The Potential of Riparian Forests in Anthropogenic Stressed River Ecosystems

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Abstract

The study was conducted to examine riparian vegetation species, anthropogenic interactions, and the due impact on the Ngerengere River riparian ecosystem in Tanzania in view of riparian forests potentials on river ecosystems. Vegetation data were collected by belt transect and field observation, and socio-economic data by household interview methods. Upon descriptive and content analyses, Pennisetum purpureum, Phragmites mauritianus, Typha domingensis, Phragmites australis, Cyperus rotundus, Sesbania sesban and Ficus sycomorus constituted the riparian zone. Most of them (80%) were grass, affected by cultivation (54%) and sand extraction (34%), causing vegetation extinction (36%), riverbanks collapse and increased sedimentation (31%). Highly vegetated areas had clean water and were ecologically stable. Riparian forests were sought vital for sustainable management of river ecosystem through enhanced carrying capacity, water cleansing and banks stabilization.

Keywords: Climate change, Nature-based solutions, Ngerengere River, Riparian vegetation, Sustainable development

Introduction

Riparian forest implies a naturally wooded or forested area of land along natural water bodies. They constitute biotic communities on the shores of streams and rivers. Their aquatic - terrestrial systems interfaces are termed as riparian zones (National Research Council, 2002; Naiman *et al.,* 2005). Likewise, vegetation within the riparian forest, forming a riparian zone are called riparian vegetation, an essential component of fluvial system (rivers, streams, and associated features) serving for multiple socio-ecological and hydrological functions (National Research Council, 2002; Naiman *et al.,* 2005; Dufour *et al.,* 2019). Riparian forests provide innumerable physicochemical and biological roles to associated water bodies' hydrology. Physically, they alter river-flow conditions by protecting banks and colonizing deposits hence inducing river metamorphosis, enabling floodwater storage in the floodplain. Simultaneously, they chemically support biogeochemical cycles within the river ecosystem and improving water quality in agricultural watershed with non-point source pollution through sediment trapping and nutrients removal commonly by denitrification (Dufour *et al.,* 2019). Riparian forests are biologically species rich (Dufour *et al.,* 2019; Trimmel *et al.,* 2018). They thus enhance corridor dispersal, biodiversity and habitat (de la Fuente *et al.,* 2018). In a socio-cultural context, they improve human well-being by providing several ecosystem services including water purification. During low flow, they shade the channel hence decreasing the rate of evaporation and water loss, while during flooding they buffer flood storm from the channel towards the floodplain by decreasing the incoming storm water velocity (Dufour *et al.,* 2019).

As of Malan *et al.* (2018) and de Sosa *et al.* (2018), the ecohydrological role of riparian vegetation are somewhat not widely recognized in some areas, leading to degradation through human influence within the riparian zone. This increases riverbank erosion, sediment deposition and reduces filtration capacity of fluvial ecosystem to incoming surface runoff (Malan *et al.,* 2018; Trimmel *et al.,* 2018; Chua *et al.,* 2019).

Considering the socio-ecological and hydrological roles played by riparian forests in the river ecosystem, they are a scientifically applicable and adaptable tool for river ecosystem management (Dufour *et al.,* 2019; Malan *et al.,* 2018; Chua *et al.,* 2019). This has risen a need for an integrated nature-based management approach that effectively make use of natural ecosystems in managing river ecosystem. Ecosystem based or sometimes referred to as a Nature based solutions approach is defined by the International Union for Conservation of Nature (IUCN) as actions employed to protect, sustainably manage and restore natural or modified ecosystems, which address societal challenges effectively and adaptively, while providing human well-being and biodiversity benefits (Cohen-Shacham *et al.,* 2016).

A potential linkage of nature based solutions to several aspects of sustainable development has been established (Fig. 1). The link shows the possible societal challenges that can be addressed.

Nature-based solutions address several societal challenges and sustainable development goals (SDG). These include SDG 6 (clean water and sanitation for all), 13 (climate action), 14 (life under water) and 15 (life on land) while at the same time indirectly supporting other goals (WWF, 2020; Vasseur *et al.,* 2017). Chief target link to economic development is introduced to show the interlinkage of several interventions and multiple developmental goals to achieve reducing poverty (SDG 1) and creating decent jobs (SDG 8) (Vasseur *et al.,* 2017).

