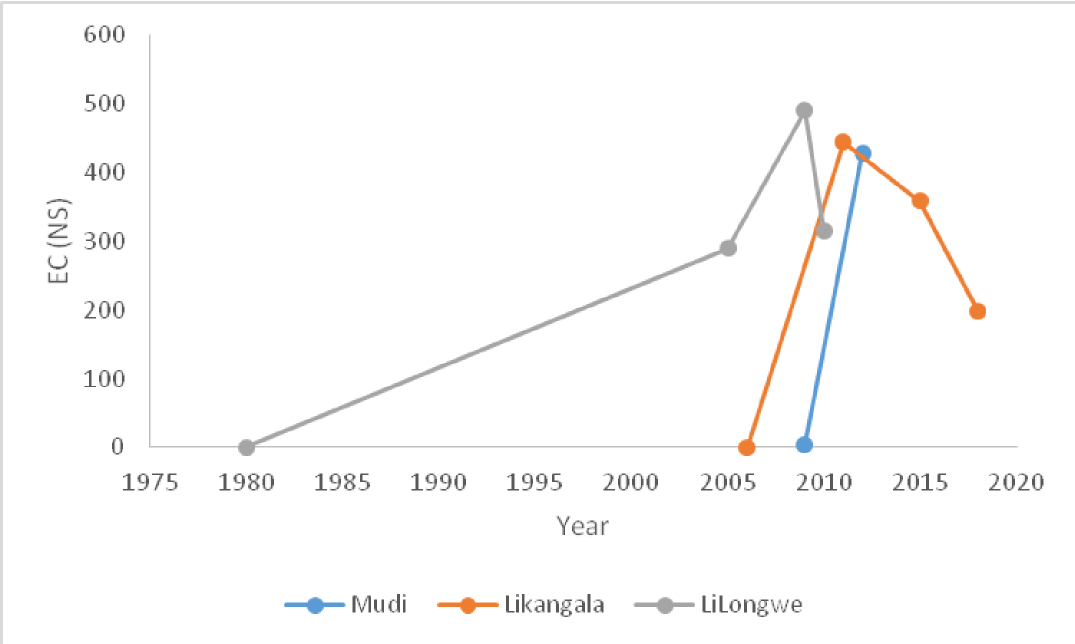

Figure 2: *Temporal variation in Electrical Conductivity (EC)*

iii. Turbidity (Turb)

Turbidity refers to the clarity of water in its natural setting and it is also an indicator of productivity of a water body (Ullberg, 2015). The causes of turbidity are suspended matters of clay, silt and organic matter as well as presence of more planktons in rivers. Turbidity does not necessarily make water hazardous to drink but reduces its acceptability to utilization (Gorde & Jadhav, 2013; Nyasulu, 2010). The results showed that the mean values for turbidity for Lilongwe, Likangala and Mudi Rivers were within the acceptable limits by WHO and MBS guidelines of <5NTU (Table 2). Turbidity spatial trend for Lilongwe River that passes through the highly urbanized capital city of Malawi was similar to Likangala River that passes through a low urbanized area of Zomba city. This could be due to the disposal of industrial wastes, broken sewer disposal and siltation carried by run off into the rivers (Figure 3). Kwanjana (2009) and Nyasulu (2010) reported similarly high values of turbidity for Lilongwe River around Kamuzu Central Hospital Bridge and Flea market. The higher values were attributable to increased effluent disposal into the river also observed for the Mudi River (Figure 3).

