Natural and anthropogenic changes threatening the ecological and limnological integrity of Lake Baringo, Kenya: A Review

Article *in* Pan-African journal · December 2021

Pan Africa Journal of Sciences
ISSN 2709-1473 | Open Access

REVIEW ARTICLE

Volume 02 – Issue 01

Natural and anthropogenic changes threatening the ecological and limnological integrity of Lake Baringo, Kenya: A Review

Job O. Omweno[1*], Steve Opiyo[1], Omondi Argwings[2], Wilfred O. Zablon[1]

[1] Department of Natural Resources and Environmental Science, Kisii University, P.O Box 408, Kisii
[2] Sigalagala National Polytechnic, P.O Box 2966, Kakamega

Correspondence: omwenojob@gmail.com

Received: 7th December 2022; Accepted: 18th December 2021

DOI: 10.47787/pasj.2021.01.23

Abstract

Lakes are characterized by dynamic responses to ecological and limnologic disturbances that occur within a constrained timeframe. Some endorheic lakes in the Kenyan Rift valley are presently regarded as environmental hotspots because of complex changes that are revealed through multiple proxies; changing lake levels and surface area, turbidity and sedimentation, proliferation of macrophytes and loss of aquatic biodiversity. Lake Baringo is characterized by widespread catchment degradation accompanied by high levels of turbidity during erratic and decline of native fishery based on *Oreochromis niloticus baringoensis.* A careful analysis implicates potential natural factors such as catchment topography and increasing anthropogenic pressure as the main causes of lake ecosystem degradation. This paper recommends several strategies for restoration of Lake Baringo based on an integrated multi-faceted approach which combines catchment rehabilitation, pollution control and provision of alternative livelihoods such as agriculture to the riparian communities.

Keywords: Catchment degradation; Turbidity; Lake Level fluctuations; Multi-faceted approaches

1. Introduction

Lakes are fundamental ecosystems for sequestering environmental pollutants, climate modification, research and extraction of aquatic resources (Dubois *et al.,* 2018). Ecological goods and services derived from lakes include water, biodiversity and tourism that support the livelihood of millions of people globally. These unique values have earned some Kenyan lakes such as Baringo, Naivasha and Nakuru global recognition as international wetlands under the Ramsar convention and others protected as national reserves (Ochieng *et al*., 2007; UNEP, 2009). In addition, lakes Naivasha and Bogoria provide important sites for geothermal power exploration. Shallow endorheic lakes of the Kenyan Rift-valley have recently experienced high magnitude of catchment degradation that tends to exceed restoration efforts due to unprecedented growth in human population (Omondi *et al*., 2016). Human activities have been manifestly conspicuous in degraded lakes, including diversion of influent rivers into dams and impoundments, unplanned land use changes, water abstraction, pollution and sedimentation and introduction of invasive species into the lake and its catchment (Leavitt *et al.,* 2009; UNEP, 2009; Hering *et al*., 2015). Ecosystem changes have been manifested through multiple proxies, such as soil erosion, flooding, turbidity or eutrophication, which have been discussed separately by many related studies.

In this review, we compare the findings of previous literature to discuss the complexity of human influence on the aquatic environment which has existed since time immemorial (Mills *et al*., 2014). The detectable impacts are revealed through multiple proxies which are compounded in changing physico-chemical parameters.

2. Location and biophysical features

Lake Baringo is a tectonically closed freshwater lake located in the Kenyan valley between the coordinates 0° 36 N and longitude 36° 04 E, ~ 60km north of the equator (KMFRI, 2007). The lake has a variable surface area which ranges between ~ 108 km^2 and 140 km^2 and covers an estimated catchment area of 6.82 square kilometers (Odada *et al*., 2006; Omondi *et al*., 2016). The lake is also recognized as a wetland of international importance and was gazette as a Ramsar site in the year 2002 (Omondi *et al*., 2016). The lake has a shallow varying bathymetry which has reportedly declined since 1972 due to observable impacts of siltation, evaporation and diversion of inflowing rivers (Aloo, 2000; Odada & Olago, 2002; Odada *et al*., 2006). River El Molo, which collects water a long way from the Mau Forest and flows through fault scarps in Ndoloita and through the Loboi swamp is the main inflow that feeds the lake. Other influent rivers are Perkerra, Ol arable, Omo, Endao, Makutan and Chemeron as shown in figure 1.

The lake levels and surface area are controlled by hydrological events; recharge occurs during the rainy season while water loss mainly occurs through high evaporation rates during the drought (Omondi et al., 2014). Whereas the main lake is located in a semi-arid region with high annual evaporation rates (1,650–2,300 mm) that exceed the average annual rainfall of ~ 450–900 mm, the lake catchment covers a wide range of climatic zones. Its hydrographic network spreads to humid areas of Mau Forest which receive bi-modally distributed rainfall averaging about 2,700 mm annually (KMFRI, 2007). It is evident that the lake has no conspicuous surface outlet. However, the discovery of splintered lake bottom which supports this assumption of subsurface drainage through seepage or percolation which renders the lake its freshwater characteristics (Onyando et al., 2005; Republic of Kenya, 2014). Unlike lakes Nakuru and Elementaita which are closed saline lakes surrounded by escarpments, lakes Naivasha and Baringo are open freshwater systems surrounded by extensive plains which makes them highly vulnerable to erosion and sedimentation.