Ecohydrology is among such nature-based approaches whose target is to increase stability and carrying capacity of river ecosystem through riparian forests where hydrology and biota influence each other, hence the term dual regulation (Zalewski, 2000; 2002: 2003; de Sosa *et al.,* 2018). It regulates ecological processes within the water cycle to enhance ecosystem

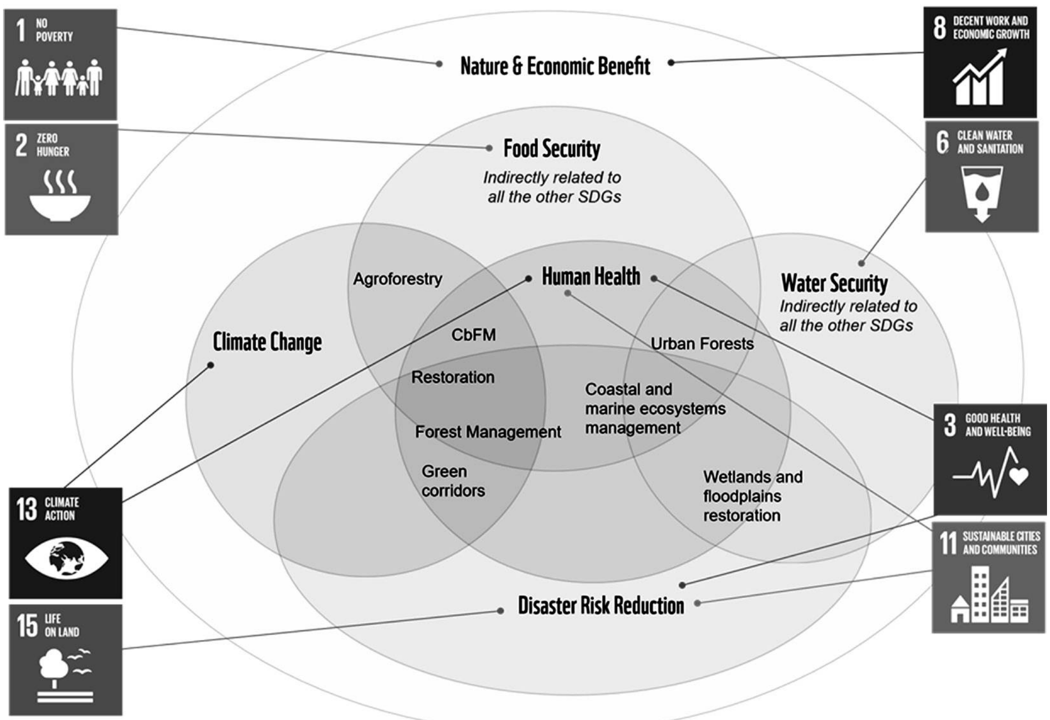

Figure 1: Nature based solutions linkage to sustainable development
Source: WWF, 2020

stability (Zalewski, 2000; 2009; 2012; 2013). This approach guides the application of biota in managing river ecosystems against degradation through ecological and hydrological processes (Zalewski, 2002; Lalika, 2020; Raphael and Lalika, 2020).

It operates through framework, target and methodological principles (Zalewski, 2000). The framework principle describes the river ecosystem as the superorganism influenced by water circulation which regulate ecosystem processes. Water and temperature constitute the major driving factors, the dominant abiotic hydrologic processes in freshwater ecosystems. The target describes the natural resilience against stress due to biological interaction of biotic and abiotic components of the riparian forests and river ecosystem (de Sosa *et al.,* 2018; Zalewski, 2002). It thus provides the basis for enhancing the absorbing capacity of the river ecosystem against human impacts through well-maintained riparian forests. The methodology emphasizes the use of ecosystem properties to bring about sustainable management (Zalewski, 2000; 2002).