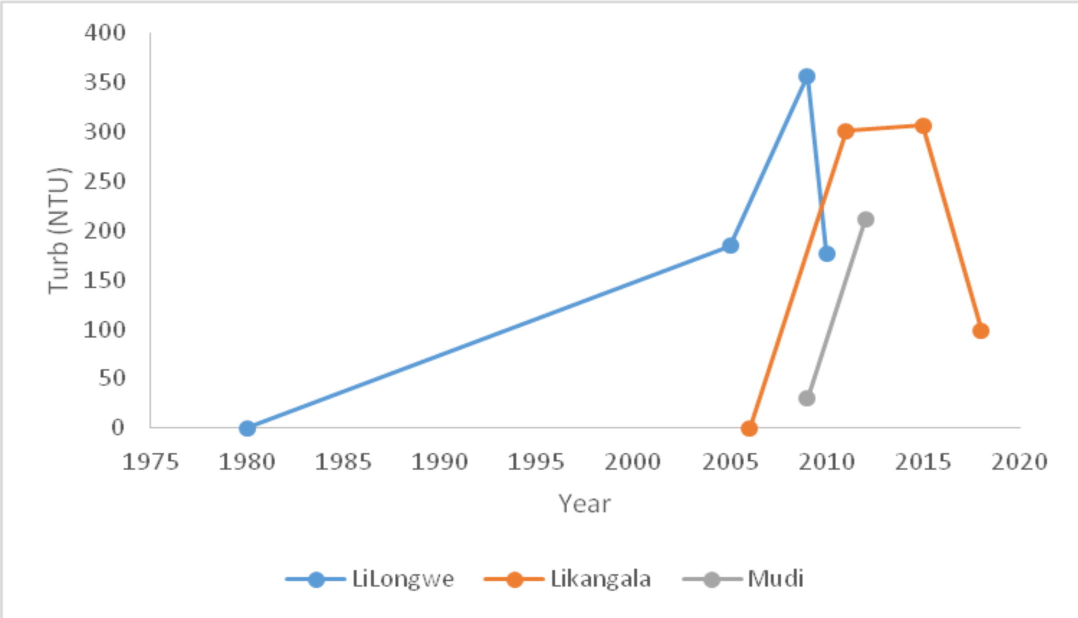

Figure 3: *Temporal variation in turbidity*

iv. Nitrate

Nitrate, nitrite and ammonia are the greatest forms of interest. Excess levels of nitrate results into utrophication causing depletion of dissolved oxygen in water bodies (Ullberg, 2015). Nitrates levels for Lilongwe, Mudi and Likangala in all the years were below WHO guidelines. However, the values for Likangala River in 2011 and Mudi River in 2012 were greater than the MBS acceptable limits (Table 2). This could signify a considerable contamination from sewer systems and agricultural runoff (Kumwenda & Kambala, 2012; Nyasulu, 2010; Pullanikkatil et al., 2015). An increasing temporal trend in nitrates is evident in Figure 4 suggesting increasing release of nitrates from point and non-point sources in the catchment of the three rivers. The following fluctuations of nitrate levels in the subsequent years in Likangala River point to fluctuations of nitrate sources in Zomba particularly point sources such as broken sewers (Chidya et al., 2011).