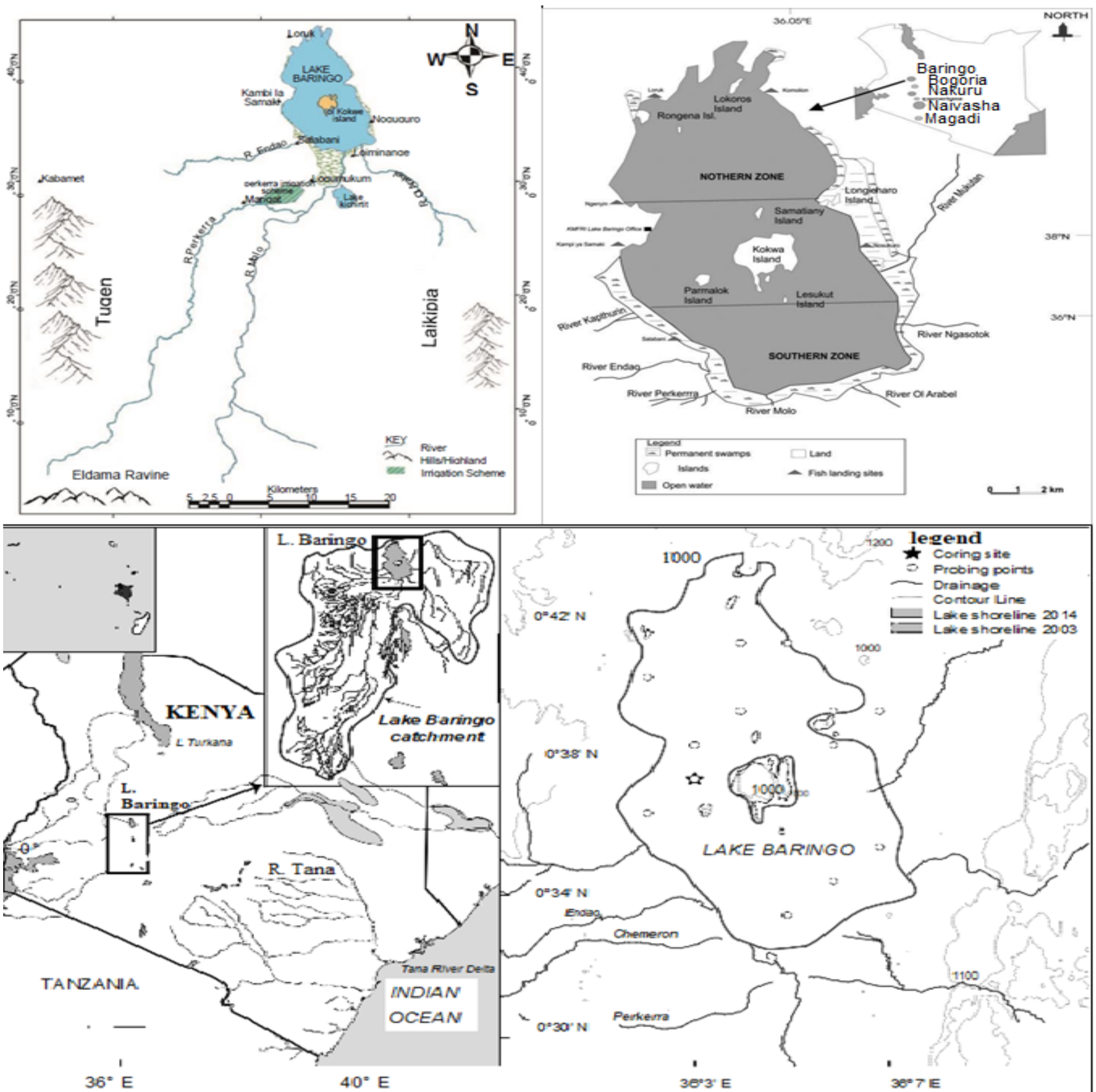

Figure 1: Maps showing the geographical location, hydrographic network and major inlet rivers flowing into Lake Baringo (Adapted from Lwenya & Yongo, 2010; Omondi *et al*., 2016; Okech *et al*., 2019)

3. Major threats facing Lake Baringo

3.1 Lake surface and water level fluctuations

East African endorheic lakes are highly sensitive to effects of drought and change in rainfall patterns which controls their water balance (Verschuren 2003; Magny *et al*., 2007). For instance, since the year 2002, most Kenyan Rift Valley lakes such as Lake Baringo, have shown marked fluctuations in water levels which led to a much-reduced lake surface and depth (Johansson & Svensson, 2002). The recent flooding and increased water levels in many of these lakes attributed to El Nino rains has been forecasted to bring significant ecological and economic disruptions (Kenya Meteorological Department, 2015). Endorrheic lakes respond rapidly to high magnitude of hydrological extremes through marked changes in lake bathymetry immediately after the floods or drawdown. The greater part of the catchment lies on steep slopes characterized by low and sporadic rainfall which contributes to high recharge volumes from influent rivers (Jaetzold *et al*., 2010). For instance, WARMA (2013) reported that the water levels of Lake Baringo rose to approximately 8.5 m in August 2012 and submersed the fringe vegetation and most buildings around the lake. The report provides evidence of a direct nexus between rising lake levels and flooding witnessed in Lake Baringo catchment which increases the lake surface area and has negatively impacted the riparian communities. The observed and predicted trend in lake surface area is shown in figure 2.