In most African countries, including Tanzania, there has been a high pace of population growth causing severe stress to river ecosystems through human activities (Lalika, 2020). Consequently, river ecosystems, riparian forests and fluvial zones are pressurized by cultivation practices, livestock grazing, poles harvesting and sand extraction (National Research Council, 2005; Naiman *et al.,* 2005; Malan *et al.,* 2018; Raphael and Lalika, 2020). Tanzania has many rivers including Ngerengere, which forms one of the major ecosystems within the large Wami/Ruvu Basin. Its catchment covers about 2780 km^2 with about four tributaries from Uluguru Mountains. Due to fertility potential, its flood plain is under several land uses that affect its stability (IUCN, 2010; Mero, 2011).

Due to its ecological, socio-economical and hydrological roles, several studies have been done to assess the water flow in several river basins in Tanzania (IUCN, 2010). Most of them had a particular focus on water quality and climate changes issues (IUCN, 2010; Mero, 2011; Natkhin *et al.,* 2013; Shagega *et al.,* 2018). This study was done to ascertain the potential of riparian forests (vegetation) to the river ecosystem by examining the distribution of available riparian vegetation species, human activities conducted within the riparian zone and their associated impacts, both to riparian vegetation and the river ecosystem.

Materials and Methods

Description of the study area

The study was conducted along Ngerengere River in Morogoro Municipality, Tanzania. Ngerengere River lies within Ngerengere sub-catchment of the Ruvu catchment in the Wami/Ruvu Basin (Eeden *et al.,* 2017) (Fig. 2) between

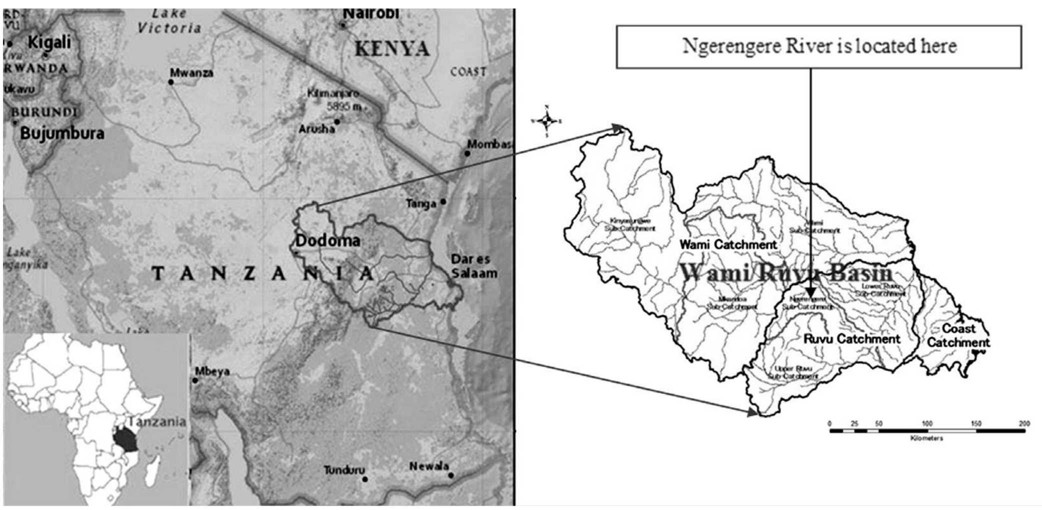

Figure 2: Location of Ngerengere River in Tanzania
Source: (Eeden *et al.,* 2017)

latitudes 6°30'00" and 7°10'00" South and between longitudes 37°58'26" and 38°31'30" East with an area of about 2780 km^2. It originates from the Uluguru mountains, extending to other parts (urban and rural) of Morogoro Region (Mero, 2011). Within the catchment, is the Mindu Dam, the main freshwater source for Morogoro Municipality serving for other socioeconomic activities of local inhabitants, like agriculture and fishing. The river forms the inflow of the dam, in its upper stage, and extends downstream as the outflow, passing through Mazimbu Darajani street. It finally joins the lower Ruvu River that heads to the Indian Ocean. The mean annual rainfall varies between 800 and 1000 mm increasing to 2000 mm in the vicinity of the Uluguru Mountains where the river originates (Natkhin *et al.,* 2013; Shagega *et al.,* 2018).