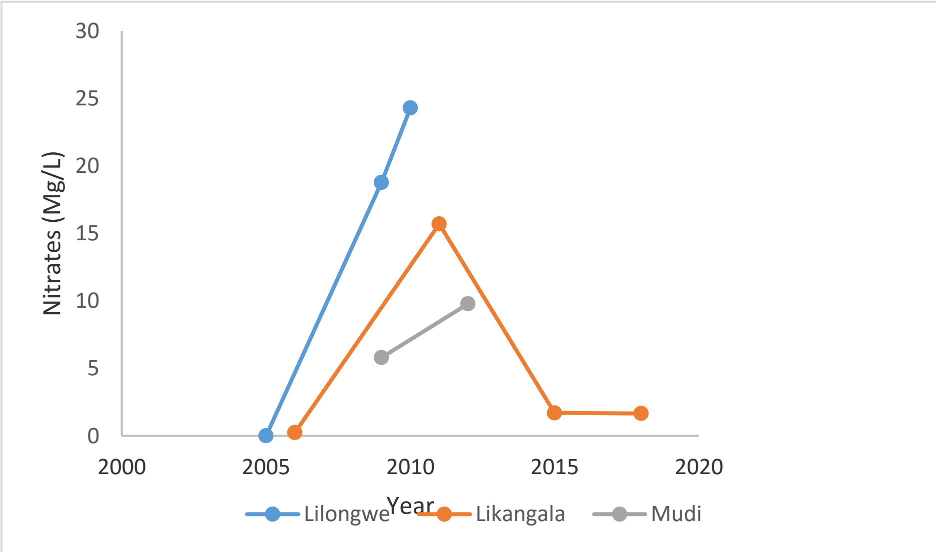

Figure 4: *Temporal variation of Nitrates*

v. Phosphorous

Phosphorous appear in both natural and waste water in a form of phosphate (PO_4^{3-}) and other forms. It is an essential element for primary productivity in water but excessive levels can lead to eutrophication (Nyasulu, 2010). Phosphate levels for Likangala River in 2011, 2015, 2018 and Mudi in 2009, were above the WHO limits of 0.5mg/L (Kuyeli et al., 2009; Chidya et al., 2011; Kumwenda & Kambala, 2012; Pullanikkatil et al., 2015; Ullberg, 2015). However, phosphate levels in 2006 in Likangala River were below detectable levels (Chimwanza, et al., 2006). Generally, high levels of phosphate in rivers is ascribed to blocked sewer that drains into the rivers. Furthermore, they are due to industries that use phosphate detergents and phosphoric acid for cleaning the production lines (Kuyeli et al., 2009; Kumwenda & Kambala, 2012; Mudaly & van der Laan, 2020). Lilongwe River has maintained a constantly low-level trend of phosphates while Mudi had a downward trend (Figure 5). In contrast, Likangala River shows a sharp increasing trend which plateaus over the years.