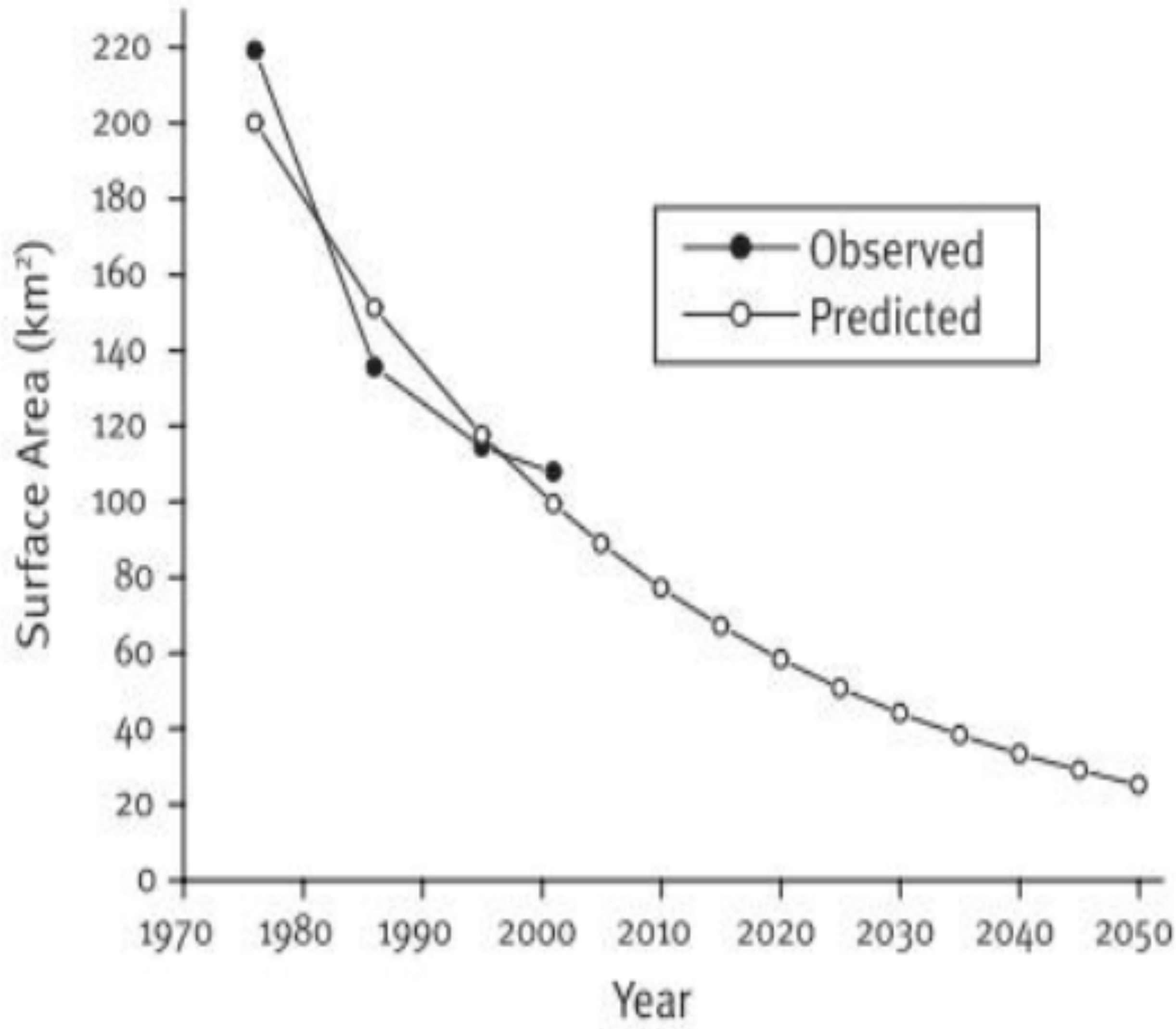

Figure 2: Observed and predicted surface area of Lake Baringo for the period 1970-2050 (Adapted from Odada *et al*., 2006).

The lake experiences a well pronounced drought as a result of semi-arid climate which causes high evaporation rates, range between 1650 to 2300 millimeters (Odada *et al*., 2006), hence damming of major influent rivers such as Endao, Perkerra, Molo and Ol Arabel to abstract water for irrigation, domestic and industrial uses also serve to reduce the lake volume and hence its surface area especially during the dry season. The dams affect the ecology of the lake by influencing the flow regime, the sediment inputs into the lake and consequently the biodiversity. A study by Johansson and Svensson (2002), reports that anthropogenic changes have significantly affected the water levels of Lake Baringo which has greatly contributed to the decline of its ecological integrity.