Sampling strategy and data collection

Biological data

The study used belt transect method for vegetation sampling along the river continuum in the Mazimbu Darajani area. With this method, a five metres belt transect (wide) and about 2 km long was established alongside the river within the riparian forest zone. Within this stripe, twenty sampling stations were systematically established at a 100 m interval from one another with the aid of a Geographical Positioning System (GPS) device. At each introduced point, sampling was done within a 2 m radius around throughout with all categories of vegetation (grass, shrubs and higher trees) being sampled. After sampling, field identification was done at least with a local name level, completely unidentified. Partially identified vegetation was taken for further identification to Sokoine University of Agriculture's Ecohydrology experts.

Socioeconomic data

A simple random probabilistic sampling procedure was used during collection of household data by means of household questionnaire. This technique was adopted to avoid bias in selection of study respondents such that each household had an equal chance of being involved in the study. Questionnaires were administered to selected households to gather data on human interaction with the riparian ecosystem and associated impact. Field observation as a verification to anthropogenic undertakings within the riparian forest ecosystem was also used. The researcher observed cultivation styles, how farms were prepared, water diversion from the river and the tools used. Checklist for key informants was used to elicit baseline information on the evolution of the river in response to activities carried out along it in the riparian zone. Further details to disclose the changes arising with time as human activities progress were explored by structured interviews with native elders, known to have resided in the study area for about fifty years, and some for their entire life.

Data analysis

The data analysis plan involved descriptive analysis for quantitative socioeconomic data and content analysis for qualitative data from interviews and direct observation. Descriptive analysis was done to quantify proportions in terms of frequencies and percentage by using the Statistical Package for Social Science (SPSS-version 20) and Microsoft Excel. Responses from interviews and observation were examined to capture themes presented therein.

Results

Major plant species found

Species assumed an irregular pattern of distribution. Table 1 highlights the composition and proportions of the major riparian plant species around Mazimbu Darajani area (part of lower Ngerengere River ecosystem) where sampling was done. It illustrates that, the riparian forest zone of the Ngerengere River ecosystem is composed of major seven riparian vegetation species (Phragmites, Elephant grasses, Reeds, Sesbania, Sedges, Ficus and Bulrush) ranging from grass, shrubs, and some higher trees, as shown below.

A large part of Ngerengere River riparian zone is covered by phragmites due to their high regeneration potential, when compared to other species. They usually grow in thickets with harsh hairs on their surface. Elephant grasses have harsh and erectile hairs too, offering them,

Table 1: Major riparian plant species Ngerengere River riparian ecosystem

Category	Common name	Botanical name	Abundancy (% occurrence)
Grass	Phragmites	*Phragmites mauritianus*	25
	Elephant grasses	*Pennisetum purpureum*	22
	Reeds	*Phragmites australis*	22
	Sedges	*Cyperus rotundus*	08
	Bulrush	*Typha domingensis*	03
Shrubs	Sesbania	*Sesbania sesban*	14
Trees	Ficus	*Ficus sycomorus*	06

Source: Field data

as phragmites, a defensive mechanism. These account for a relatively higher abundancies of phragmites and elephant grasses. Reeds on the other hand are not mostly preferred for livestock fodder, accounting for its observed high abundance. They experience slight disturbances, except during farm preparation where they are cleared with sedges (hence its low abundancy) as weeds. Bulrush (commonly Typha) dominate the flooding zone where paddy fields are established. These fields are completely cleared for rice cultivation and thatches, hence their low abundance. Due to anthropogenic disturbance in the riparian zone, most sites were unfavourable for Sesbania and Ficus, commonly due to unstable soil and slopes observed in the study area. Uncontrolled cultivation practices within the riparian zone contributed for the observed low abundance of Ficus (Table 1) and generally trees, as shown in Table 2 categorical percentage proportions of available species of riparian plants.

Table 2: Proportion of Ngerengere River riparian vegetation species ecological categories

Vegetation category	Percentages (%)
Grass	80
Shrubs	14
Trees	6

Source: Field data

While grasses dominate other types of riparian plants, low percentage abundance (6%) of trees implies low regeneration and resistance on disturbance.

Anthropogenic influences in the riparian ecosystem

Figure 3 presents the major forms of human alterations and interaction in the Ngerengere River riparian ecosystem.