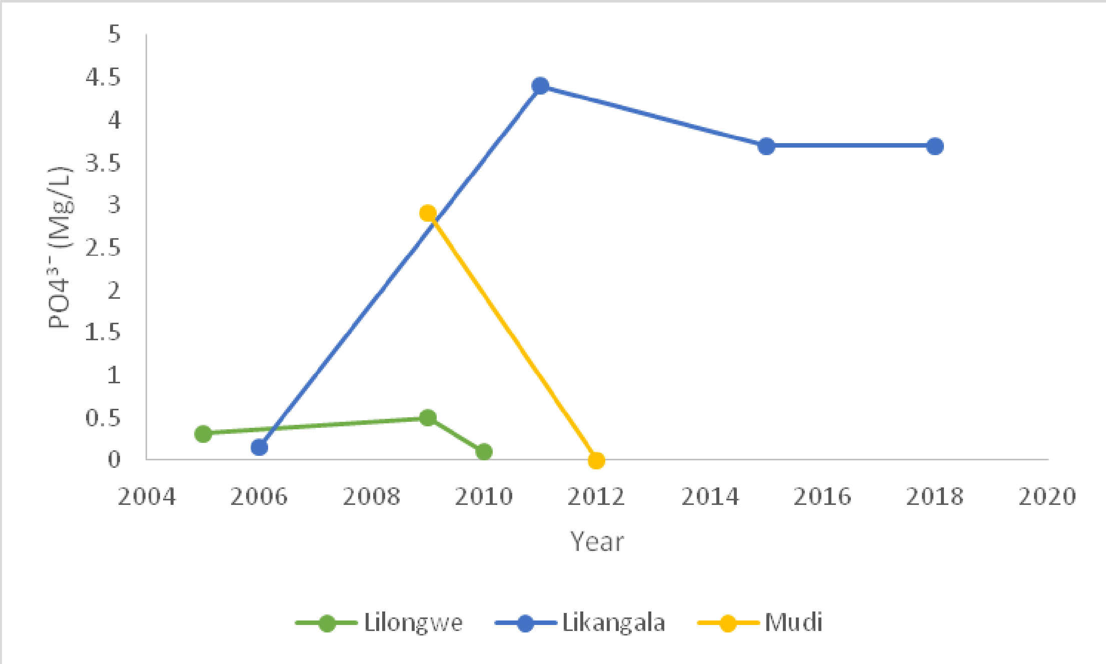

Figure 5: *Temporal variation in phosphates*

vi. Heavy metal

Heavy metals such as lead, chromium, mercury and cadmium have negative effect on human health. Lilongwe, Mudi and Likangala Rivers showed values of lead and cadmium higher than the acceptable limits by WHO of 0.1 mg/L and 0.003mg/L respectively (Table 1A and Table 2). The presence of lead and cadmium in these rivers could entail that the rivers pass through industrial areas with metal processing industries, automobile industries and paint manufacturing areas which tend to have high cadmium and lead. Extreme high levels of cadmium and lead cause lung impairment and thereafter death and damage of nervous system respectively (Chidya et al., 2011; Suleiman & Abdullahi, 2012; Ullberg, 2015).

vii. Total dissolved solids

Total dissolved solids for all rivers were within the acceptable limits for MBS and WHO guidelines limits of 1000mg/L. All the rivers that pass through urban areas such as Likangala, Lilongwe, and Mudi that showed high TDS values. An increasing trend of TDS was observed in all the three rivers pointing to a steady increase of release of TDS from sources (Figure 6). Commercial activities and urbanisation which result in many solid and liquid wastes being discharged into the rivers and increasing the amount of dissolved solids are likely causes in the case of the three rivers given their urban location (Phiri et al., 2005; Nyasulu, 2010; Chidya et al., 2011).