3.2 Catchment degradation

The Lake Baringo catchment is threatened by increasing pressure from climate change and rapid population growth (Omondi *et al*., 2016). Rapid degradation has been accelerated by unsustainable land use conversion into urban development, agriculture and industrial expansion, which have been accompanied by indiscriminate deforestation. Odada *et al*., (2006) established that the natural forest cover of the Baringo catchment decreased from 829 km^2 to 417 km^2 within the period of 30 years from 1976 to 2006. Loss of forest cover is a threat to ecosystem benefits such as regulation of the rainfall patterns, sediment regime, flooding and sustains the ground water recharge. In addition, this aggravation is likely to accelerate the processes of land degradation because of changing land tenure from the traditional pastoral nomadism to agro-based sedentary practices (Obando *et al*., 2016). Livestock rearing accounts for more than 70 % of the Baringo County`s income and livelihoods and sustains approximately 90 % of the County population (Government of Kenya 2010) and the number of livestock correspondingly increases with human population. In some areas, land use changes involving the replacement of natural vegetation with exotic deep-rooted *Eucalyptus spp.* trees planted at the riparian zones of rivers have negatively affected stream flows and such factors contribute to diminishing the lake surface. Nearly all agricultural activities are concentrated on the upper reaches of the catchment which offer a favourable climate for farming. As a result of soil erosion, high sediment loads are transported downstream by rivers, wind and other agents into the lake.

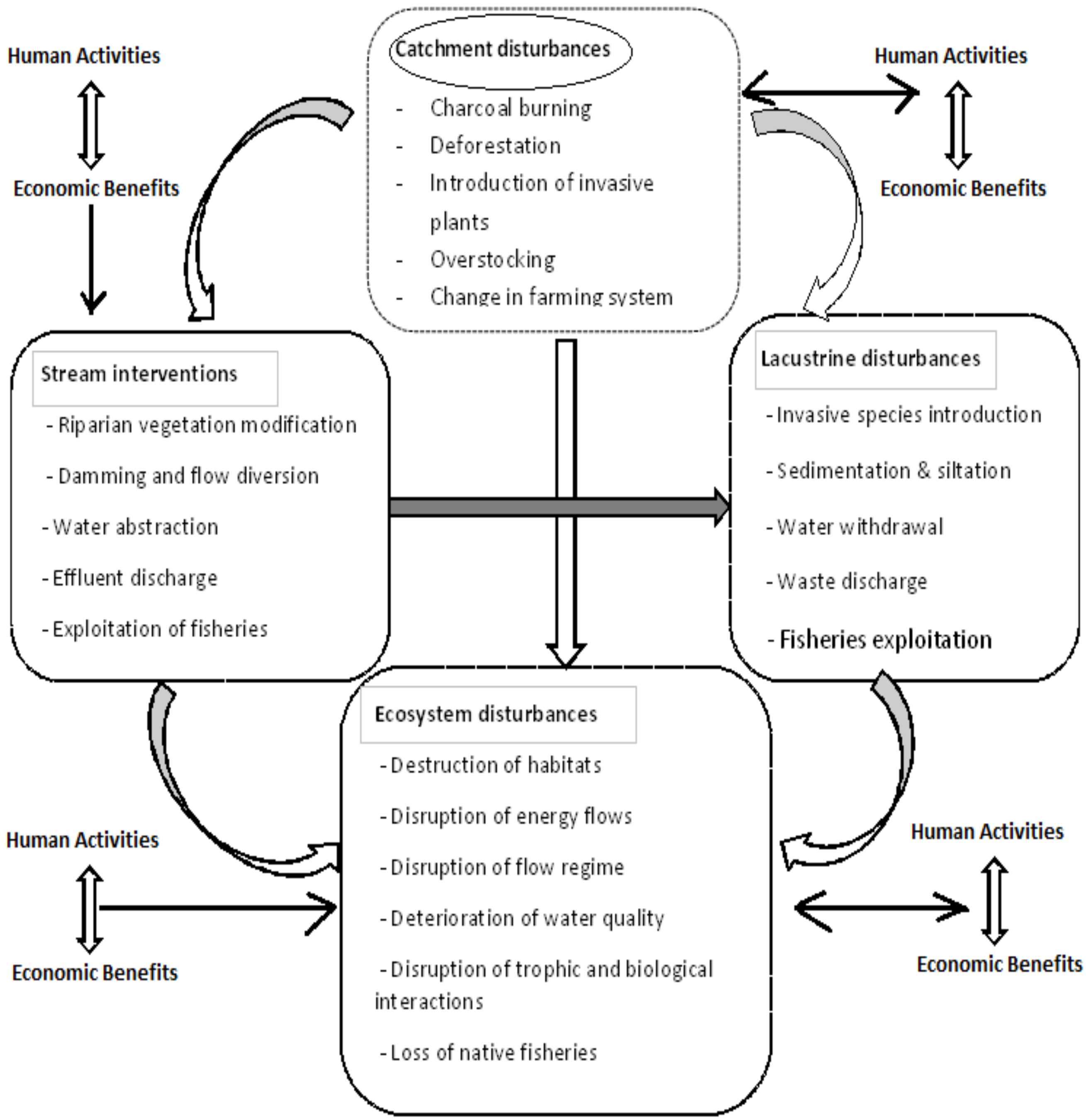

Figure 3. The process of catchment degradation and loss of ecosystem integrity in Lake Baringo.