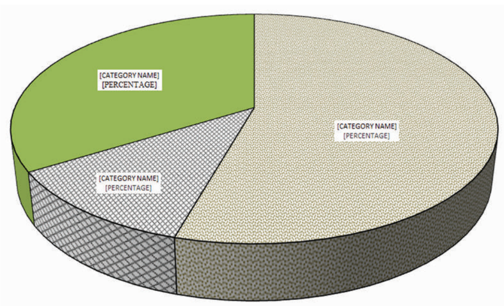

Figure 3: Major forms of human alteration in Ngerengere riparian ecosystem
Source: Field data

The anthropogenic stressor to Ngerengere River riparian zone includes cultivation practices accompanied by application of fertilizers and mechanized tools (generator and water pumps for diverting water to agricultural fields). The major crops include rice, maize, vegetables, and horticultural crops along the river. Grazing activities also pose another threat by clearing for livestock fodder and pasture. Since a large proportion of vegetation around are grass (Table 1 and 2), they are thus in danger of disappearing unless interventions (that emphasize stopping grazing activities to reduce pressure and anthropogenic stress) to manage them are in place.

Impacts of anthropogenic activities to riparian forests ecosystem

Human activities conducted within the riparian zone cause several adverse impacts to both plant species and the river ecosystem. For instance, inappropriate application of organic and inorganic fertilizers cause pollution and thus affect water quality. Table 3 highlights these effects as pointed out by respondents and evidenced by observation across the riparian forest zone of the study area.

Table 3: Proportion of responses on the impacts of anthropogenic activities to the river and riparian vegetation (n=100)

Effect to the river	Responses (%)	Effect to riparian vegetation	Responses (%)
Accelerated sedimentation	31	Plant disappearance	36
Reduction in volume	23	Deforestation	23
Bank erosion	20	Unplanned burning	22
Water pollution	18	Morphological changes	17
Change in River stream	08	NA[1]	02
Total	**100**		**100**

[1]Not aware of riparian vegetation
Source: Field data

As indicated in Table 3, there is a close increasing parallel relationship between the impacts occurring to riparian vegetation in reflection to the river stability. The percentage severity levels of the impacts assume the same magnitudes ranges for both riparian vegetation and the river. This illustrates the relationship between proper management, conservation of riparian forests and the sustainability of the river ecosystem. Having 2% out of all randomly interviewed respondents unaware of riparian vegetation and how they are impacted by human behaviour worsen the threats to riparian vegetation. For that matter, some people degraded vegetation by ignoring their potential to the river ecosystem and contribution to their livelihoods and well-being.

Those areas with abundant riparian vegetation had both stable banks and clean water compared to where they were cleared out. This was the indication of the potential role of these vegetation species to both water cleansing and stabilization of the riverbanks. Regardless of such observation, the only management option encountered on site was dredging. During rainy period, excavated sediments and mud returns to the river, leading to further sedimentation. Dredged sediments were retained from returning to the river only where there was vegetation on the sides of the river. The situation also revealed a need for natural solutions like enhancing riparian buffer to enhance natural carrying capacity of the river ecosystem.

Discussion

Riparian forests and Hydrology

The riparian forest zone of Ngerengere River is among the anthropogenically influenced ecosystems as found in other studies (Shagega *et al.,* 2018). Undefined and irregular pattern of riparian forest (GLOWS-FIU, 2016) worsens anthropogenic conducts within this zone along the river channel. Consequently, riparian forests keep on decreasing, by being cleared for domestic use and agricultural fields establishment. These are also cited drivers of their degradation across the world (National Research Council, 2005; Naiman *et al.,* 2005; Dufour *et al.,* 2019; Malan *et al.,* 2018; Naiman and Decamps, 1997). The findings of this study imply a remarkable interaction of riparian forests with the geomorphology, soil dynamics, hydrological and biotic features (Fig. 4) influencing spatial and temporal variation, as proposed by Naiman and Decamps (1997). All these account for inherent physical and morphological heterogeneity of the riparian vegetations across the globe with respect to time and space (National Research Council, 2005; Naiman *et al.,* 2005; de Sosa *et al.,* 2018). With exception of Ficus, riparian vegetation of the study area was different from that found in India (Amitha, 2003), while coinciding with those in other parts of Wami/Ruvu River Basin, Tanzania (GLOWS-FIU, 2016). The variation might be attributable to differences in soil and other hydro-geo-morphology of an area.

mainly agricultural production.