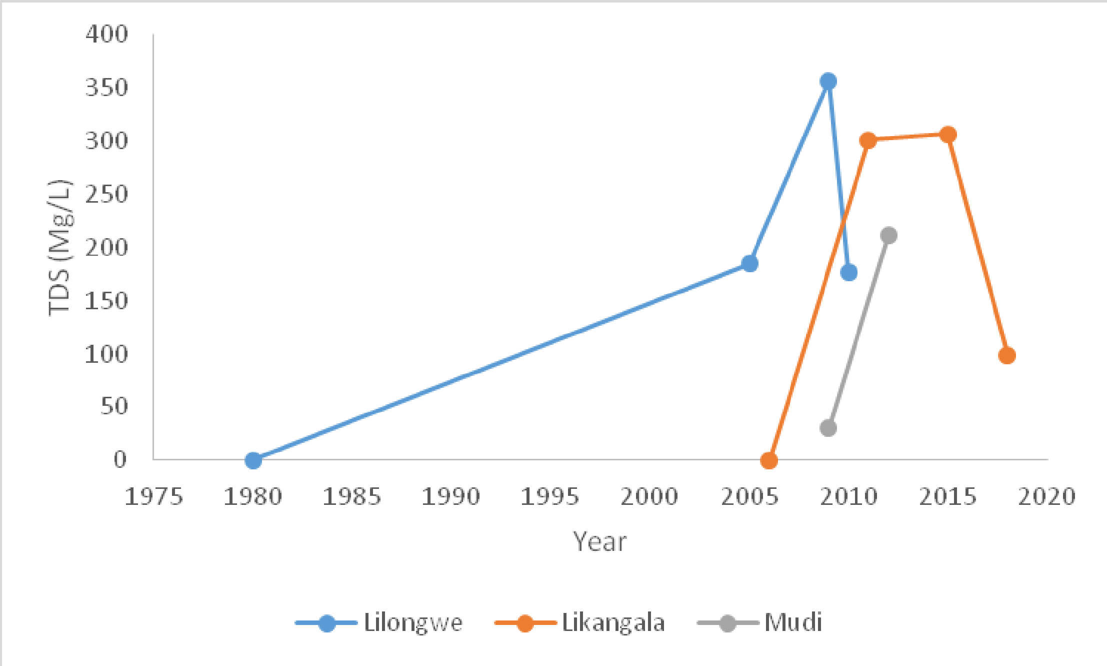

Figure 6: *Temporal variation in TDS*

viii. Faecal Coliforms

Faecal coliform are the microorganisms that live in the intestines of all warm-blooded animals, and in animal wastes or faeces eliminated from the intestinal tract (Ritter et. al., 2002). The presence of faecal coliforms in water in rivers could point to the existence of disease carrying organisms that live in the same environment as the faecal coliform bacteria. The mean values for faecal coliform for Lilongwe, Likangala, and Mudi Rivers ranged between 300 to 20408 cfu/100ml (Table 1B). The coliforms counts were above the accepted limits by MBS and WHO of 0cfu/100ml. All the three rivers showed a temporal increase of the mean values pf faecal coliform over the years (Figure 7). Lilongwe and Likangala Rivers later exhibited a downward trend of faecal coliform suggesting a decline in faecal matter release into the rivers. A study by Chidya et al. (2011) revealed that urban areas had elevated coliform counts due to open defecation in the public places like the flea markets and increased livestock farming in the river catchment (Chidya et al., 2011).

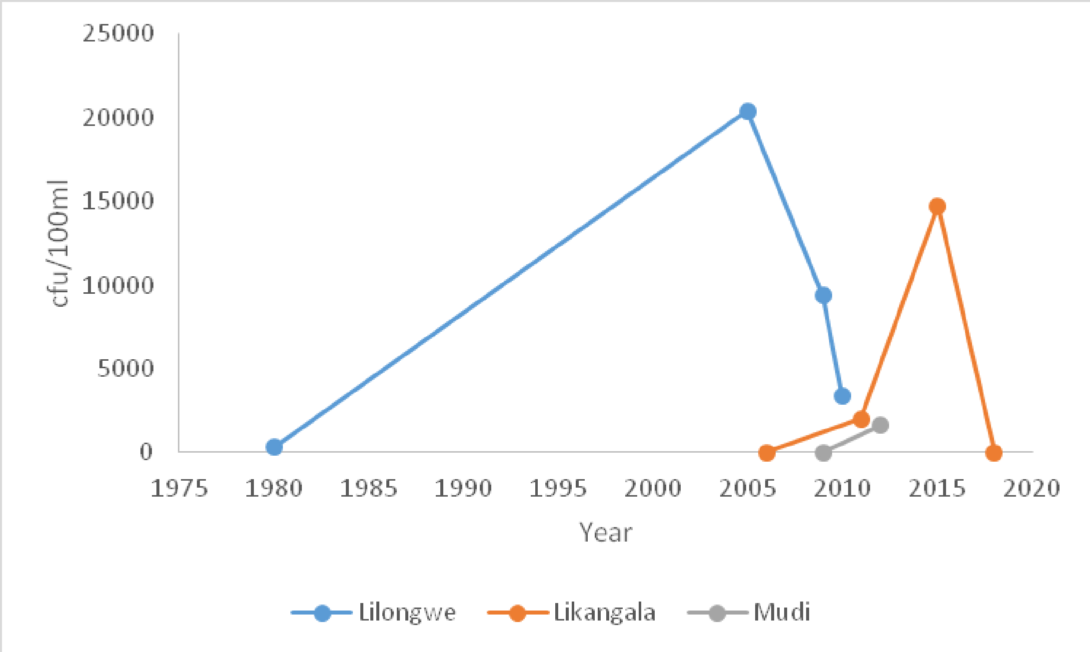

***Figure 7:** Temporal variation in faecal coli form*

4. CONCLUSION

Generally, rivers are polluted particularly in terms of faecal coliforms, turbidity, and heavy metals, whose levels were above the accepted limits by MBS and WHO. Nitrates and phosphates though generally below the standards, are considerably variable over the years oscillating between being within and outside the standards in the rivers. Other parameters such as DO and TDS are below standards in the rivers. A general increasing trend in the rivers in EC, Turbidity, Nitrates, Phosphates, TDs and faecal coliform is worrisome as it predicts pollution of most rivers with passage of time.

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