3.3. Sedimentation and Turbidity

Shallow lakes are often susceptible to wind instigated erosion and sedimentation (Wetzel and Likens, 1990). According to Wahlberg *et al*. (2003), wind is the most prominent agent which transports eroded materials from the catchment into the lake ecosystem which reduce the water transparency by increasing turbidity of the lake waters. Sedimentation also originates from the allochthonous substances from surrounding areas (Oduor, 2000). Replacement of indigenous phreatophytes with exotic Eucalyptus sp. has degraded the riverine components, but the major cause of siltation are the economic activities which provide livelihood to the riparian communities around Lake Baringo, such as livestock rearing, charcoal burning and crop faming (Lwenya and Yongo, 2010). Studies have found that Lake Baringo is frequently characterized by extreme turbidity levels of up to 9.5cm of the Secchi disc reading (Omondi *et al*., 2016; Odada and Olago, 2003) and the sediment amounts approximately 1,038, 0000 metric tons/ year (Onyando et al., 2005). Apart from reducing the lake bathymetry, sediment particles attenuate the light penetrating into the water column affecting the rate of primary production (Hart, 1992) and affects feeding and reproduction in cichlids (Gardner, 1981). Extreme turbidity has resulted to near extinction of submerged macrophytes and benthic fauna, and the lake has currently no documented submerged macrophytes due to high turbidity levels. Turbidity and eutrophication have resulted to declining phytoplankton diversity and the phytoplankton community is currently dominated by cyanobacteria *Microcystis spp.* which possesses the vacuoles for buoyancy and is capable of nitrogen fixation (Odada *et al*., 2006). Ballot *et al*., (2003) reported that the algal biomass in L. Baringo ranges between 1.5-8.2 mgL^{-1}. Various studies (Wahlberg *et al*., 2003; Oduor, 2000) have reported extreme turbidity in Lake Baringo, which has been attributed to re-suspension of the sediment by wind action. Suspended sediments cause light attenuation which in turn reduces secchi depth. By reducing transparency, turbidity reduces the rate of photosynthesis, hence indirectly decreasing the level of dissolved oxygen. This could also be due to fluvial nutrient influx from detritus derived from decaying submerged terrestrial vegetation, which contributes to growth of phytoplankton, periphyton and zooplankton (Weyl, 2007) and optimal temperatures which generally influence the physiology and increases metabolism which favours growth and reproduction in most fish species. Thus, in prolonged periods of decreased water levels in the lake there were low species populations. The zooplankton community comprises of 31 species characterized by high dominance of rotifers with approximately 21 species which were recorded by Omondi *et al*. (2011).

3.4 Invasive Plant species

The magnitude of anthropogenic effects to the natural environmental is evidenced substantially in the disturbance of natural vegetation cover at local and global scales (Edwards and Whittington, 2001), prompting the Neolithic sustainable land-use changes which according to Ruddiman (2005), were detectable as early as 8000 years ago through the perceived increased atmospheric CO_2 levels. Lake Baringo is no exception. Lake Baringo is currently threatened by the invasive plant species, *Prosopis juliflora,* locally known as Mathenge weed (Omondi *et al*., 2016; Odada *et al*., 2006). The invasiveness of this species is shown by its fast and efficient propagation through which it has spread to cover the greater part of this catchment (Mwangi and Swallow, 2005). The plant is deep rooted and grows into a huge blanket of thicket which smothers the growth of other plants and consequently leaving the land bare and vulnerable for erosion. The plant also affects the local livestock keepers because it is a thorny shrub which cannot be fed by livestock, yet it chokes the available grass (Gichua, 2013). This plant together with *Eichornia crassipes* pose a threat to the ecology of Lake Baringo and could easily lead to disruption of the trophic structure. Proliferation of free floating macrophytes such as *Eichhornia crassipes* which cover the lake surface is caused by nutrient loading and runoff which affects biodiversity and ecological functioning of the lake (Omondi *et al*., 2016).