Riparian forests act as nutrient filters, sinks and transformers, acting to reduce nutrients loaded in the river stream (Chua *et al.,* 2019; Raphael and Lalika, 2020; Zalewski, 2003; Naiman and Decamps, 1997). Through filtration, they remove up to 15% of the non-soil-bound phosphorus. As a nutrient sink, they uptake about 88% and 76% nitrogen and

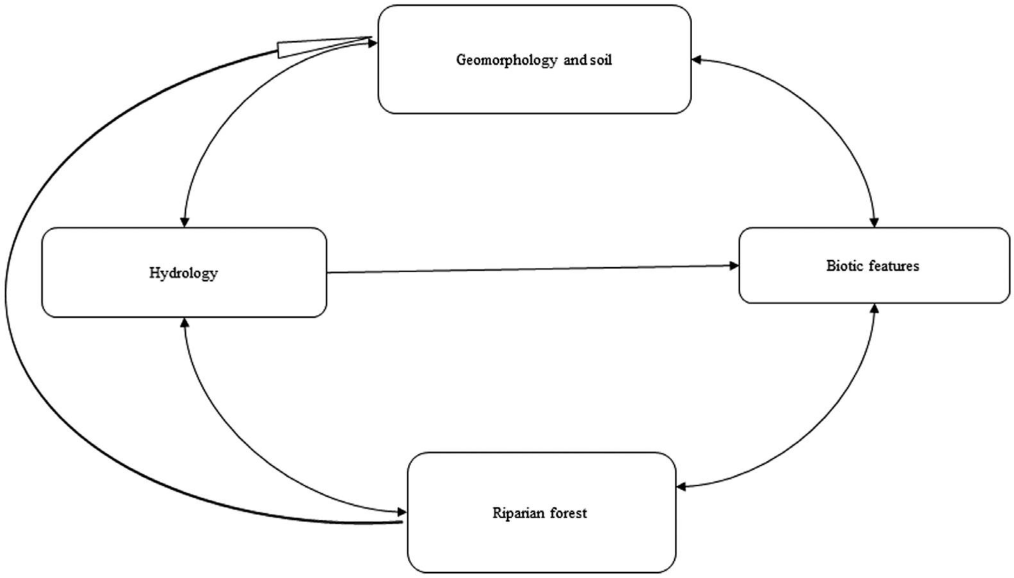

Figure 4: The interaction between riparian forests and abiotic factors
Source: Amitha, 2003

Riparian forest plays key hydro-morphological roles to stabilize the river ecosystem, more specifically the riverbanks and flow regulation. Previous studies have acknowledged their significance in holding soil particles thereby controlling bank erosion, reducing incoming and in-stream storm velocity (Hultine, 2004). They are also important for water cleansing through retaining suspended particles and sediments, and enhancing in-stream biodiversity aquatic invertebrate sustenance.

Like other riparian ecosystems around the globe (National Research Council, 2002; Naiman *et al.,* 2005; Dufour *et al.,* 2019), riparian species along Ngerengere River are influenced by several anthropogenic activities. Due to high moisture content and fertility potentials (Dufour *et al.,* 2019), many riparian zones are subject to anthropogenic interactions

phosphorous respectively from surface run-off flowing through them and groundwater moving across the roots (Chua *et al.,* 2019).

Due to good pasture, livestock grazing forms one of the common land use types in riparian ecosystems (Pinchak *et al.,* 1991; Jemison and Raish, 2000; Dufour and Rodriguez-Gonzalez, 2019). High abundance of elephant grasses and phragmites favour grazing activities (Jemison and Raish, 2000). Other activities that lead to degrading riparian forests and the river ecosystem include charcoal burning, sand mining and brick making (Dufour and Rodriguez-Gonzalez, 2019; Dufour *et al.,* 2015; Kondolf *et al.,* 2007; Brown *et al.,* 2018). The associated impacts include bank and riverbed erosion, deposition and sedimentation, reduction in river depth and water pollution, thus complementing to other studies (Naiman *et al.,* 2005: Brown *et al.,* 2018). Other reported significant drivers of influence include bioclimatic regimes (Bendix and Stella, 2013), morphological pattern (Corenblit *et al.,* 2015) and unlawful water abstraction (Dufour *et al.,* 2019). While bioclimatic factors alter the quantity and timing of water availability and post-floods disturbance relaxation times, morphological pattern creates a physical template for vegetation colonization, growth and drives disturbance regimes (Bendix and Stella, 2013; Corenblit *et al.,* 2015).

In appraising the role of riparian forests, a study on riparian vegetation's influence on Fitzroy basin's water quality revealed poor water quality in streams with poor riparian vegetation (Chua *et al.,* 2019; Dodds and Oakes, 2008). Polluted water with poor riparian vegetation, contrary to their counterpart across Ngerengere River, justified the essential hydrological role of riparian vegetation to water quality. Rivers and stream sites with low riparian vegetation abundance are thus more vulnerable to pollution due to agricultural land use (Dodds and Oakes, 2008). For that similar situation, degraded riparian sites and low-ordered streams in Queensland are considered priority sites for quick restoration and rehabilitation to maintain ecosystem structure, assemblage and enhancing ecological health (Pert *et al.,* 2010), while hydrologically anticipating downstream water quality and stream flow improvement (Chua *et al.,* 2019; Pert *et al.,* 2010).

Upholding the role of riparian plants and vegetation, several scientific investigations have called for enhancing natural forest ecosystems along waterways (Chua *et al.,* 2019; Zalewski, 2013). With the prevalence of riparian vegetation degradation mainly by anthropogenic influences in Ngerengere River catchment as in some other areas like Fitzroy (Chua *et al.,* 2019), it is of great recommendation that proper watershed management be integrated with conserving riparian zones to achieve sustainable freshwater ecosystems management using natural ecosystems, with riparian vegetations (forests) being the frontline.

Nature-based solutions in the context of sustainable economic development

Integrated governance and management of water resources through application of nature-based solutions and ecosystemic approaches contribute significantly to complying with SDGs by enhancing natural ecosystems, water resources management and water safety (UNESCO 2011; Vasseur *et al.,* 2017; Albert *et al.,* 2020; Dickens *et al.,* 2020). The application of nature-based solutions has a potential for delivering integrated ecosystem services, biodiversity net gain, promoting human health and well-being and empowering local people (Kabisch *et al.,* 2016). Simple techniques include enhancing native vegetation and ecosystem absorbing capacity to control soil erosion and reduce water runoff along road embankments and watershed restoration to improve water quality and availability (Vasseur *et al.,* 2017; WWF, 2020).

One potential element of natural riparian forests enhancement approach, as evidenced in the study area, appreciates over time (WWF, 2020). Vegetation grows denser, becoming resilient over time while supporting some other livelihood potentials compared to artificial structures which need a closer maintenance and replacement. Nature-based solutions can help reversing degradation while resolving some societal challenges such as climate change, food, and water insecurity and natural disasters (UNESCO 2011; Cohen-Shacham *et al.,* 2016; WWF, 2020). Consequently, the interventions used can also generate a range of benefits to nature and the economy by promoting natural capital.

Conclusion

Cultivation practices stand-out as the major driver of ecosystem degradation. Clearance and disturbance of riparian vegetation affect the hydrology and water resources by reducing the river flow, depth, and water quality. The threats of anthropogenic conducts were sedimentation and enhanced deposition-causing pollution to the river. These effects will become more severe due to ongoing riparian degradation following the high pace of population growth. The failure of existing management approaches calls for a natural riparian forest ecosystem enhancement measures (like enhancement of the buffer zone) to curb ongoing degradation by enhancing the carrying capacity and ability to withstand stress. Once the created buffer zone is stabilized, activities like gardening on the riverbanks become limited by the trees, causing them to cease, reducing degradation and pressure on the river. This counts for cost-effective approach that help in maintaining natural ecosystems diversity.

Acknowledgments

Authors are grateful to the UNESCO Chair on Ecohydrology and Transboundary Water Management of Sokoine University of Agriculture for supporting this study. They are also thankful to Fátima Noronha from the University of Algarve for her linguistic check on this paper. A significant role of the reviewers and editors is highly appreciated too.

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