3.5. Decline in native fisheries

Globally, deliberate introductions of exotic fish species to promote recovery of overfished native fish stocks and fill the apparently empty niches has often led to serious consequences such as trophic shifts and biotic competitions in lacustrine ecosystems resulting to loss of native species. This has been mainly reported in the Lake Victoria ecosystem where Nile perch and four Tilapiine cichlids were introduced resulting to decimation of native Tilapia and *Haplochromine* cichlids (Van Zwieten *et al*., 2016; Ouma *et al*., 2012). For a long time, the lake used to support commercial fishery based on the native *Oreochromis niloticus baringoensis* and *Clarias gariepinus* but the native fishery declined due to increased human interventions in the catchment. However, introduction of marbled African lungfish *Protopterus aethiopicus* led to the decline of the native *O. niloticus baringoensis* fishery from about 500 - 600 metric tonnes per annum reported in the 1960s to less than 200 metric tons per annum by late 1980`s (Hickley *et al*., 2004; Mlewa and Green, 2006), which has been attributed to predation pressure and completion for habitats with the native species. There is a growing need to manage the loss of aquatic biodiversity in the face of increasing social economic demands putting pressure on the available aquatic resources which result in perturbations and degradation of aquatic ecosystems (UN-CBD, 2018). This can be achieved by increasing the number of ecological niches which creates habitat complexity, with a high species diversity expected in more heterogeneous habitats (Oberdorff *et al*., 2011). In the order of importance, Jansea *et al*. (2015) categorized the main drivers for loss of biodiversity in inland aquatic ecosystems into hydrological or climatic, land use and eutrophication respectively, citing that about 60-80% of the species are lost due to severe hydrological disturbance through wetland conversion, encroachment of riparian zones, damming of streams and eutrophication. Therefore, the constructed dams may encourage accumulation of sediments rather than allowing for the formation of depositional features downstream and consequently loss of riverine habitats such as riffles, oxbow lakes, deltas, alluvial fans, braided rivers, levees and coastal shores. In addition, dams cause fragmentation of the river continuum which interrupts the upstream spawning migrations of potamodramous fish such *Labeo cylindricus* and *Barbus gregory* whose remarkable decline in Lake Baringo has been previously attributed to damming of the major influent rivers feeding the lake (Nyamweya *et al*., 2012; Hickey *et al*., 2004). According to Britton *et al*., (2009), *O. n. baringoensis* tends to maximize their reproduction and growth when the lake levels increase and turbidity decreases, which results to increased abundance of *O. n. baringoensis* in lake catches. Although there have been concerted efforts made to revive the fishery, such as the ongoing culture trials, the current fishery largely depends on and is dominated by the introduced African lungfish, *Protopterus aetiopicus*.

4. CONCLUSION AND RECOMMENDATIONS

The lake Baringo ecosystems are marred by a combination of both natural and human-caused factors that threatened its existence and productivity. Lakes are highly sensitive ecosystems that are easily degraded by anthropogenic and environmental threats. The problems facing Lake Baringo are complex and multi-faceted, and therefore various insights to understand and resolve them would need an integrative multi-faceted approach that cut across different disciplines. Part of the integrative multifaceted approach to catchment restoration is to replant indigenous vegetation within the catchment and riparian zones, which have shown little progress due to lack of co-ordination by individual institutions, the nature of the landscape, the insufficient funding and lack of political will to support such initiatives (Lwenya and Yongo, 2010). The study suggests the following:

• Soil erosion from the upper reaches of the catchment should be mitigated through building gabions, terraces and contour farming to reduce the sedimentation and turbidity levels. The sediment flow to the rivers draining to the lake should be prevented by planting suitable phreatic plants on the flood plains that captures them such as cactus. This can counteract the reducing water levels which come from the huge amount of sediment deposition. Construction of check dams and semi-circular bands to reduce overland flow rate to counteract the effects of brought about by construction of the dams across the feeding rivers. Implementation of laws and regulations concerning the conservation of this fragile ecosystems such as the ones about deforestation, riparian lands and wetlands to prevent the encroachment and reduction of the catchment surface area, the degradation of the lake`s ecosystem. Provision of alternative livelihood to fishing and sedentary farming remains a viable option to reduce exploitation pressures on lacustrine resources. This can be possible through micro-enterprises, harnessing and production of solar power energy. This approach serves to restore vegetation cover, although, also challenged by fragile soils with low nutrient content and poor physical properties for water infiltration and storage which is a characteristic of arid and semi-arid land (ASAL) (Jaetzold *et al*., 2010). Appropriate mechanical and biological mechanisms should be adopted for controlling the invasive species such as the water hyacinth.

Author Contributions: Conceptualization, S.O., O.J; methodology, O.J., and O.A; validation, O.J., and O.A; formal analysis, Z.W., O.J., and O.A; data curation, A.O.; writing—original draft preparation, O.J, S.O., O.A., and Z.W

Conflicts of Interest: The authors declare no conflict of interest.

REFERENCES

1. Aloo, P. A. (2002). Effects of climate and human activity on the ecosystem of Lake Baringo, Kenya. In: Odada EO, Olago DO (eds) The East African Great Lakes: limnology, palaeolimonology and biodiversity. Kluwer, Dordrecht, pp 332-347
2. Ballot, A., S. Pfl ugmacher, C. Wiegand, K. Kotut, and L. Krienitz. (2003). Cyanobacterial toxins in Lake Baringo, Kenya. Limnologica 33: 2-9.
3. Britton, J. R., Jackson, M. C., Muchiri, M., Tarras-Wahlberg, H., Harper, D. M. and Grey, J. (2009). Status, ecology and conservation of an endemic fish, *Oreochromis niloticus baringoensis*, in Lake Baringo, Kenya. Aquatic Conserv: Mar. Freshw. Ecosyst. 19: 487-49. DOI: 10.1002/aqc.998
4. Bukola D, Zaid A, Olalekan EI, Falilu A (2015) Consequences of Anthropogenic Activities on Fish and the Aquatic Environment. Poult Fish Wildl Sci 3: 138. doi:10.4172/2375-446X.1000138
5. Dubois, N., Saulnier-Talbot, E., Mills, K., Gell, P., Battarbee, R., Bennion, H. et al., (2018). First human impacts and responses of aquatic systems: A review of palaeolimnological records from around the world. The Anthropocene Review, 5(1): 28-68
6. Edwards KJ and Whittington G (2001). Lake sediments, erosion and landscape change
7. Gardner, M.B. (1981). Effects of turbidity on feeding rates and selectivity of bluegills. Transactions of the American Fisheries Society 110: 446- 450.

8. Gichua, M. K. (2013). Impacts of *Prosopis julifora* Linnaeaus emend. Burkart on aspects of biodiversity and selected habitat conditions in Baringo, Kenya, Unpublished PhD Thesis, Jomo Kenyatta University, Kenya
9. Government of Kenya (2010). Kenya National Bureau of Statistics (KNBS), The 2009 Kenya population and housing census; volume II, population and household distribution by Socio-Economic Characteristics, August 2010, Government of Kenya. http://www.knbs.or.ke/index.php?option¼com_phocadownload&view¼category&id¼109: population-and-housing-census-2009&Itemid¼599. Accessed 19th Oct 2018
10. Hart, R.C. (1992). Experimental studies of food and suspended sediment effects on growth and reproduction of six planktonic cladocerans. Journal of Plankton Research 14: 1425-1448.
11. Hering D, Carvahlo L, Argillier C et al. (2015) Managing aquatic ecosystems and water resources under multiple stress. An introduction to the MARS project. Science of the Total Environment 503-504: 10-21.
12. Hickley, P., Muchiri, M., Boar, R. Britton, R., Adams, C., Gichuru, N. and Harper, D. (2004). Habitat degradation and subsequent fishery collapse in Lakes Naivasha and Baringo, Kenya. Ecohydrology & Hydrobiology, 4: 503-517.
13. Jaetzold, R., Schmidt, H., Hornetz, B., Shisanya, C. (2010). Farm Management handbook of Kenya, vol II, 2nd edition, Part B, Subpart B1a: Southern Rift Valley Province, Ministry of Agriculture, Kenya, in Cooperation with the German Agency for Technical Corporation
14. Jansea, J. H., Kuipera, J. J., Weijtersc, M. J., Westerbeeka, E. P., Jeukena, M. H. J. L., Bakkenesa, M., Alkemadea, R., Mooijb, W.M., and Verhoevenca, J.T.A. (2015). GLOBIO-Aquatic, a global model of human impact on the biodiversity of inland aquatic ecosystems. Envrnmntl sci. & pol. (48):99-114
15. Johansson, J., Svensson, J. (2002). Land degradation in the semi-arid catchment of Lake Baringo, Kenya a minor field study of physical causes with a socio-economic aspect. Earth Sciences Centre, Goteborg University

16. Kenya Meteorological Department (2015). Seasonal forecast: short rains season October to December 2015, Press Release. www.meteo.go.ke/ranet/Wx/seasonal.pdf. Accessed 20th Oct, 2015
17. KMFRI (2007). Fisheries and Environmental Impacts. Technical Report No 1 KMFRI, Lake Baringo Research Station, Kampi ya Samaki Kenya.
18. "Lake Baringo". www.lake-baringo.com. Archived from the original on 2012-01-15. Retrieved 2012-02-16.
19. Leavitt PR, Fritz SC, Anderson NJ et al. (2009) Paleolimnological evidence of the effects on lakes of energy and mass transfer from climate and humans. Limnology and Oceanography 54: 2330-2348.
20. Lwenya, C. and Yongo, E. (2010). Human aspects of siltation of Lake Baringo: Causes, impacts and interventions. Aquatic Ecosystem Health & Management, 13(4):437-441. ISSN: 1463-4988 print / 1539-4077 online. DOI: 10.1080/14634988.2010.524497
21. Magnuson JJ, Benson BJ and Kratz TK (2004) Patterns of coherent dynamics within and between lake dis-tricts at local to intercontinental scales. *Boreal Environmental Research,* 9: 359-369.
22. Magny M, De Beaulieu JL, Drescher-Schneider R, Vanniere B, Walter-Simonnet AV, Miras Y, Millet L, Bossuet G, Peyron O, Bruglapaglia E, Leroux A. 2007. Holocene climate changes in the central Mediterranean as recorded by lake-level fluctuations at Lake Accesa (Tuscany, Italy). *Journal of Quaternary Science Reviews* 26: 1736-1758.
23. Mlewa, C. M. and Green, J. M. (2006) Translocation of marbled African lungfish, *Protopterus aethiopicus* (Telostei: Protopteridae), and its fishery in Lake Baringo, Kenya. J. Aquat. Sci., 31: 131-6.
24. Mills K, Ryves DB, Anderson NJ et al. (2014) Expressions of climate perturbations in western Ugandan crater lake sediment records during the last 1000 years. Climate of the Past 10: 1581-1601.

25. Mwangi, E. and Swallow, B. (2005). Invasion of *Prosopis juliflora* and local livelihoods: case study from the Lake Baringo area of Kenya, ICRAF working paper 3, World Agroforestry Centre, Nairobi
26. Nyamweya, C. S., Mlewa, C. M., Ngugi, C. C., Kaunda-Arara,B. Njiru, J. Gichuki, J. W., Ojwang, W. O., and Ojuok, J. E. (2012). Aspects of the biology of *Labeo cylindricus* (Pisces: cyprinidae) in Lake Baringo, Kenya. Lakes & Reservoirs: Research and Management, 17: 225-229
27. Obando, J. A., Onywere, S., Shisanya, C., Ndubi, A., Masiga, D., Irura, Z., Mariita, N. and Maragia, H. (2016). Impact of Short-Term Flooding on Livelihoods in the Kenya Rift Valley Lakes. Advances in Geographical and Environmental Sciences, 193-215. DOI 10.1007/978-4-431-56000-5_12
28. Oberdorff, T., Tedesco P. A., Hugueny, B., Leprieur, F., Beauchard, O., Brosse, S. and Dürr, H. H. (2011). Global and regional patterns in riverine fish species richness: a review. International Journal of Ecology. 2011:1-12. doi: 10.1155/2011/967631.
29. Ochieng, E. Z., Lalah, J. O. and Wandiga, S. O. (2007) Analysis of heavy metals in water and surface sediment in five Rift Valley lakes in Kenya for assessment of recent anthropogenic activities. Bull Environ Contam Toxicol 79:570-576
30. Odada EO, Olago DO, Bugenyi F, Kulindwa K, Karimumuryango J, West K, Ntiba M, Wandiga S, Obudho PA, Achola P. (2003). Environmental assessment of the East African Rift Valley Lakes. *Journal of Aquatic Science* 65: 254-271.
31. Odada, E. O., Onyando, J. O. and Obudho, P. A. (2006). Lake Baringo: addressing threatened biodiversity and livelihoods. Lakes Reserv. Res. Manag, 11:287-99.
32. Oduor, S. O. (2000). Physico-chemical dynamics, pelagial primary production and algal composition in Lake Baringo, Kenya. MSc. Thesis, Deft, Austria: IHE. 83pp.
33. Okech, EO, Kitaka, N, Omondi, S. and Verschuren, D. (2019). Water level fluctuations in Lake Baringo, Kenya, during the 19th and 20th centuries: Evidence from lake sediments, African Journal of Aquatic Science, 44:1, 25-33, https://doi.org/10.2989/16085914.2019.1583087

34. Omondi R, Kembenya E, Nyamweya C, Ouma H, Machua SK, Ogari Z. (2014). Recent limnological changes and their implication on fisheries in Lake Baringo, Kenya. J Ecol Nat Environ; 6(5):154-63.
35. Omondi, R., Yasindi A. W. and Magana A. (2011). Spatial and temporal variations of zooplankton in relation to some environmental factors in Lake Baringo, Kenya. Eger. J. Sci. Technol., 11: 29-50
36. Omondi R., Ojwang W., Olilo C., Mugo J., Agembe S., Ojuok J.E. (2016) Lakes Baringo and Naivasha: Endorheic Freshwater Lakes of the Rift Valley (Kenya). In: Finlayson C., Milton G., Prentice R., Davidson N. (eds) The Wetland Book. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-6173-5_133-1
37. Onyando, J. O., Kisoyan, P., Chemelil, M. C. (2005). Estimation of potential soil erosion for River Perkerra catchment in Kenya. Water Resource Manag; 19:133-43.
38. Ouma, M. D., Manyala, J. O. and Ngugi, C. C. (2012). Fish introductions and their impact on the biodiversity and the fisheries of Lake Victoria. Oceandocs.org
39. Ruddiman WF (2005). How did humans first alter global climate? Scientific American 292: 46-53.
40. Spigel RH, Coulter GW. 1996. Comparison of hydrology and physical limnology of the East African Great Lakes: Tanganyika, Malawi, Victoria, Kivu and Turkana (with reference to some North American Great Lakes). In: Johnson TC, Odada E (Eds), *The Limnology, Climatology and Paleoclimatology of East African Lakes.* pp. 103-139. Toronto: Gordon and Breach.
41. UN-CBD [United Nations Convention on Biological Diversity] (2018): Inland Waters Biodiversity-What is the problem? http://www.cbd.Intl/
42. UNEP [United Nations Environment Programme] (2009). Kenya: atlas of our changing environment. UNEP, Nairobi
43. Van Zwieten, P, A.M.; Kolding, J; Plank, M., J.; Hecky, R., E.; Bridgeman, T., B.; MacIntyre, S.; Seehausen, O; Silsbe, G., M.; Giacomini, H. (2016). The Nile perch invasion in Lake Victoria: cause or consequence of the haplochromine decline? Canadian Journal of Fisheries & Aquatic Sciences. 2016, Vol. 73(4):622-643.

44. Verschuren, D. (2003). Lake-based climate reconstruction in Africa: Progress and Challenges. *Hydrobiologia* 500: 315-330.
45. Wahlberg, H. T., Harper, D. and Wahlberg, N. T. (2003). A first limnological description of Lake Kichiritith, Kenya: a possible reference site for the freshwater lakes of the Gregory Rift Valley. South African Journal of Science, 99: 494-496.
46. Wetzel, R. G. and Likens, G. E. (1990). Limnological Analyses. Springer Verlag, New York. 391p.
47. Weyl, O. L. F. (2007). Rapid invasion of a subtropical lake fishery in central Mozambique by Nile tilapia *Oreochromis niloticus* (Pisces: Cichlidae). Aquatic Conservation: Marine and Freshwater Ecosystems 18: 839-851.